

# THE UNIVERSITY of EDINBURGH

# Edinburgh Research Explorer

# Variability along the Frontier

#### Citation for published version:

Alaica, A, Clayton-Schalburg, J, Dalton, A, Kranioti, E, Echávarri, GG & Pickard, C 2018, 'Variability along the Frontier: Stable carbon and nitrogen isotope ratio analysis of human remains from the Late Roman-Early Byzantine cemetery site of Joan Planells, Ibiza, Spain', *Archaeological and Anthropological Sciences*, pp. 1-14. https://doi.org/10.1007/s12520-018-0656-0

## **Digital Object Identifier (DOI):**

10.1007/s12520-018-0656-0

#### Link:

Link to publication record in Edinburgh Research Explorer

**Document Version:** Peer reviewed version

Published In: Archaeological and Anthropological Sciences

#### **Publisher Rights Statement:**

The final publication is available at Springer via https://link.springer.com/article/10.1007%2Fs12520-018-0656-0.

#### **General rights**

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

#### Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



- Variability along the Frontier: Stable carbon and nitrogen isotope ratio analysis of human
   remains from the Late Roman-Early Byzantine cemetery site of Joan Planells, Ibiza, Spain
- 3
- Aleksa K. Alaica<sup>1\*</sup>, Jessica Schalburg-Clayton<sup>2</sup>, Alan Dalton<sup>2</sup>, Elena Kranioti<sup>2</sup>, Glenda Graziani
  Echávarri<sup>3</sup> and Catriona Pickard<sup>2</sup>
- 6

<sup>1</sup>Department of Anthropology, University of Toronto, 19 Russell Street, Toronto, Ontario, M5S
2S2.

9 <sup>2</sup>School of History, Classics and Archaeology, University of Edinburgh, William Robertson

10 Wing, Old Medical Quad, Teviot Place, Edinburgh, EH8 9AG, UK.

<sup>3</sup>Department of Sciences of Antiquity and Medieval Ages, Autonomous University of Barcelona.

12 \*Corresponding author e-mail - <u>aleksa.alaica@mail.utoronto.ca</u>

13

# 14 Abstract

Carbon ( $\delta^{13}$ C) and nitrogen ( $\delta^{15}$ N) stable isotope analysis of human bone collagen from 38 15 individuals was undertaken to assess diet at the Late Roman-Early Byzantine (AD 300-700) 16 cemetery site, Joan Planells, in Ibiza, Spain. The results ( $\delta^{13}C$ =-18.7±0.5‰ and 17  $\delta^{15}$ N=10.1±1.3‰) that the diet of this population was derived predominantly from C<sub>3</sub> terrestrial 18 19 resources; plant foods were likely dietary staples along with meat and/or dairy produce 20 comprising an important component of diet. Variation in stable isotope ratio values suggest individual differences in diet. Two individuals, both males, are statistical outliers with distinctive 21  $\delta^{15}$ N values (14.4‰ and 14.8‰) that point to significant consumption of marine resources. 22 Females, on average, have higher  $\delta^{13}$ C values than males. The parsimonious explanation for this 23 24 observation is the greater inclusion of C<sub>4</sub> resources such as millet in the diets of females. Comparison of the diet of the Joan Planells population with other Late Roman period sites on the 25 26 Hispanic mainland and other parts of the Mediterranean region suggests that populations may have been responding to a combination of socio-political and environmental factors that could 27 28 have included Roman influence of food consumptive practices in some of these distant locales.

- 29
- 30
- 31

# 32 **1. Introduction**

Ibiza, one of the westernmost of the Balearic Islands, is located near the confluence of the
Mediterranean and Atlantic Seas. Colonized by the 3<sup>rd</sup> millennium BC, the occupation history of
Ibiza has been marked by successive waves of invasion and migration (Pomeroy 1976; Curchin
1991; Márquez-Grant 2005).

From the late 1<sup>st</sup> century BC until at least the late 3rd century AD, the social, economic and 37 political structures throughout Europe, Asia and North Africa were influenced and altered, to a 38 greater or lesser extent, by the expansion of the Roman Empire (Pericot Garcia 1972; Woolf and 39 Gosden 1997). Ibiza came into the sphere of Roman influence in the mid-2<sup>nd</sup> century BC 40 following the collapse of Carthage in 146 BC. Remaining largely politically and economically 41 autonomous for much of the following century it became a municipality of Rome in AD 70 42 (Curchin 1991). While Ibiza became more strongly connected to Roman exchange networks, the 43 evidence at Joan Planells dates to the 3<sup>rd</sup> to 7<sup>th</sup> centuries. These political and economic 44 transformations were happened at a time called the Roman Warm Period, which saw the 45 development of Roman civilization across the Western Mediterranean during a period of quiet 46 47 storm activity. This period was succeeded by a period of the highest storm activity witnessed in 48 this part of the Western Mediterranean in over 3 millennia (Degei et al. 2015). It is important to emphasize that climate and paleoecological studies have corroborated that the North Atlantic 49 Oscillation (NAO) was a regional mechanism driving natural in the environmental fluctuation of 50 51 the western Mediterranean during the Late Holocene (Lamb 1995; Nieto-Moreno et al. 2011, 2013). With these dramatic shifts happening, this paper contextualizes how the Roman influence 52 in the region during the 3<sup>rd</sup> to 5<sup>th</sup> centuries (and continuing into the 7<sup>th</sup> century) was impacting 53 the island of Ibiza, while other socio-political and environmental transformations were occurring. 54 55 As diet and food consumption are important interlocutors for political, cultural and social 56 exchange, this isotopic dataset provides ideal evidence to consider how the population in the Late Roman period were mitigating change. 57

Carbon and nitrogen stable isotope analysis of human bone collagen, an established method of investigating diet in past populations, was used to determine food consumption patterns in a Late Roman-Early Byzantine cemetery population at Joan Planells, Ibiza. In Late Roman times, the Iberian Peninsula is considered an essential region in the Imperial economy, which makes this study an essential contribution of data to the growing corpus of information on diet and dietarychange in prehistoric and early historic Ibiza (Kulikowski 2004).

64

# 65 2. Joan Planells – Historical, Environmental and Archaeological Background

Joan Planells is a large cemetery site in Eivissa, Ibiza (Figure 1). As mentioned above, the island was first impacted by Roman expansion in the  $2^{nd}$  and  $3^{rd}$  centuries. During the time that this island was in the sphere of Roman influence, there was relative economic stability, but from the  $4^{th}$  century onward the Roman presence in the Iberian Peninsula experienced economic crisis and

70 political break down ensued (Kulikowski 2004). With this economic crisis, the Atlantic

71 commerce deteriorated rapidly.

72 During the 3<sup>rd</sup> to 5<sup>th</sup> centuries and into the 7<sup>th</sup> century, the Iberian Peninsula experienced

important environmental changes. In Galicia, from the  $2^{nd}$  to  $4^{th}$  centuries, temperature and

humidity conditions were optimal for agriculture, providing good growing seasons for most of

the crops (Lopez Costas and Muldner 2016). When there were crop failures, millet and

76 fish/shellfish were alternative foods sources. The marine resources exploited are an important

contribution to Late Roman/post-Roman diet and may have been specific to the local perspective

78 (Lopez Costas and Muldner 2016).

Prior to its use as a cemetery the site was an urban area used for pottery production (Esquembre 79 Bebia et al. 2005; Martinez 2011; Girdwood 2012). The site is 36 m by 14 m in size and only a 80 portion was excavated. The remains of 74 individuals were recovered in both single cist and 81 multiple burials, some with comingled remains, and from a small number of simple pit burials 82 (Martinez 2011). Individuals were placed in supine position and accompanied by few graves 83 goods (Martinez 2011; Graziani Echávarri 2013). The small number of artifacts that were found 84 in association with the skeletal remains indicate that this necropolis was in use from the Late 85 Roman period, c. 3<sup>th</sup>-5<sup>th</sup> century AD, and continued to be used until the end of the Byzantine 86 period, in the 7<sup>th</sup> century AD. 87

88

<sup>89</sup> FIGURE 1 HERE

Sex and age were assessed and recorded under the supervision of one of the authors (EK). 91 Standard methods for sex estimation utilizing the morphological features of the pelvis and 92 93 cranium were employed wherever possible with the inclusion of metric techniques (Buikstra and Ubelaker 1994). Discriminant functions based on cranial and postcranial measurements were 94 also employed to classify individuals when the pelvis was not available. The discriminant 95 functions used for sex estimation was derived from a pooled sample from Ibiza of the same 96 97 period and not from the American Standards. At first, sex was estimated using pelvic morphology and from these estimates discriminant functions were developed for long bones (e.g. 98 femur) and teeth using bootstrapping to account for sample size bias. The individuals with over 99 100 80% posterior probability of correct classification were considered reliable while anything under 80% was considered unknown. This information provided the demographic information 101 necessary to sample the 38 individuals that were analyzed for isotopes, in which males, females 102 and children were considered for the study. Of the 74 individuals recovered from Joan Planells, 103 43 were adults, 7 were juveniles and 24 were of unknown age at death (García-Donas et al. 104 2014). Sex estimation was possible for 25 individuals with 11 males and 14 females (García-105 106 Donas et al. 2014). Indicators of degenerative joint disease, including Schmorl's nodes, were found to be more common in females than among the males, whereas trauma and metabolic 107 108 ailments were more prevalent in males (see García-Donas et al. 2014 for more details). The preservation of the Joan Planells assemblage was poor, and the remains were highly fragmented. 109 110 Many of the burials were weathered and the bone was cracked, which made the collection of samples for isotope analysis difficult. The population of Joan Planells appears to be from a local 111 112 area, as the community buried in the cemetery includes men, women and children. Most evidence from ceramic remains and from textual records suggest that this site was urban, but this 113 114 is not completely corroborated. The dietary evidence that is present below sheds some light on 115 the kinds of patterns related to status and identity in relation to food consumption.

116

# 117 **3. Reconstructing Diet**

# 118 *3.1 Historical Sources*

Documentary sources indicate that in the Mediterranean region in the 2<sup>nd</sup> to 7<sup>th</sup> centuries AD diet was based largely on cereals (principally wheat and barley as well as millet, rye and oats), olive oil and wine, as well as legumes, such as lentils and chickpeas (Garnsey 1999). As the principal 122 staple in the Mediterranean diet, wheat was often imported/exported throughout the Roman and Byzantine empires (e.g. Curchin 1991). Resources were not equally available to all. Meat did not 123 figure prominently in the diets of many individuals, although it was an important component of 124 the diets of the Roman upper classes (Garnsey 1999). Large herds of sheep and goat were 125 reportedly kept predominantly for secondary products, such as wool and milk to produce cheese 126 (Dalby and Grainger 2012; Garnsey 1999). Archaeologically, sheep, goat and pig appear to have 127 128 been the primary sources of meat (Prowse et al. 2005). Cattle may have been reared primarily for use in traction (Garnsey 1999). 129

130 Salt fish and fish sauces and pastes were produced in quantity in the Roman provinces of Spain and continued to be economically important into the Byzantine period (Ponsich and Tarradell 131 1965; Garnsey 1999; Shepard 2004). In AD 301 the Edict of Diocletian V. 1-5 likely led to the 132 133 reduced cost of freshwater fish across the Roman Empire (Rutgers et al. 2009) and this may in 134 turn have resulted in social widening of access to fish and fish products. However, consumption 135 of fish in Roman society was often related to status. Fish products, such as garum made from 136 tuna fish, were luxury foods with many elites having access. For members of the lower echelons of Roman society, fish products were a difficult resource to obtain (Corcoran 1963; Garnsey 137 1998). In northwestern Spain, evidence of salting facilities has been uncovered for processing 138 and preserving seafood dating back to the Iron Age. Historical sources during the Late Roman 139 140 and Medieval periods suggest that a local marshland was exploited heavily for salt production 141 (Lopez Costas and Muldner 2016). Local salting facilities on the Balaeric islands have not been extensively studied. There may have been more localized fish consuming practices on the islands 142 and therefore large-scale salting activities may not have been a priority during the Late Roman 143 period. From the work conducted by Ramon Torres et al. (2012) it appears that at the site of Sa 144 Caleta, Phoenicians were actively extracting salt, which turned into a prosperous industry by 145 around 650BC. Therefore, Ibiza has strong ties to trade within the Mediterranean, carrying over 146 147 to Roman and Early Byzantine exchange networks.

148

# 149 *3.2 Stable Isotope Analysis*

150 Carbon and nitrogen stable isotope ratios of bone collagen have been demonstrated to be reliable 151 indicators of long-term dietary protein intake (Sealy 2001, Schoeninger 2010).  $\delta^{13}$ C and  $\delta^{15}$ N 152 isotope values of different categories of foods (e.g. marine and freshwater foods, and terrestrial 153 resources from C<sub>3</sub> and C<sub>4</sub> plant foodwebs) are generally distinctive. Plants in different environments (terrestrial, marine and freshwater) fix/acquire carbon during photosynthesis in 154 155 different ways. Plants utilized as dietary staples fix carbon by one of two pathways, either the C<sub>3</sub> or C<sub>4</sub> pathway. C<sub>3</sub> plants comprise most grasses and plants native to temperate regions, including 156 oats, barley, wheat, and rice. C<sub>4</sub> plants include important cereal staples such as maize and millet. 157  $C_3$  plants generally have lower  $\delta^{13}C$  values than  $C_4$  plants. For example, a typical consumer of 158 foods drawn from the terrestrial C<sub>3</sub> foodweb might have  $\delta^{13}$ C values between approximately -159 20‰ and -18‰, while a consumer entirely dependent on resources from the C<sub>4</sub> foodweb would 160 be anticipated to have  $\delta^{13}$ C around -7.5‰ (cf. van der Merwe and Vogel 1978; Tykot 2004). 161 Marine plants also fix carbon by the C<sub>3</sub> pathway. However, the  $\delta^{13}$ C values of marine plants are 162 distinctive from terrestrial C<sub>3</sub> plants because marine carbon isotope ratios are enriched relative to 163 atmospheric carbon isotope ratios (Tykot 2004). A typical consumer of predominantly marine 164 resources might have isotope values of  $\delta^{13}C = -12\%$ . Although this overlaps with the carbon 165 isotope values of C<sub>4</sub> consumers, the two dietary components can *often* be distinguished by  $\delta^{15}N$ 166 analysis. 167

Nitrogen stable isotopes are enriched with each trophic level by at least c. 3-5‰ (Bocherens and 168 Drucker 2003) and potentially up to 6‰ (O'Connell et al. 2012). Human consumers of terrestrial 169 resources will typically have  $\delta^{15}$ N values c. 6-10‰ (Tykot 2004). Marine/freshwater food-chains 170 are generally longer than terrestrial food-chains so consumers of aquatic resources tend to have 171 higher  $\delta^{15}$ N values than consumers of terrestrial resources (although see Hedges and Reynard 172 [2007] for discussion of uncertainties in  $\delta^{15}N$  trophic shift variation). This  $\delta^{15}N$  difference 173 between terrestrial and aquatic food-chains generally allows diets based on marine resources to 174 175 be distinguished from those derived from the C<sub>4</sub> foodweb.

176 Co-analysis of  $\delta^{13}$ C and  $\delta^{15}$ N signals of humans and fauna may distinguish between diets based 177 on terrestrial C<sub>3</sub> and C<sub>4</sub> plant foodwebs, freshwater and marine resources, and identify the trophic 178 level of the consumer (e.g. Chisholm et al. 1982; Schoeninger and DeNiro 1984; Tykot 2004).

179

# 180 4. Materials and Method

181 Bone samples for stable isotope analysis were obtained from the individuals that were relatively 182 well preserved in comparison to most the human bone material recovered. In the case of comingled remains only one sample was taken to ensure that there was no duplication in sampling.
A total of 38 individuals were sampled (see Table 1), comprising 12 males, 8 females and 18
individuals of unknown sex. Twenty-two of these individuals are adults; one is a juvenile and 15
are of unknown age.

A sample of approximately 1 g of bone was taken from each specimen. Pre-treatment consisted
of cleaning each sample with the removal of 1-2 mm of surface bone. This was done to eliminate
remnant external contaminants accumulated while buried (van Klinken and Hedges 1995).
Cancellous bone was removed from samples taken from the long bones. Collagen was extracted
from all samples using a modified version of the Longin (1971) method (Brown et al. 1988).

192 Each sample was demineralized in 1 N HCl at 20°C for a minimum of 24 hours, and gelatinized in 0.03 N HCl at 80°C for approximately 16 hours. The resulting solution was then lyophilized. 193 Well-preserved collagen samples, i.e. those with % wt yield of >1.00% (van Klinken 1999), were 194 measured for  $\delta^{13}$ C and  $\delta^{15}$ N by the SUERC Radiocarbon Laboratory in East Kilbride, UK, using 195 a Costech ECS 4010 combustion elemental analyzer coupled to a Thermofisher Delta V 196 197 Advantage gas source isotope ratio mass spectrometer. In-house gelatine standards, which are 198 calibrated to the International Atomic Energy Agency (IAEA) reference materials USGS40 (Lglutamic acid,  $\delta^{13}C_{V-PDB} = -26.39\%$ ), USGS41 (L-glutamic acid,  $\delta^{13}C_{V-PDB} = +37.63\%$ ), IAEA-199 CH-6 (sucrose,  $\delta^{13}C_{V-PDB} = -10.45\%$ ), USGS25 (ammonium sulphate,  $\delta^{15}N_{AIR} = -30.41\%$ ), 200 IAEA-N-1 (ammonium sulphate,  $\delta^{15}N_{AIR} = +0.43\%$ ) and IAEA-N-2 (ammonium sulphate, 201  $\delta^{15}N_{AIR} = +20.41\%$ ), are run in duplicate for every ten unknown samples. Results are corrected 202 for linearity and instrumental drift, and are reported as per mil (‰) relative to the internationally 203 accepted standards V-PDB and AIR, with 1 $\sigma$  precisions of  $\pm$  0.2‰ and  $\pm$  0.3‰ for  $\delta^{13}$ C and 204  $\delta^{15}$ N. respectively. 205

Collagen integrity was assessed by the following criteria: (i) atomic C:N ratio in the range 2.9 to 3.6 (DeNiro 1985), and (ii) minimum %C = 13% and %N = 5% (Ambrose 1990). All the samples discussed below met these criteria.

209 Comparison of human stable isotope values with those of potential food sources improves the 210 accuracy of dietary models. However, no faunal remains were recovered from the Joan Planells 211 cemetery. The Joan Planells data were therefore compared to published archaeological faunal stable isotope values from the near-contemporary site of S'Hort des Llimoners also located at
Eivissa, Ibiza (see Table 2, data from Fuller et al. 2010).

214

# 215 **5. Results and Discussion**

The  $\delta^{13}C$  and  $\delta^{15}N$  isotope values of the Joan Planells human bone samples are presented in 216 Table 1 and in Figures 2 and 3. Mean±standard deviation (1 $\sigma$ )  $\delta^{13}$ C and  $\delta^{15}$ N values of the 217 sampled population (n=38) are  $-18.7\pm0.5\%$  and  $10.1\pm1.3\%$ , respectively. In a Mediterranean 218 population, these values are consistent with a diet based largely, but not necessarily exclusively, 219 on terrestrial C<sub>3</sub> resources including meat and dairy produce (e.g. Richards et al. 1998; Tykot 220 2004). Comparison with Late Antiquity-Early Byzantine (LA-EB) animal isotope data (from 221 222 Fuller et al. 2010) to set baseline values for the local foodweb suggests that animal protein was a noteworthy component of average diet but that additional resources, such as cereals, were likely 223 to have been important dietary staples – see Table 2 and Figure 3. The average  $\delta^{15}$ N value of the 224 Joan Planells individuals is 4.6% above the caprine mean  $\delta^{15}$ N value (of 5.5%, n=8), 4.3% 225 above the pig mean  $\delta^{15}$ N value (of 5.8‰, n=2) and 2.6‰ above the cattle mean  $\delta^{15}$ N value (of 226 7.5‰, n=2). Caprine and porcine products may therefore have played a more important role in 227 human diet than those of cattle. This corresponds not only to the reported dominance of goat in 228 the animal remains recovered from Late Antiquity-Early Byzantine sites in Ibiza but also to 229 accounts of Roman period diet, which point to greater dependence on pork (Fuller et al. 2010). 230

The higher mean  $\delta^{13}$ C value of humans compared to animal food-species (-18.7%) in humans in 231 comparison to -20.1‰ in cattle, pigs and caprines) is statistically significant (Mann-Whitney U 232 Test  $\delta^{13}$ C, U=32.5, p<0.05 – see Table 3 for all p-values and U statistics). This may reflect 233 additional or distinctive protein sources in human diet (e.g. a small component of C<sub>4</sub> resources) 234 or, alternatively, may be the result of a  $\delta^{13}$ C food-consumer offset. Bocherens and Drucker 235 (2003) argued that the  $\delta^{13}$ C trophic level shift between 'predator' and 'prey' could be up to 236 237 2.0‰. Notably, the food species dataset from S'Hort des Llimoners is limited, comprising a total of 12 specimens from three taxa. It is therefore possible that the observed difference in human 238 and domesticate  $\delta^{13}C$  values is an artefact of sample size. 239

240 TABLE 1 HERE

- 241 FIGURE 2 HERE
- 242 FIGURE 3 HERE
- 243 TABLE 2 HERE
- 244 TABLE 3 HERE
- 245 5.1 Limitations of Study

This study serves to add to the growing body of research on dietary trends during the Late 246 Roman period of the Balearic Islands. Fuller et al (2010) provide an extensive diachronic 247 perspective from various sites on Ibiza and Formentera, with human and animal isotopic 248 signatures being gathered. Within the scope of our project, and with the resources available to 249 the authors on site context information as well as historical correlates, the project does suffer 250 from a lack of local animal signatures to tease apart the human signatures and the sources of 251 dietary consumption as well as provide a stronger connection to the kinds of biocultural and 252 historical processes that may have been impacting diets between men, women and children. In 253 254 addition to this, the burials available to analyze for isotopic signatures were limited to 38 individuals, as there was some poorly preserved remains from the cemetery of Joan Planells. 255 Furthermore, due to the limited contact with the original excavators there is not as much in-depth 256 257 contextual information that could be added to the background and interpretations of dietary 258 practice at this site. This limitation is a testament to the necessity of osteological specialists to be present during excavations and for more conversations to occur during and after the recovery of 259 260 the material from the field.

Despite these limitations, the study allows for comparisons to be made more closely among men and women from Joan Planells, which is a greater step towards discussing gendered dietary trends in the past. This kind of conversation allows for more nuanced interpretations to be made about the ways that Romanization were influencing frontier sites at the confluence of the Roman and non-Roman world.

266 *5.2 Differences in individual diets* 

At Joan Planells stable carbon isotope ratios have a relatively narrow range of values from -17.7‰ to -19.7‰ (within ±1‰, which DeNiro and Schoeninger [1983] identified as the typical range for populations consuming uniform diet). The range of the  $\delta^{13}$ C values is consistent with a

predominantly C<sub>3</sub> foodweb-derived diet for *this* region. C<sub>3</sub> plants are reported to have mean  $\delta^{13}$ C 270 of -26.5‰ (e.g. Tykot 2004): assuming a diet-bone collagen offset of +5‰, consumers of an 271 exclusively C<sub>3</sub> derived diets would be anticipated to have  $\delta^{13}$ C values of c. -21.5‰. However, C<sub>3</sub> 272 cereals from the West-Mediterranean region of Spain have been demonstrated to be relatively 273 <sup>13</sup>C-enriched. Archaeological specimens of Triticum durum, Hordeum vulgare and Hordeum 274 *vulgare nudum* recovered from Neolithic to Iron Age contexts have mean  $\delta^{13}$ C values of -22.6%. 275 -22.8‰ and -22.6‰, respectively (see table 1, Araus et al. 1997). Consumers of these C<sub>3</sub> 276 resources would have  $\delta^{13}$ C values of c. -17.7‰. 277

The nitrogen isotope ( $\delta^{15}$ N) values exhibit a wide range from 9.0% to 14.8% spanning 278 approximately one trophic level (O'Connell et al. 2012), suggestive of individual differences in 279 dietary intake. It should be noted, however, that most of the sampled population have  $\delta^{15}N$ 280 values of  $\leq 12.7\%$ . Two males, UE303 and UE301, are statistical outliers with especially high 281  $\delta^{15}$ N values of 14.4‰ and 14.8‰, but typical  $\delta^{13}$ C values of -18.6‰ and -19.1‰, respectively. 282 This suggests that the diet of these individuals was distinctive from other members of this group. 283 Increased  $\delta^{15}$ N values are typical of diets that include aquatic resources such as fish and sea 284 mammals. Generally, consumption of marine resources is associated with the co-linear increase 285 of both  $\delta^{13}$ C and  $\delta^{15}$ N values (Schoeninger et al. 1990). Spearman's Rank Order Correlation test 286 indicated a moderate positive correlation ( $r_s=0.37$ ) between the  $\delta^{13}$ C and  $\delta^{15}$ N values in the Joan 287 Planells population (see also Figure 2). Arguably, however,  $\delta^{15}N$  values are a more reliable 288 indicator of marine resource consumption than  $\delta^{13}$ C in Mediterranean populations where diets 289 may be relatively high in carbohydrate and low in protein (Prowse et al. 2005; Craig et al. 2013). 290 In individuals with relatively low protein diets nutrient scrambling (Prowse et al. 2004; Craig et 291 292 al. 2013) may result in carbon and nitrogen being drawn from different dietary constituents carbon may be assimilated from dietary proteins, carbohydrates and/or lipids in protein 293 inadequate diets (Hedges 2004). It is likely therefore that the <sup>15</sup>N-enriched values of individuals 294 UE301 and UE303 are the result of increased access to aquatic/marine resources, which may be 295 status- or activity-related. This interpretation is offered cautiously - in the Mediterranean region 296 identifying the consumption of marine foods is non-trivial. Among the men of Joan Planells, 297 there is a stepwise, linear pattern that shows there is incremental differences in  $\delta^{15}N$  values, 298 while  $\delta^{13}$ C values are almost the same (Figure 2) (positive linear trend is highlighted by a 299 300 vertical dashed red line). This pattern may be suggestive of differential access to fish resources

- among the men of this population and that possibly there were men of highly distinct statuses being buried in the same cemetery. The  $\delta^{13}$ C and  $\delta^{15}$ N values of fish from the Mediterranean Sea vary widely (see Pinnegar and Polunin 2000; Garvie-Lok 2001; Polunin et al. 2001; Badalamenti et al. 2002; Prowse et al. 2004; Keenleyside et al. 2009). Polunin et al. (2001) reported that the mean  $\delta^{13}$ C and  $\delta^{15}$ N values of modern fish specimens captured off the southeast coast of Ibiza were -17.8‰, much lower than the  $\delta^{13}$ C range (-8.3‰ to -14.1‰) for modern and archaeological Mediterranean fish published by Garcia-Guixé et al. (2010).
- The mean±s.d. (1 $\sigma$ )  $\delta^{13}$ C and  $\delta^{15}$ N values of the females (n=8) at Joan Planells are -18.3±0.5‰ 308 and  $11.5\pm0.8\%$ , respectively, while those of the males (n=12) are -18.9\pm0.3\% and  $11.3\pm1.7\%$ , 309 respectively. There is a statistically significant difference between male and female  $\delta^{13}$ C values. 310 but not in  $\delta^{15}$ N values, even with the statistical outliers included (Mann-Whitney U Test  $\delta^{13}$ C, 311 U=19.5, p<0.05;  $\delta^{15}$ N, U=64.5, p>0.05). This difference along with isotopic signatures for an 312 increased preponderance of degenerative conditions may point to activity and/or sex-based 313 differences in access to food. The parsimonious explanation for relative <sup>13</sup>C-enrichment in 314 females with no associated increase in  $\delta^{15}$ N values is a greater contribution of C<sub>4</sub> plant resources 315 to diet (cf. Müldner et al. 2011 and Pickard et al. 2017). Millet, a C<sub>4</sub> cereal, may have contributed 316 317 to the diets of Late Roman-Early Byzantine interred on Ibiza (e.g. Fuller et al. 2010). An alternative possibility is the consumption of low trophic level aquatic/marine resources such as 318 shellfish and garum made from low trophic level fish. For example, stable isotope values of 319 samples of garum from Roman Pompeii have high  $\delta^{13}$ C values (-12.2‰) and relatively low  $\delta^{15}$ N 320 values (4.9‰) (Pate 2016). Similar mean values are quoted by Prowse et al. (2004) for five 321 ancient garum samples, with  $\delta^{13}$ C=-14.7±0.6‰ and  $\delta^{15}$ N=6.5±1.7‰. Hedges (2004) indicated 322 that as much as 20% of dietary protein would need to be drawn from marine resources for this 323 component of diet to be isotopically visible. Given an average daily requirement of c. 50 g of 324 protein in females and traditional Southeast Asian fish sauces, which are considered to "parallel 325 almost exactly" garum, have a protein content of 100g/L (see Curtis 2009), consumption of 100 326 ml of garum per day should be isotopically visible. Additionally, in carbohydrate rich diets that 327 are relatively low in protein, protein-rich foods can make a disproportionate contribution to 328 collagen isotope signals reflecting amino acid routing as opposed to biosysthesis (Webb et al. 329 2016). 330
- 331

# 332 5.3 Demographics and diet

A further consideration in isotope-based dietary reconstruction is the structure and 'isotope age' 333 334 of the population sampled. The Joan Planells bone collagen samples were obtained from individuals of varying age as well as from different skeletal elements (including long bones, 335 digits and ribs) The isotope signatures of these individuals therefore potentially reflect diet at 336 different stages of life and over varying timespans. The timespan reflected in bone collagen 337 338 stable isotope values depends on (i) the age of the individual at death, and (ii) the type of bone sampled, i.e. whether it is trabecular or cortical tissue. In infants and young children there is 339 340 rapid bone development and sampled bone collagen may reflect diet only during the year prior to death (Tsutaya and Yoneda 2013). During adolescence, another key period of substantial bone 341 342 growth, complete collagen turnover may occur in both trabecular and cortical bone in as little as one to two years (Ubelaker and Parra 2011; Tsutaya and Yoneda 2013). In adulthood, with 343 cessation of bone growth, collagen turnover reduces significantly - it is estimated to take, on 344 average, between 10 and 30 years for collagen to turnover completely (Libby et al. 1964; 345 346 Stenhouse and Baxter 1979; Hedges et al. 2007). Consequently, in young to middle aged adults there is disproportionate representation of dietary intake during adolescence in bone collagen 347 isotope signatures depending on skeletal element sampled (Hedges et al. 2007; Ubelaker and 348 Parra 2011). Collagen turnover in cancellous elements is generally more rapid than that in 349 350 cortical tissues. Collagen in adult ribs may turnover completely in as little as c. 2 years and in vertebrae in 1-3 years, while turnover in the mid-shaft of an adult femur may take over 20 years 351 (Bryant & Loutit 1964; Hedges et al. 2007). 352

The majority of the aged individuals sampled at Joan Planells fall into the young to middle adult categories. In these individuals analysis of cortical bone would be anticipated to mainly reflect dietary intake during adolescence, while analysis of largely cancellous bone tissue should reflect diet in the last 2-5 years before death. Comparison of cortical vs cancellous elements indicated no significant difference in  $\delta^{13}$ C nor in  $\delta^{15}$ N values (Mann-Whitney U Test  $\delta^{13}$ C, U=227.5, p>0.05;  $\delta^{15}$ N, U=170.5, p>0.05) suggesting that dietary intake did not change significantly between adolescence and adulthood.

Notably, 88% of the females analyzed were of reproductive age. A range of factors, includingpregnancy as well as nutritional stress and pathological conditions can result in non-dietary

related variation in individual  $\delta^{13}$ C and  $\delta^{15}$ N values (e.g. Fuller et al. 2005; Nitsch et al. 2010; Olsen et al. 2014).

364

# 365 5.4 Diet in the Late Antiquity-Early Byzantine period – a stable isotope perspective

366 Diet of the Late Antiquity-Early Byzantine cemetery population at S'Horts des Llimoners is 367 broadly like that of the Joan Planells population, with primary dependence on  $C_3$  resources and potentially with a small component of  $C_4$  or marine resources (Table 4; Fuller et al. 2010). Given 368 the proximity contemporaneity of the two sites the similarity in diets is perhaps not unexpected. 369 However, differences in minor components of diet are evident. While the  $\delta^{15}N$  values of the adult 370 populations at Joan Planells (n=23) and S'Horts des Llimoners (n=34) are statistically 371 indistinguishable, there is a significant difference in the  $\delta^{13}$ C values (Mann-Whitney U-test, 372  $\delta^{13}$ C, U=525.5, p<0.05:  $\delta^{15}$ N, U=402, p>0.05). The relative <sup>13</sup>C-enrichment of the Joan Planells 373 374 adult population compared to that of S'Horts des Llimoners lends support to the suggestion that a C<sub>4</sub> resource, such as millet, may have contributed to diet at Joan Planells, and possibly more 375 376 among women of this population. Alternatively, this difference may reflect more complex patterns of dietary difference resulting from macronutrient scrambling in carbohydrate rich diets 377 that include marine protein (e.g. Prowse et al. 2005; Craig et al. 2013). 378

# 379 TABLE 4 HERE

It is apparent that there was no one 'Roman' diet in both Italy, mainland Spain and the Balearic Islands (Killgrove and Montgomery 2016). Direct comparison of stable isotope values and diets at Late Roman sites in other regions is limited by the demonstrably different baseline isotope values of domesticates across these regions (e.g. Prowse et al. 2004; Keenleyside et al. 2009; Craig et al. 2009; Rissech et al. 2016). However, some general observations can be drawn.

Dependence on  $C_3$  plants, with an important but variable contribution from meat and/or dairy products, is characteristic of many Late Roman sites in the sphere of Roman influence and on mainland Spain and throughout the Mediterranean Basin (e.g. Killgrove and Tykot 2013; Rissech et al. 2016; Salazar-García et al. 2016; Saragoça et al. 2016). The range and relative importance of the foods consumed at S'Horts des Llimoners and Joan Planells are remarkably like the diets inferred for individuals interred at the Late Roman cemeteries of Casal Bertone and Castellaccio Europarco, Rome, Italy (see Killgrove and Tykot 2013). At each of these sites diet was based principally on  $C_3$  plants with meat/other animal products, while  $C_4$  and/or aquatic resources minor contributors to diet. However, interestingly this pattern is reverse for mainland NW Spain, which shows high consumption of fish and C4 resources (Lopez-Costas and Muldner 2016).

As at Joan Planells, caprines and pigs were likely the primary sources of animal protein at the 395 late Roman necropolis at Carrer Ample 1, Barcelona, Spain. Rissech et al. (2016) highlighted the 396 distinctive nature of diet at Carrer Ample 1 in comparison to other Late Roman sites in the 397 398 Mediterranean owing to the slight or absent contribution of fish at this coastally located site. The  $\Delta^{15}$ N spacing of 6.4‰ between humans and domesticates is relatively high at Carrer Ample 1, 399 larger than one trophic level (O'Connell 2012) - see Table 5. The likely contribution of fish to 400 401 diet at Carrer Ample 1 thus appears to be greater than that at Joan Planells or Casal Bertone and 402 Castellaccio Europarco. This interpretation is complicated by the single chicken bone analyzed from Carrer Ample 1, which has a  $\delta^{15}$ N value of 10.8‰. However, broadly Carrer Ample 1 fits 403 the C<sub>3</sub>-dominated dietary pattern evident at many other sites. 404

405 Although discerning the role of marine resources in Mediterranean diet in Antiquity is complex, 406 the stable isotope evidence, at least at the population level, points to little contribution of fish to 407 diet at many sites (e.g. Fuller et al. 2010; Killgrove and Tykot 2013; Rissech et al. 2016; and see Table 5). These patterns differ from those seen in Late Roman contexts at A Lanzada in Galicia, 408 where there is frequent consumption of local fish species (Lopez-Costas and Muldner 2016). A 409 Lanzada has some of the most C<sup>13</sup>-enriched values observed in any Iberian population. There is 410 furthermore a significant shift in diet between the Roman and post-Roman period during the 2<sup>nd</sup> 411 and 4<sup>th</sup> centuries AD where there is economic and environmental transformation. Archaeological 412 and/or osteological indicators at sites such as Carrer Ample 1, Castellaccio Europarco, as well as 413 414 Joan Planells, suggest that the interred populations were generally of low socio-economic standing (Killgrove and Tykot 2013; Rissech et al. 2016). However, some of the individuals 415 interred at these sites do have <sup>15</sup>N-enrichment consistent with a greater, and in some instances, a 416 sizeable proportion of fish in diet (e.g. UE 301 and UE303 at Joan Planells) These two male 417 418 individuals are both in their 20s or 30s and their graves were single cist burials with undifferentiated artifacts. Perhaps these were individuals who had direct connections with the 419 fishing industry? 420

#### 421 TABLE 5 HERE

An alternative hypothesis is that individuals of higher status had greater access to prestige foods. 422 Prowse and colleagues (2004) demonstrated that the affluent population of Portus Romae, 423 interred at Isola Sacra, consumed a significant proportion of fish, with up to 40% of dietary 424 protein derived from marine resources. In contrast to this, the rural, inland, farming population 425 from the cemetery at an ANAS excavated site in Rome's suburbs had relatively low <sup>13</sup>C and <sup>15</sup>N 426 reflecting the minor importance of fish to diet (Prowse et al. 2004). However, this correlation 427 428 between status and fish consumption if far from universal. At the contemporary trading port of 429 Velia, in southern Italy, Craig and colleagues (2009) identified variation in access to marine resources: this could not be clearly linked to status inferred from burial style. As Craig et al. 430 (2009) pointed out there is no evidence to support the notion that the individuals interred at Isola 431 432 Sacra were of higher status than the population at Velia. Craig et al. (2009) therefore concluded 433 that the increased consumption of fish evident at Isola Sacra did not directly reflect status but was specific to the economy, occupations and access to traded foods of those employed at one of 434 435 the largest trading ports in the Roman world.

436 Differences in the diets of males and females are suggested by stable isotope ratios at Isola 437 Sacra, Velia and Joan Planells (Prowse et al. 2005; Craig et al. 2009). At each of these sites females appear to consume more plants, while males have greater access to either meat or fish. 438 This trend is evident also in the pre-Roman, Celtic population from the necropolis of Seminario 439 Vescovile in Verona, dating from the 3<sup>rd</sup> to 1<sup>st</sup> century BC, which indicates that women 440 consumed higher amounts of C4 plants (and cereals in general), while men had greater access to 441 meat (Laffranchi et al. 2016). For cultural and practical reason men in Roman society generally 442 had greater access to higher prestige food such as meat and fish. Socio-economic status may 443 have influenced the manifestation of dietary differences. The effects of sex-based dietary 444 445 restrictions would have been more pronounced in wealthier households. All members of lower 446 status households, male and female would have had limited access to meat (Garnsey 1999). The cultural restriction of certain foods based on the perceived negative effects on health in females 447 may have permeated the social makeup of the colonies. 448

449 Dietary differences between males and females at Joan Planells hint at greater consumption of a 450  $C_4$  resource. The stable isotope values of the domesticates from S'Horts des Llimoners show no

evidence for a C<sub>4</sub> component in animal feed. Thus, if sex-based dietary differences at Joan 451 Planells reflect C<sub>4</sub> input, it is likely that this was in the form of the C<sub>4</sub> cereal millet. Stable 452 isotope analyses have indicated that the consumption of millet was widespread in later 453 454 prehistoric and Roman Europe and that it correlated with socio-economic status (e.g. Murray and Schoeninger 1988; Bonsall et al. 2004; Le Huray and Schutkowski 2005). In Roman society 455 millet was viewed as a poor-quality cereal (Iacumin et al. 2014; Kulikowski 2004), not used in 456 457 the kitchens of the elite, and often grown for animal fodder (Adamson 2004). Millet flour was also used to produce bread and a sort of porridge cooked in water and salt. Often, these kinds of 458 foods were accompanied by vegetables and cheese and very rarely with meat (Columella, De Re 459 Rustica, 2, 9, 14-16; Pliny the Elder, Naturalis Historiae XVIII, 83-84; Lafrranchi et al. 2016). 460 Cemetery sites in the locus of Rome confirm the correlation between millet intake and socio-461 economic status. At the more rural, suburban cemetery of Castellaccio Europarco consumption 462 of millet was greater than at the urban cemetery of Casal Bertone - this is reflected in relative 463 <sup>13</sup>C at the former site (Castellaccio Europarco adult  $\delta^{13}$ C= -17.8±2.6‰ and  $\delta^{15}$ N=9.4±1.4‰; 464 Casal Bertone adult  $\delta^{13}$ C=-18.2±0.6 and  $\delta^{15}$ N=10.0±1.5‰). 465

The evidence from Joan Planells spans the 3<sup>rd</sup> to 7<sup>th</sup> centuries AD and the isotopic signatures are 466 evaluated at the site level. This means that the population average for  $\delta^{13}$ C and  $\delta^{15}$ N values 467 account for the entire spread of this timeframe. While most the burials are from the 3<sup>rd</sup> to 5<sup>th</sup> 468 centuries, the later 7<sup>th</sup> century evidence may present some variability among the trends for this 469 470 Late Roman period. Nevertheless, the dataset is an important contribution to discuss how diet can differ not only between geographically closer locales, such as Joan Planells and A Lanzada 471 in mainland Spain, but also how diet can vary within a population, in which two men have 472 significantly higher  $\delta^{15}$ N values than the rest of the population. 473

474 The discussion above highlights the clear similarities between the diet, and potentially cultural restrictions that limit access to foods, at Joan Planells and other sites both in Italy and in the 475 476 sphere of Roman influence on mainland Spain and the Balearic Islands. However, to determine if these similarities are the result of Roman influence comparisons must be made with pre-Roman 477 478 diet on Ibiza. The diet of the Joan Planells adult population is distinctive from that of the earlier Punic (5<sup>th</sup>-2<sup>nd</sup>/1<sup>st</sup> centuries BC) population from the rural necropolis Ses Païsses de Cala d'Hort 479  $(\delta^{13}C = -18.7 \pm 0.3\%)$  and  $\delta^{15}N = 12.5 \pm 0.5\%$ , n = 38), situated in southwest Ibiza: Fuller et al. 2010). 480 Relative <sup>15</sup>N-enrichment is evident at the latter site (Mann-Whitney U test  $\delta^{13}$ C, U=354, p>0.05; 481

 $\delta^{15}$ N, U=135, p<0.05) suggesting increased consumption of higher trophic level foods, such as 482 meat and potentially fish or fish products. While it is tempting to attribute this apparent shift in 483 484 dietary pattern to Roman influence, it is important to acknowledge that there is no difference (Mann-Whitney U test  $\delta^{13}$ C, U=61.5 p>0.05;  $\delta^{15}$ N, U=71, p>0.05) in the isotope values of the 485 Joan Planells population and that of an urban Punic population at Puig des Molins ( $\delta^{13}$ C=-486 18.8±0.3 and  $\delta^{15}$ N=-11.3±0.8, n=6: Fuller et al. 2010). This suggests the diet of urban 487 488 populations remained largely unchanged in Ibiza through the Punic period and into the Roman period. However, the number of adults sampled for Puig des Molins is very small. Additionally, 489 there was no demographic information available for either the Puig des Molins or Ses Païsses de 490 Cala d'Hort populations so it was not possible to investigate sex-based variability in Punic diet. 491 Further research into dietary variability at Punic and Roman period sites on Ibiza would assist in 492 clarifying the impact of external spheres of influence on local cultural practices. 493

It is apparent then that the dietary patterns of population at Joan Planells varied internally, but 494 also it varied greatly from the pattern of food consumption in Italy and in mainland Spain during 495 the Late Roman period. Twiss (2007) articulates that food forms the basis of identity politics and 496 forms the basis of sustaining group cohesion and responses to internal and external pressures to a 497 community. For the population of Joan Planells, the negotiation of identity was occurring 498 through the Late Roman context and in the Early Byzantine period, when new internal and 499 external pressures were mounting. This community may have faced environmental and socio-500 501 political change that was mitigated by consuming more local, C3 plant resources, instead of engaging with the millet trade and fish acquisition. The ability for this population to negotiate 502 503 their role in the midst the cessation of Roman influence recognizes the ingenuity and agency for the community at Joan Planells. 504

505

# 506 6. Conclusions

507 The results of  $\delta^{13}$ C and  $\delta^{15}$ N analysis of human bone collagen indicate that the population 508 sampled at Joan Planells consumed a diet based largely on C<sub>3</sub> resources with a possible small 509 contribution from C<sub>4</sub> plants and/or aquatic resources. The  $\delta^{13}$ C values of the men and women are 510 statistically significantly different, suggesting dietary and potentially gender-differences. The 511 enriched  $\delta^{15}$ N signatures of two males in particular may have implications for status and/or 512 activity-related differences in dietary intake. 513 This investigation reveals important dietary trends for a region that was in the sphere of Roman influence. The combination of carbon and nitrogen isotopes along with demographic data 514 indicates dietary diversity at Joan Planells. While there are limitations in the detail of 515 archaeological contextual information, these dietary trends at Joan Planells to attest to great 516 variation in subsistence practices and gendered access to food at a time when the Roman sphere 517 was being impacted climatically with surges in extreme storm frequencies as well as greater 518 519 contact with hostile groups. With the eventual transition to Byzantine dominance in the Mediterranean, these dietary trends reflect the diversity of strategies that may have been 520 practiced during a period of political, economic and social instability. This paper contributes to a 521 more in-depth understanding that scholars have of diet in the Late Roman period, in which no 522 singular dietary trend can be labelled Roman. Better understand the variation in these subsistence 523 524 signatures can begin to tell us more about local responses to socio-political, economic and environmental changes. 525

526

# 527 Acknowledgements

We thank the School of History, Classics and Archaeology, University of Edinburgh, the Scotland Saltire Scholarship Foundation and Trinity College, University of Toronto, for their financial support. Special thanks to Luis Manuel Gonzalez La Rosa for his support in the final stages of writing this manuscript. Also, we would like to thank the comments from anonymous reviewers who helped to greatly improve this article. Any faults or errors are our own.

533

#### 535 **References**

- Adamson MW (2004) Food in Medieval Times. Westport, Connecticut: Greenwood Press.
- 537 Ambrose SH (1990) Preparation and Characterization of Bone and Tooth Collagen for Isotopic
- 538 Analysis. Journal of Archaeological Science 17:431-451. doi:10.1016/0305-4403(90)90007-R
- 539 Araus JL, Febrero A, Buxó R, Rodríguez-Ariza MO, Molina F, Camalich MD, Martín D, Voltas
- 540 J (1997) Identification of Ancient Irrigation Practices based on the Carbon Isotope
- 541 Discrimination of Plant Seeds: a Case Study from the South-East Iberian Peninsula. Journal of
- 542 Archaeological Science 24: 729-740. https://doi.org/10.1006/jasc.1997.0154
- 543 Badalamenti F, D'Anna G, Pinnegar J, Polunin N (2002) Size-related trophodynamic changes in
- three target fish species recovering from intensive trawling. *Marine Biology* 141:561-570.
  doi:10.1007/s00227-002-0844-3
- 546 Bocherens H, Drucker D (2003) Trophic level isotopic enrichment of carbon and nitrogen in
- bone collagen: case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology* 13:46-53. doi:10.1002/oa.662
- Bonsall C, Cook GT, Hedges REM, Higham TFG, Pickard C, Radovanovic I (2004)
  Radiocarbon and stable isotope evidence of dietary change from the Mesolithic to the middle
  ages in the Iron Gates: new results from Lepenski Vir. *Radiocarbon* 46:293–300.
  doi:10.2458/azu\_js\_rc.46.4269
- Brown T, Nelson D, Vogel J, Southon J (1988) Improved collagen extraction by modified
  Longin method. *Radiocarbon* 30:171-177. doi:10.2458/azu\_js\_rc.30.1096
- Bryant FJ, Loutit JF (1964) The entry of Strontium-90 into human bone. Proceedings of the 555 of London. Series В. 556 Royal Society Biological Sciences 159: 449-465. doi: 10.1098/rspb.1964.0013Buikstra JE, Ubelaker DH (1994) Standards for the data collection from 557 human skeletal remains. Arkansas Archaeological Survey Research Series 44. Fayetteville: 558 Arkansas Archaeological Survey. 559
- Chisholm BS, Nelson DE, Schwarcz HP (1982) Stable-Carbon Isotope Ratios as a Measure of
  Marine versus Terrestrial Protein in Ancient Diets. *Science* 216:1131-1132.
  doi:10.1126/science.216.4550.1131
- 563 Corcoran TH (1963) Roman Fish Sauces. *The Classical Journal* 58:381-384.

- Craig O, Bondioli L, Fattore L, Higham T, Hedges R (2013) Evaluating marine diets through
  radiocarbon dating and stable isotope analysis of victims of the AD79 eruption of Vesuvius. *American Journal of Physical Anthropology* 152:345-352. doi:10.1002/ajpa.22352
- 567 Craig OE, Biazzo M, O'Connell TC, Garnsey P, Martinez-Labarga C, Lelli R, Salvadei L,
- 568 Tartaglia G, Nava A, Reno L, Fiammenghi A, Richards O, Bondioli L (2009) Stable Isotopic
- 569 Evidence for Diet at the Imperial Roman Costal Site of Velia (1<sup>st</sup> and 2<sup>nd</sup> Centuries AD) in
- 570 Southern Italy. American Journal of Physical Anthropology 139:572-583.
  571 doi:10.1002/ajpa.21021
- 572 Curchin L (1991) *Roman Spain: Conquest and Assimilation*. London. Routledge.
- 573 Curtis RI (2009) Umami and the foods of classical antiquity. American Journal of Clinical
- 574 *Nutrition* 90: 712S-718S. doi: 10.3945/ajcn.2009.27462C
- 575 Dalby A, Grainger S (2012) *The Classical Cookbook*. Los Angeles: Getty Trust Pub.
- 576 Decker M (2004) Export Wine Trade to West and East. In Mango MM (ed) Byzantine Trade, 4<sup>th</sup>-
- 577 12<sup>th</sup> Centuries: The Archaeology of Local, Regional and International Exchange. Surrey:
  578 Ashgate, 239-252.
- 579 Degeai, J.-P., B. Devillers, L. Dezileau, H. Oueslati and G. Bony. (2015). Major storm periods
- and climate forcing in the Western Mediterranean during the Late Holocene. *Quaternary Science Reviews* 129:37-56.
- 582 DeNiro MJ (1985) Postmortem preservation and alteration of in vivo bone collagen isotope
- ratios in relation to palaeodietary reconstruction. *Nature* 317:806-809. doi:10.1038/317806a0
- 584 DeNiro MJ, Schoeninger MJ (1983) Stable carbon and nitrogen isotope ratios of bone collagen:
- 585 Variations within individuals, between sexes, and within populations raised on monotonous
- 586 diets. Journal of Archaeological Science 10:199-203. doi:10.1016/0305-4403(83)90002-X
- 587 Esquembre Bebia MA, Graziani Echavarri GJ, Moltó Poveda FJ, Ortega Pérez JR (2005)
- 588 Excavaciones arqueológicas en un solar de la calle Joan Planells (Eivissa). *Fites* 5:9-16.
- 589 Fuller BT, Fuller JL, Sage NE, Harris DA, O'Connell TC, Hedges REM (2005) Nitrogen balance
- and  $\delta^{15}$ N: why you're not what you eat during nutritional stress. *Rapid Communications in Mass*
- 591 *Spectrometry* 19:2497-2506. doi:10.1002/rcm.2090

- Fuller BT, Marquez-Grant N, Richards MP (2010) Investigation of Diachronic Dietary Patterns
  on the Islands of Ibiza and Formentera, Spain: Evidence from Carbon and Nitrogen Stable
  Isotope Ratio Analysis. *American Journal of Physical Anthropology* 143:512-522.
  doi:10.1002/ajpa.21334
- García-Donas J, Langstaff H, Kranioti E (2014) Vía Púnica 34 and Joan Planells: Demographic
  study of two cemetery populations from Ibiza. *Journades D'Arqueologia De Les Illes Balears* 6:
  285-294.
- 599 Garcia-Guixé E, Subira ME, Marlasca R, Richards MP (2010)  $\delta^{13}$ C and  $\delta^{15}$ N in ancient and 600 recent fish bones from the Mediterranean Sea. *Journal of Nordic Archaeological Science* 17: 83-601 92.
- Garnsey P (1998) Cities, Peasants and Food in Classical Antiquity: Essays in Social and *Economic History*. Cambridge: Cambridge University Press.
- Garnsey P (1999) Food and Society in Classical Antiquity. Cambridge: Cambridge University
  Press.
- Garvie-Lok S (2001) Loaves and fishes: a stable isotope reconstruction of diet in Medieval *Greece*. Unpublished PhD Dissertation, University of Calgary, Calgary.
- Girdwood L (2012) A Comparative Analysis of Dental Non-Metric Traits in three Ibizan
   Populations (c. 3<sup>rd</sup>-12<sup>th</sup> centuries AD). Unpublished MSc Dissertation. University of Edinburgh.
- 610 Graziani Echavarri G (2013) Informe de la excavacion arqueologica en el solar Maymo. Inedito.
- Greco G (1975) Velia e Palinuro: problem di topografia antica. *MEFRA* 87:81-142.
- Hedges REM (2004) Isotopes and red herrings: comments on Milner et al. and Lidén et al. *Antiquity* 78:34–37. doi:10.1017/S0003598X00092905
- Hedges REM, Reynard LM (2007) Nitrogen isotopes and the trophic level of humans in
  archaeology. *Journal of Archaeological Science* 34:1240-1251.
  doi:http://dx.doi.org/10.1016/j.jas.2006.10.015
- 617 Iacumin P, Galli E, Cavalli F, Cecere L. 2014. C4-Consumers in Southern Europe: The Case of
- 618 Friuli V.G. (NE-Italy) During Early and Central Middle Ages. American Journal of Physical
- 619 Anthropology 154: 561–574. doi:10.1002/ajpa.22553

- 620 Keenleyside A, Schwarcz H, Stirling L, Ben Lazreg N (2009) Stable isotopic evidence for diet in
- a Roman and Late Roman population from Leptiminus, Tunisia. Journal of Archaeological 621
- 622 Science 36: 51-63. https://doi.org/10.1016/j.jas.2008.07.008
- Killgrove K, Tykot RH (2013) Food for Rome: A stable isotope investigation of diet in the 623
- Imperial period (1<sup>st</sup>-3<sup>rd</sup> centuries AD). Journal of Anthropological Archaeology 32:28-38. 624
- doi:http://dx.doi.org/10.1016/j.jas.2006.05.006 625
- Killgrove, Kristina and Janet Montgomery. (2016). All Roads Lead to Rome: Exploring Human 626
- Migration to the Eternal Cith through Biochemistry of Skeletons from Two Imperial-Era 627 Cemeteries (1<sup>st</sup>-3<sup>rd</sup> c AD). *PLOS One* 11(2): 1-30.
- 628
- Kulikowski, M. (2004). Late Roman Span and its cities. The Johns Hopkins University Press, 629 630 Baltimore.
- 631 Laffranchi, Zita, A. Delgado Huertas, S. A. Jimenez Brobeil, A. Granados Torres and J.A.
- Riquelme Cantal. (2016). Stable C & N isotopes in 2100 Year-B.P. human bone collagen 632
- indicate rare dietary dominance of C4 plants in NE-Italy. Scientific Reports 6(38817):1-8. 633
- 634 Lamb, H.H. (1995) Climate History and the Modern World. Routledge, London.
- Le Huray JD, Schutkowski H (2005) Diet and social status during the La Tène period in 635
- Bohemia: Carbon and nitrogen stable isotope analysis of bone collagen from Kutná Hora-Karlov 636
- and Radovesice. J Anthropol Archaeol 24:135–147. doi:10.1016/j.jaa.2004.09.002 637
- Lopez-Costas, O. and G. Muldner. (2016). Fringes of the empire: Diet and cultural change at the 638
- Roman to post-Roman transition in NW Iberia. American Journal of Physical Anthropology 639 161:141-154. 640
- Libby WF, Berger R, Mead JF, Alexander GV, Ross JF (1964) Replacement rates for human 641
- tissue from atmospheric radiocarbon. Science 146: 1170-1172. 642
- Longin R (1971) New Method of Collagen Extraction for Radiocarbon Dating. Nature 230:241-643 242. doi:10.1038/230241a0 644
- Márquez-Grant N (2005) The presence of african individuals in punic populations from the 645 646 Island of Ibiza (Spain): contributions from physical anthropology. Mayurqa 30: 611-637.
- Martinez RG (2011) Comparative Analysis of Dental Non-Metric Variation between Two 647
- Archaeological Populations of Ibiza, Spain (4<sup>th</sup>-12<sup>th</sup> centuries AD). Unpublished MSc 648
- Dissertation. University of Edinburgh. 649

- 650 Müldner G, Chenery C, Eckhardt H (2011) The 'Headless Romans': multi-isotope investigations
- of an unusual burial ground from Roman Britain. Journal of Archaeological Science 38:280-290. 651
- 652 doi:10.1016/j.jas.2010.09.003
- Murray M, Schoeninger MJ (1988) Diet, Status, and Complex Social Structure in Iron Age 653
- Central Europe: Some Contributions of Bone Chemistry. In: Gibson DB, Geselowitz M (eds) 654
- Tribe and Polity in Late Prehistoric Europe. New York: Plenum, 155–176. 655
- Nieto-Moreno, V., F. Martinez-Ruiz, S. Giralt, F. Jimenez-Espejo, D. Gallego-Torres, M. 656
- Rodrigo-Gamiz, J. Garcia-Orellana, Ml. Orega-Huertas, and G.J. de Lange. (2011). Tracking 657
- climate variability in the western Mediterranean during the Late Holocene: a multiproxy 658 approach. Climate Past 7:1395-1414.
- 659
- Nieto-Moreno, V., F. Martinez-Ruiz, V. Willmott, J. Garcia-Orellana, P. Masque and J.S. 660
- Sinninghe Damste. (2013). Climate conditions in the westernmost Mediterranean over the last 661
- 662 two millennia: An integrated biomarker approach. Organic Geochemistry 55:1-10.
- Nitsch EK, Humphrey LT, Hedges REM (2010) The effect of parity status on  $\delta^{15}$ N: looking for 663
- the 'pregnancy effect' in 18th and 19th century London. Journal of Archaeological Science 664
- 37:3191-3199. doi:http://dx.doi.org/10.1016/j.jas.2010.07.019 665
- O'Connell TC, Kneale CJ, Tasevska N, Kuhnle GGC (2012) The diet-body offset in human 666
- nitrogen isotopic values: A controlled dietary study. American Journal of Physical Anthropology 667 149:426-443. doi:10.1002/ajpa.22140 668
- Olsen KC, White CD, Longstaffe FJ, von Heyking K, McGlynn G, Grupe G, Rühli FJ (2014) 669
- Intraskeletal isotopic compositions ( $\delta^{13}$ C,  $\delta^{15}$ N) of bone collagen: nonpathological and 670 American Journal of Physical Anthropology pathological variation. 153:598-604. 671
- doi:10.1002/ajpa.22459 672
- Pate DF, Henneberg RJ, Nenneberg M (2016) Stable Carbon and Nitrogen Isotope Evidence For 673
- 674 Dietary Variability At Ancient Pompeii, Italy. Mediterranean Archaeology and Archaeometry
- 16: 127-133. 675
- 676 Pericot Garcia, L. (1972). The Balearic Islands. Thames & Hudson, London.
- Pickard C, Girdwood L-K, Kranioti E, Marquez-Grant N, Richards M, Fuller B (2017) Isotopic 677
- evidence for dietary diversity at the mediaeval Islamic necropolis of Can Fonoll (10<sup>th</sup> to 13<sup>th</sup> 678

- centuries CE), Ibiza, Spain. *Journal of Archaeological Science: Reports* 13:1-10. doi:
  http://dx.doi.org/10.1016/j.jasrep.2017.03.027
- Pinnegar JK, Polunin NVC (2000) Contributions of stable-isotope data to elucidating food webs
  of Mediterranean rocky littoral fishes. *Oecologia* 122:399-409. doi:10.1007/s004420050046

683 Polunin NVC, Morales-Nin B, Pawsey WE, Cartes JE, Pinnegar JK, Moranta J (2001) Feeding

- relationships in Mediterranean bathyal assemblages elucidated by stable nitrogen and carbon
- 685 isotope data. *Marine Ecology Progress Series* 220:13-23. doi:10.3354/meps220013
- Ponsich M, Tarradell M (1965) *Garum et industries antiques de salaison dans la Méditerranée occidentale*. Paris: Presses Universitaires de France.
- Pomeroy SB (1976) *Goddesses, Whores, Wives and Slaves: Women in Classical Antiquity.* New
  York: Schocken Books.
- 690 Prowse T, Schwarcz HP, Saunders S, Macchiarelli R, Bondioli L (2004) Isotopic paleodiet
- studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science* 31:259–272. doi:10.1016/j.jas.2003.08.008
- 693 Prowse TL, Schwarcz HP, Saunders SR, Macchiarelli R, Bondioli L (2005) Isotopic Evidence
- 694 for Age-Related Variation in Diet from Isola Sacra, Italy. American Journal of Physical
- 695 Anthropology 128:2-13. doi:10.1002/ajpa.20094
- Ramon Torres, J., X. Lois Armada, N. Rafel Fontanals and M. Renzi (2012) Protohistoric trade:
- 697 on the record of the Northeastern Iberian peninsula and the circulation of lead ore in Ibiza and
- Baix Priorat (Tarragona province). *Saguntum* 43:55-81.
- Richards MP, Hedges REM, Molleson TI, Vogel JC (1998) Stable Isotope Analysis Reveals
  Variations in Human Diet at the Poundbury Camp Cemetery. *Journal of Archaeological Science*25: 1247-1252.
- Rissech C, Pujol A, Christie N, Lloveras L, Richards MP, Fuller BT (2016) Isotopic
  reconstruction of human diet at the Roman site (1st-4th c. AD) of Carrer Ample 1, Barcelona,
- 704Spain. Journal of Archaeological Science: Reports 9:366-374.

- Rutgers LV, van Strydonck M, Boudin M, van der Linde C (2009) Stable isotope data from the
  Early Christian catacombs of Ancient Rome: new insights into the dietary habits of Rome's
  Early Christians. *Journal of Archaeological Science* 36(5):1127-1134.
- Salazar-García DC (2016) A combined dietary approach using isotope and dental buccalmicrowear analysis of human remains from the Neolithic, Roman and Medieval periods from the
  archaeological site of Tossal de les Basses (Alicante, Spain). *Journal of Archaeological Science:*
- 711 *Reports* 6: 610-619.
- 712 Schoeninger MJ (2010) Diet reconstruction and ecology using stable isotope ratios. In Larsen CS
- (ed.) *A companion to biological anthropology*. Chichester: Wiley-Blackwell, 445-464.
- Schoeninger MJ, DeNiro MJ (1984) Nitrogen and carbon isotopic composition of bone collagen
- from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48:625-639.
  doi:10.1016/0016-7037(84)90091-7
- Schoeninger MJ, van der Merwe NJ, Moore K, Lee Thorp J, Larsen CS (1990) Decrease in diet
  quality between the Prehistoric and the Contact periods. In: Larsen CS (ed.) *The Archaeology of Mission Santa Catalina De Guale:* 2. New York: American Museum of Natural History, 78-93.
- Sealy J (2001) Body tissue chemistry and paleodiet. In Brothwell DR, Pollard AM (eds) *Handbook of Archaeological Sciences*. Chichester: Wiley, 269-279.
- Shepard J (2004) 'Mists and portals': the Black Sea's north coast. In Mango MM (ed.) Byzantine
- 723 Trade, 4<sup>th</sup>-12<sup>th</sup> Centuries: The Archaeology of Local, Regional and International Exchange.
  724 Surrey: Ashgate, 421-441.
- Stenhouse MJ, Baxter MS (1979) The uptake of bomb 14C in humans. In Berger R and Suess
  HE (eds) *Radiocarbon Dating*. Berkeley: 324-341.
- Tsutaya T, Yoneda M (2013) Quantitative reconstruction of weaning ages in archaeological
  human populations using bone collagen nitrogen isotope ratios and approximate Bayesian
  computation. PLOS ONE 8(8):e72327. https://doi.org/10.1371/journal.pone.0072327
- 730 Tykot RH 2004 Stable isotopes and diet: You are what you eat. In Martini M, Milazzo M,
- 731 Piacentini M (eds) *Physics Methods in Archaeometry*. Proceedings of the International School of
- 732 Physics "Enrico Fermi" Course CLIV. Amsterdam: IOS Press, 433-444.

- 733 Twiss, K. (Ed.) (2007). Archaeology of Food and Identity. Southern Illinois University, Chicago.
- 734 Ubelaker DH, Parra RC (2011) Radiocarbon analysis of dental enamel and bone to evaluate date

of birth and death: Perspective from the southern hemisphere. Forensic Science International

- 736 208: 103-107. doi: 10.1016/j.forsciint.2010.11.013
- van der Merwe NJ, Vogel JC (1978) <sup>13</sup>C content of human collagen as a measure of prehistoric
  diet in Woodland North America. *Nature* 276:815-816. doi:10.1038/276815a0
- 739 Van Klinken GJ, Hedges REM (1995) Experiments on Collagen-Humic Interactions: Speed of
- 740 Humic Uptake, and Effects of Diverse Chemical Treatments. Journal of Archaeological Science
- 741 22:263-270. doi:10.1006/jasc.1995.0028
- 742 Van Klinken GJ (1999) Bone collagen quality indicator for palaeodietary and radiocarbon
- measurements. *Journal of Archaeological Science* 26:687-695. doi:10.1006/jasc.1998.0385
- 744 Webb EC, Honch NV, Dunn PJH, Linderholm A, Eriksson G, Lidén K, Evershed RP, 2016.
- 745 Compound-specific amino acid isotopic proxies for distinguishing between terrestrial and aquatic
- resource consumption. Archaeological and Anthropological Sciences 1-16.
  https://doi.org/10.1007/s12520-015-0309-5
- 748 Woolf G, Gosden C (1997) Beyond Romans and natives. World Archaeology 28:339-350.
- 749 doi:http://dx.doi.org/10.1080/00438243.1997.9980352

Table 1: Carb	on and nitrogen	stable isotope	ratio values	and collagen	quality i	indicators	of the Jo	an
Planells sampl	es.							

GUsi	Context ID	Element	Sex	Age	$\delta^{13}C$	$\delta^{15}N$	C/N	%N	%C
2589	JP03 UE324	Scapula	F	17-25	-17.7	12.2	3.2	14.8	40.6
2590	JP03 UE352	Phalanx	Μ	adult	-18.9	10.2	3.2	15.2	41.8
2591	JP03 UE325	Metacarpal	F	17-25	-17.9	11.3	3.2	14.7	40.1
2592	JP03 UE304	Metacarpal	Μ	17-24	-18.9	11.2	3.2	15.2	41.7
2593	JP03 UE333	Radius	Μ	17-35	-18.4	10.9	3.2	10.0	27.7
2594	JP03 UE340	Rib	F	17-44	-18.4	11.3	3.2	12.4	34.4
2595	JP03 UE355	Phalanx	F	17-25	-18.6	11.6	3.2	15.0	40.9
2596	JP03 UE323	Fibula	F	17-35	-18.7	10.3	3.2	15.2	41.6
2597	JP03 UE302	Long bone	Μ	30-39	-18.2	10.6	3.2	10.3	28.3
2598	JP03 UE357	Long bone	Μ	>23	-18.9	9.8	3.3	8.2	23.5
2599	JP03 UE303	Long bone	Μ	25-45	-18.6	14.4	3.2	15.3	42.1
2600	JP03 UE316	Radius	F	22-24	-19.0	12.0	3.2	14.8	40.5
2601	JP03 UE305	Rib	Μ	21-25	-18.6	11.4	3.2	14.4	39.7
2602	JP03 UE329	Rib	F	17-25	-18.1	12.7	3.2	14.8	40.6
	JP03 UE301								
2603	201x103	Scapula	Μ	17-39	-19.1	14.8	3.2	14.9	41.1
	JP03 UE349-								
2604	2	Metatarsal	Μ	17-39	-18.6	12.1	3.2	16.1	44.0
4707	JP 03 UE 307	Long Bone	UN	UN	-19.3	9.7	3.2	14.1	38.3
4709	JP 03 UE 310	Fibula	UN	UN	-19.1	10.2	3.2	14.8	40.5
4702	JP 03 UE 312	Long Bone	UN	UN	-19.0	9.4	3.2	15.7	43.1
4703	JP 03 UE 314	Long Bone	UN	17-21	-19.7	9.0	3.2	13.7	37.7
4716	JP 03 UE 315	Metatarsal	UN	UN	-19.0	10.4	3.2	15.8	43.0
	JP 03 UE								
4712	316A	Long Bone	UN	25-45	-19.7	11.5	3.3	14.5	40.5
4706	JP 03 UE 319	Fibula	UN	UN	-18.3	11.1	3.2	13.9	37.9
4720	JP 03 UE 320	Rib	UN	UN	-18.4	9.8	3.2	13.4	36.8
4715	JP 03 UE 321	Fibula	UN	UN	-18.7	10.5	3.2	14.4	39.4
	JP 03 UE								
4718	329B	Long Bone	UN	19-25	-18.9	12.1	3.2	15.5	42.8
4700	JP 03 UE 332	Ulna	UN	<1	-18.9	9.2	3.2	14.2	39.3
4701	JP 03 UE 334	Long Bone	<b>M</b> ?	30-34	-19.3	9.6	3.2	14.4	39.7
	JP 03 UE								
4711	341-2	Long Bone	UN	25-35	-19.5	10.0	3.3	15.0	41.9
4704	JP 03 UE 344	Metacarpal	UN	25-35	-18.8	9.1	3.2	14.7	40.2
4719	JP 03 UE 346	Fibula	UN	UN	-18.0	12.4	3.2	14.8	40.7
4717	JP 03 UE 347	Humerus	UN	UN	-18.9	10.4	3.2	15.1	41.7
	JP 03 UE								
4710	348-5	Long Bone	UN	UN	-18.0	12.0	3.2	15.6	42.7
4699	JP 03 UE 352	Phalanx	Μ	UN	-18.9	10.0	3.2	14.9	40.8
4708	JP 03 UE 354	Metatarsal	F?	UN	-17.7	10.9	3.2	14.6	39.6
4714	JP 03 UE 357	Rib	M?	23-35	-19.0	10.5	3.2	15.4	42.0
		4th							
4713	JP 03 UE 359	Metacarpal	UN	UN	-18.6	9.1	3.2	15.5	42.2
4705	JP 03 UE 405	Radius	UN	UN	-18.7	10.7	3.2	14.8	40.3

Sample	Species	δ <sup>13</sup> C (‰)	δ <sup>15</sup> N (‰)	C:N
IBF 9	Pig	-20.8	5.5	3.4
IB-A-13	Pig	-20.8	6.1	3.2
IBF 10	Sheep/goat	-21.0	5.7	3.3
IBF 8	Sheep/goat	-20.1	4.2	3.3
IB-A-2	Sheep/goat	-20.2	8.7	3.2
IB-A-3	Sheep/goat	-19.8	4.6	3.2
IB-A-4	Sheep/goat	-19.9	5.8	3.2
IB-A-5	Sheep/goat	-20.2	5.5	3.2
IB-A-6	Sheep/goat	-19.8	4.2	3.2
IB-A-14	Sheep/goat	-18.1	5.5	3.2
IBF 11	Cow	-20.3	7.7	3.3
IBF 14	Cow	-19.9	7.2	3.3
IBF 13	Dog	-19.0	9.2	3.3

**Table 2:** Carbon ( $\delta^{13}$ C) and nitrogen ( $\delta^{15}$ N) stable isotope ratio values of Late Antiquity-Early

Byzantine fauna from S'Hort des Llimoners, Ibiza (data from Fuller et al., 2	2010).
--	--------

**Table 3:** Mann-Whitney p-values, U statistics and indication of statistically significant

757 difference (SSD) data

Variables compared	p-value		U statist	ic	SSD		
	δ <sup>13</sup> C	$\delta^{15}N$	δ <sup>13</sup> C	δ <sup>15</sup> N	δ <sup>13</sup> C	$\delta^{15}$ N	
trabecular (n= 15) vs cortical (n= 23)	0.100482	0.952372	227.5	170.5	Ν	N	
human (n=38) vs animal-food species (n= 12)	0.000009	n/a	32.5	n/a	Y	n/a	
Joan Planells males (n=12) vs females (n=8)	0.027891	0.203017	19.5	64.5	Y	N	
Joan Planells (n=23) vs S'Horts des Llimoners (n=34)	0.028689	0.857998	525.5	402	Y	N	
Joan Planells (n=23) vs Ses Païsses de Cala d'Hort (n=38)	0.216777	0.000007	354	135	N	Y	
Joan Planells (n=23) vs Puig des Molins (n=6)	0.686370	0.914252	61.5	71	N	N	

758

**Table 4**: Comparison of Joan Planells and S'Horts des Llimoners  $\delta^{13}$ C and  $\delta^{15}$ N values.

Sita		$\delta^{13}C$		δ	Ra				
Site	Av.	Max	Min	Av.	Max	Min	$\delta^{13}C$	$\delta^{15}$ N	n
Joan Planells	-18.7±0.5	-19.7	-17.7	11.2±1.5	14.8	9.0	2.0	5.8	23
S'Horts des Llimoners	-19.0±0.4	-19.7	-18.0	11.1±0.9	12.6	8.3	1.7	4.3	34

# 763 Table 5 – Summary data of Roman/Late Roman period sites in the Mediterranean region

# 764 Where available the data reflect adult values. For those sites marked with \* demographic information

765 was not available.

	·· 5 <sup>13</sup> e		<b>5</b> <sup>15</sup>			Demosticate S <sup>13</sup> C						M vs				
			Human ò	5 <sup></sup> C		Human δ	N	n	Don	Domesticate o C Domesticate o N		eδ⁻N	n	F		
		m ea			me							mea				
Site	Date	n	min	max	an	min	max		mean	min	max	n	min	max		
		-		-			-							-		
ANAS,		19.			9.5											
Rome,		4±			±1.											
Italy*	-	0.4	-20.0	-18.9	8	6.9	11.3	14	-	-	-	-	-	-	-	n/a
-		-														
Carrer	AD	18.			11.											
Ample 1,	1st-	9±			0±							4.6±				
Spain	4th C	0.3	-19.5	-18.4	0.4	10.4	11.7	15	-20.4±0.7	-22.0	-19.4	2.0	1.9	8.7	11	Ν
Casal		-														
Bertone,	AD	18.			10.											
Rome	2nd-	2±			0±											
Italy	3rd C	0.6	-19.5	-16.8	1.5	7.0	11.8	23	-	-	-	-	-	-	-	Ν
Castellac																
cio		-														
Europarc	AD	17.			9.4											
o, Rome,	1st-	8±			±1.											
Italy	3rd C	2.6	-19.5	-12.5	4	7.8	11.5	7	-	-	-	-	-	-	-	n/a
Isola		-														
Sacra,	AD	18.			10.											
Rome,	1st-	8±			8±											
Italy*	3rd C	0.3	-19.7	-17.8	1.2	7.5	14.4	105	-21.0	-	-	5.4	-	-	-	Y
		-														
Leptimin	AD	17.			13.											
us,	2nd-	8±			0±							9.2±			_	
Tunisia	5th C	0.6	-19.0	-16.5	1.3	10.00	15.7	52	-19.4±1.0	-21.1	-18.3	2.7	6.0	12.9	6	N
Monte		-														
de		18.			10.											
Cagonna,	AD	3±	10.0	47.4	3±	0.0	12.2	22	20.210.7	24.2	40.0	7.1±	6.4	0	10	
Portugal	7th C	0.3	-18.8	-17.4	0.7	9.8	13.2	23	-20.2±0.7	-21.3	-18.8	0.7	6.1	8	10	N
S'Horts	40	-			11											
des	AD 4+h	19.			11. 1+							F 0+				
Liimoner	4tn-	0±	10.6	10.0	1±	0.2	12.6	24	20 1+0 7	20.0	10.1	5.9±	4.2	07	10	NI
S C+	7010	0.4	-19.0	-18.0	0.9	0.5	12.0	54	-20.1±0.7	-20.8	-18.1	1.4	4.2	8.7	12	IN
Callivtus		- 10			10											
Pomo	AD 2rd	19. 7+			10. 6+											
Italy	5th C	0.4	20.2	18.0	01	07	11 0	1/	_	-	_	_	_	_	_	n/2
	Juic	- 0.4	-20.2	-10.5	0.5	5.7	11.0	14	-	-	-	-	_	_	_	ny a
les	AD	18			10											
Bassos	6th-	2+			10. 8+											
Snain	7th C	03	-18 7	-177	01	8.4	12.2	37	_	_	_	_	_	_	_	N
Spann		-	-10.7	-11.1	0.5	0.4	12.2	57	-	-	-	-	-	-	-	IN IN
	1st-	19			87											
Velia	2nd	<u>1</u> 3. 4+			+1.							4.4+				
Italy	C	0.3	-20.0	-18.7	3	6.6	14.1	117	-21.0+1.0	-22.6	-19.1	1.9	2.6	7.9	8	Y
	~	0.5	20.0	10.7	5	0.0	±7.1	/	21.011.0	22.0	10.1	1.5	2.0		5	



**Figure 1**: Map of Ibiza with the site of Joan Planells identified.





- **Figure 2**: Scatterplot of Joan Planells human  $\delta^{13}$ C vs  $\delta^{15}$ N values. <u>The positive linear</u>
- **774** relationship is indicated by the dashed red line. The  $R^2$  value is 0.11086 and the p value is
- 775 <u>0.04108 (<0.05).</u>



777

**Figure 3**: Scatterplot comparing the human remains from Joan Planells with the animal remains from S'Hort de Llimoners (Fuller et al. 2010) – data presented as mean $\pm$ sd (1 $\sigma$ ) where appropriate.