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Craig, Oliver Edward orcid.org/0000-0002-4296-8402 (2017) Capturing Roman dietary variability in the catastrophic death assemblage at Herculaneum. *Journal of Archaeological Science Reports*. pp. 1-7. ISSN 2352-409X

<https://doi.org/10.1016/j.jasrep.2017.08.008>

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Capturing Roman dietary variability in the catastrophic death assemblage at Herculaneum

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Abstract

Here we present a comparative study of stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope data from 81 individuals from the catastrophic death assemblage at Herculaneum (79 AD) and compare these with the attritional sites of Velia (Salerno, Italy, 1st-2nd century AD) and Isola Sacra (Rome, Italy, 1st-2nd century AD). The instantaneous deposition of the Herculaneum assemblage highlights some interesting differences in our contextual and methodological understanding of stable dietary isotopes, suggesting that isotopic variation between sites may sometimes be a result of greater temporal variability rather than truly comparable differences. Our results suggest that the people of Herculaneum obtained a relatively small proportion (ca. 30%) of their dietary carbon from marine foods; the majority originating from terrestrial foodstuffs of a similar carbon isotopic composition, most likely cereals. Also observed is a generally greater dietary isotopic enrichment in male individuals than females. We infer that males had greater access to fish which may be reflective, in part, of the sociodemographic framework characteristic of Roman society. Finally, we highlight the methodological challenges which may be faced when undertaking comparisons of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data between the various age-related strata of a population, particularly due to the slow and variable rate of collagen turnover.

Keywords: Herculaneum; stable isotopes; palaeodiet; Vesuvius

1.1 Introduction

The health and economic 'well-being' of the Roman world is a fundamental benchmark in the historic investigation of past civilisations. Although the study of the Roman productive economy is extensive, our knowledge regarding the distribution of wealth and differences in living conditions in Roman society is limited to partial and incomplete records (Garnsey and Saller, 2015). We do not yet know how food was distributed to different elements of the population, between households, villages or towns. Historical accounts (Rackham, 1967; Edwards, 2001; Wolf, 2010) and archaeological evidence from animal and plant remains

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43 (Meyer, 1980; Pagano, 1994; Reese, 2002; Rowan, 2014; Robinson and Rowan, 2015)
44 provide specific information regarding the types of foods that were eaten but lack the
45 resolution required to quantify dietary content, or to study dietary variability within societies.
46 Such information is crucial if we are to make meaningful comparisons between Roman and
47 other pre-modern and developing societies, and to clarify relationships between social
48 status, health and nutrition.

49

50 Stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analysis of bone collagen offers a direct
51 approach to the inter- and intra-population study of ancient diet. Isotopic signals represent a
52 direct measure of an individual's average dietary intake during the period of bone collagen
53 formation. These analyses are particularly useful for discriminating diets of coastal
54 inhabitants with access to mixed marine and terrestrial diets, and where the major dietary
55 sources (e.g. marine fish, terrestrial herbivores, terrestrial omnivores and cereal grains) have
56 distinct isotope values. So far, the analyses of over 500 individuals from Roman Imperial
57 period necropolises in southern Italy have succeeded in identifying relative isotopic
58 differences within and between assemblages, attributed to differences in occupation, age
59 and sex, and mainly relating to the differential consumption of marine foods (Prowse *et al.*,
60 2004; Craig *et al.*, 2009; Killgrove and Tykot, 2013; Killgrove and Tykot, in press).
61 Nevertheless, the analysis of diet in such attritional death assemblages is heavily burdened
62 by methodological and interpretative limitations. Unlike census data, skeletal assemblages
63 from burial grounds are palimpsests that gradually accumulate over time, and their fidelity to
64 any living population is undermined by both selective burial and selective mortality (Wood *et al.*,
65 1992; Roberts and Grauer, 2001; Jackes, 2011; DeWitte and Stojanowski, 2015). For
66 example, individuals who were afforded cremation, a common Roman funerary custom,
67 cannot be studied, whilst frail individuals who succumbed to disease are likely to be over-
68 represented in the younger age classes (Wood *et al.*, 1992).

69

70 In studying stable isotopic data from a sample of 81 individuals from the catastrophic death
71 assemblage at Herculaneum (Bisel, 1991; Capasso and Domenicantonio, 1998; Capasso
72 and Capasso, 1999; Capasso, 2000; Mastrolorenzo *et al.*, 2001; Mastrolorenzo *et al.*, 2010;
73 Petrone, 2011), we hope to circumvent these problems and derive a clearer picture of
74 dietary variability in at least one Roman town. All were victims of the 79 AD eruption of
75 Vesuvius and were discovered within 9 *fornici* (stone vaults) running adjacent to the seafront
76 (Fattore *et al.*, 2012). The stable isotope data for 72 individuals were originally reported in
77 Craig *et al.* (2013) but here we investigate these data with respect to new osteological
78 information regarding the age and sex of the skeletons. Notably, this revision identified one
79 of the 72 individuals (F8I10) as a juvenile. In addition, we also report new isotopic data from
80 9 infants and juveniles (<20 years of age). Albeit a modest sample of a small Imperial
81 coastal town of ca. 4-5,000 residents (Wallace-Hadrill, 2011), the assemblage contains a
82 broadly equal mixture of adult males and females, with juveniles and infants also
83 represented (Capasso, 2000; Mastrolorenzo *et al.*, 2001). Whilst some selectivity in those
84 sheltering in the vaults is to be expected, the assemblage offers a rare glimpse of
85 contemporary Roman life, where sudden and collective death negated the selective biases
86 usually faced in osteoarchaeological analysis. Therefore, we are able for the first time to
87 quantify the differential access to foods within an ancient 'living' population.

88 1.2 Methods

89 Collagen for the new 9 samples was extracted from bone and analysed by EA-IRMS exactly
90 as described previously (Craig *et al.*, 2013). In the majority of for both these samples and
91 those presented in Craig *et al.* (2013), rib samples were chosen (Craig *et al.* 2013; see
92 Supporting Information, Table 1) and any samples showing signs of pathological change
93 were excluded. Briefly, bone samples (0.5-1g) were coarsely ground and demineralised (0.6
94 M HCl, 4°C, 3-12 days), samples were rinsed with distilled water and then gelatinised (pH3
95 [0.001M] HCl, 80°C, 48h). The supernatant containing the collagen was filtered (30 kDa,
96 Amicon® Ultra-4 Centrifugal Filter Units, Millipore, Billerica, MA, USA), frozen, and
97 lyophilised. Collagen samples (1mg) were analysed in duplicate or triplicate by EA/IRMS in a
98 Sercon GSL analyser coupled to a Sercon 20-22 Mass Spectrometer (Sercon, Crewe, UK)
99 at the University of York, or a Roboprep Combustion Device coupled to a Europa 20-20
100 Mass Spectrometer (PDZ-Europa, Crewe, UK). The analytical error, calculated from
101 repeated measurements of each sample and measurements of the bovine control from
102 multiple extracts, was <0.2‰ (1σ). Accuracy was determined by measurements of
103 international standard reference materials (IAEA 600, IAEA N2, IA Cane) within each
104 analytical run, with the error being less than <0.5‰ in all instances. The difference in the
105 ¹⁵N/¹⁴N ratio between the sample and the internationally defined standard AIR (atmospheric
106 air) in ‰ units is referred to as δ¹⁵N, and δ¹³C refers to the difference in ¹³C/¹²C ratio
107 between the sample and the internationally defined standard, PDB (Vienna Pee Dee
108 Belemnite Limestone). The reported ratios are calculated using the equation: $\delta x = ((R_{\text{sample}} -$
109 $R_{\text{standard}})/R_{\text{standard}}) \times 1000$.

110

111 For Herculaneum, the ¹⁴C offset attributable to the marine reservoir effect was estimated for
112 each sample using the following regression equation derived from radiocarbon dating and
113 stable isotope analysis of 9 samples (Craig *et al.*, 2013):

114

115 (1) $y = 34.3 - 300x$, $R^2 = 9.1$ where $y =$ ¹⁴C offset (years) and $x =$ δ¹⁵N value (‰).

116

117 These 9 individuals are a sub-sample of the 81 individuals analysed for δ¹³C and δ¹⁵N in the
118 current study.

119

120 The calculated ¹⁴C offset from the above equation was used to estimate the % of total
121 carbon derived from a marine source, assuming a maximum reservoir age of 390 years
122 corresponding to 100% marine derived carbon. The % of marine protein contribution to
123 collagen was derived through linear interpolation of values between the terrestrial endpoint
124 (+7.2‰) and marine endpoint (+16‰). The latter were derived from measurements of
125 contemporary herbivore and marine fish values, using similar assumptions as previously
126 reported (Craig *et al.*, 2013). All statistical analysis was carried out using R version 3.1.2.

127

128 The human osteological material was analysed according to the common standards reported
129 in the literature (Krogman and İşcan, 1986; Buikstra and Ubelaker, 1994; White and Folkens,
130 2005). Sex determination in the adults was obtained by the application of the visual
131 assessment of the morphological traits of skull and pelvis (Ferembach *et al.*, 1980; White
132 and Folkens, 2005). Age at death was determined using multiple age indicators. For adult
133 individuals, methods included: degenerative changes of the pubic symphysis (Todd, 1921),
134 the auricular surface of the innominate (Buikstra and Ubelaker, 1994), and the sternal ends

135 of ribs (Işcan *et al.*, 1984); ecto- and endo-cranial suture closure (Buikstra and Ubelaker,
136 1994). For individuals still growing at the time of death the following criteria were applied:
137 stages of epiphyseal fusion (Scheuer *et al.*, 2010), long bone dimensions (Scheuer *et al.*,
138 2010), and the stages of formation and eruption of teeth (AlQahtani *et al.*, 2010). The
139 analyses were independently performed by three observers (PP, LF, AS,) and cases of
140 discrepancy were resolved by a fourth joint and consensual analysis (on the reliability of the
141 age-at-death assessment see (Baccino *et al.*, 1999; Garvin and Passalacqua, 2012). The
142 extraordinary preservation state of the skeletal and dental material allowed for the age at
143 death to be determined by 5 year intervals for subadults and 10 year intervals for adult
144 individuals (the last age class being 50+), thus permitting comparison with almost
145 contemporaneous central Italian skeletal series (Prowse *et al.*, 2004; Prowse *et al.*, 2005;
146 FitzGerald *et al.*, 2006; Craig *et al.*, 2009; Crowe *et al.*, 2010; Petrone *et al.*, 2011).
147 The Herculaneum sample set reported in this paper is composed of 81 individuals: 28
148 females, 37 males, 6 unsexed individuals older than 15 years and 10 individuals (<15 years)
149 which were unsexed, see Supplementary Information, Table 1.
150 For the dietary reconstruction, we included the biological sub-adults (age 15-20, 5 males, 2
151 females, and 4 unsexed) within the analysis of the adult individuals on the grounds that they
152 probably ate an adult diet, being classed 'social' adults in accordance with the trend of
153 traditional Roman life (Treggiari, 1993).

154

155 **1.3 Results and Discussion**

156 **1.3.1. Dietary variation at Herculaneum and other coastal Roman sites**

157 The carbon and nitrogen stable isotope data for the Herculaneum population are reported in
158 Supporting Information, Table 1. These include all the data reported in Craig *et al.* (2013)
159 plus those from an additional 9 infants and juveniles. Overall, the isotope data for all
160 individuals >15 years fall within the range of similar age cohorts from other coastal Imperial
161 necropolises (Fig. 2). These are Isola Sacra (Prowse *et al.*, 2004; Crowe *et al.*, 2010), the
162 cemetery that served Portus Romae- the gateway to Rome, and Velia- a small coastal town
163 south of Naples (Craig *et al.*, 2009) (Fig. 1). The $\delta^{13}\text{C}$ values at each of the three sites have
164 comparable ranges (Herculaneum = -18.2‰ to -20.2‰; Isola Sacra = -17.8‰ to -19.5‰;
165 Velia = -18.7‰ to -20.0‰) but the variances are significantly different between sites (Fligner-
166 Killeen test of homogeneity of variances; $\chi^2 = 6.8$, $p = 0.03$).



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Fig. 1: Map showing approximate locations of Italian Roman Imperial period sites referred to in the text (after Craig *et al.* (2013)).

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It is noticeable, however, that that the $\delta^{15}\text{N}$ values for Herculaneum show a narrower range (8.2‰ to 11.7‰) than for Isola Sacra (7.5‰ to 15.3‰) or Velia (6.4‰ to 14.1‰), despite similar sample sizes (Velia = 117; Isola Sacra = 94; Herculaneum = 71). Conversely, the variances within samples are not significantly different (Fligner-Killeen test of homogeneity of variances; $\chi^2 = 3.4$, $p = 0.18$). The bagplots (Fig. 2 (Rousseeuw *et al.*, 1999)) clearly show that Herculaneum has an "intermediate" position between the two other coastal sites both for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, and a much narrower distribution of $\delta^{15}\text{N}$ values. One explanation for the relatively reduced dietary variation at Herculaneum compared to Isola Sacra and Velia is the nature of the assemblage formations. As the latter are individuals from cemeteries that were used for many generations (ca. 150 years for Velia and ca. 300 years for Isola Sacra), greater isotopic variation may simply reflect greater dietary variation through time, rather than real differences in the diet of the living populations, as is commonly assumed when such comparisons are made.

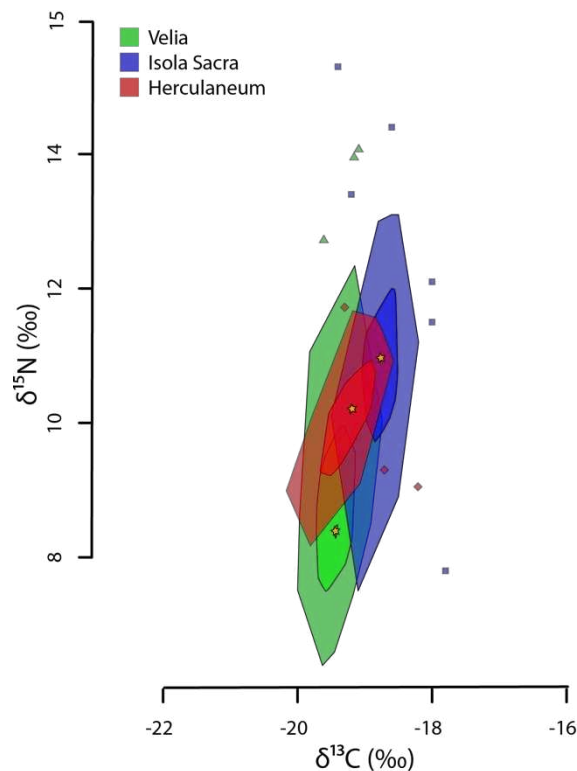
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To test for inter-site differences in $\delta^{15}\text{N}$, a robust ANOVA model was used. As diet is significantly affected by sex in each of these assemblages (see section 1.3.2.), it was particularly important to examine whether differences in the demographic profiles are a more likely explanation for the amplitude of isotopic variation between sites. The $\delta^{15}\text{N}$ values are significantly different by site ($F = 129.4$, $p = <0.001$) as expected but not when the interaction between sex and site is considered ($F = 0.1$, $p = 0.89$). Therefore, the distribution of $\delta^{15}\text{N}$ values genuinely reflects greater dietary variation at the attritional assemblages, compared to Herculaneum. Interestingly the core distributions, containing 25% to 75% of the $\delta^{15}\text{N}$ data (Fig. 2), at each assemblage are comparable in terms of amplitude of variance. The main

196 difference between the sites is that Velia and Isola Sacra have a greater number of outliers,
197 particularly individuals with high marine protein diets (i.e. high $\delta^{15}\text{N}$ values).

198

199 Finally, the amplitude of variance in $\delta^{15}\text{N}$ between the sites is not easily explained by greater
200 absolute differences in dietary end-points (plants and fish) as discussed previously (Craig *et al.*,
201 2009), although temporal variation in these, particularly changes in location of grain
202 supply, would be interesting to check. The consumption of leguminous vegetables, thought
203 to be integral to the Roman diet (Garnsey, 1999) and with ample evidence from Vesuvian
204 cities (Meyer, 1980; Wolf, 2010), should also be explored. These may have a large effect on
205 the isotopic endpoints since they are relatively depleted in ^{15}N . Finally, the presence in the
206 Velia assemblage of a specific subset of individuals, possibly fishermen, has been observed
207 (Crowe *et al.*, 2010) and contributes to the broad range of $\delta^{15}\text{N}$ for this site.
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211 **Fig. 2: Bagplot of three Roman Imperial period mortuary assemblages.** Comparison of human
212 stable isotope data between Velia (left) and Isola Sacra (middle) by means of bagplots. A bagplot is a
213 bivariate generalization of the boxplot. The central darker shaded area contains 50% of all data
214 points. The outer lighter shaded area is three times the area of the central part and is fenced by a line
215 connecting data points that lie on the periphery of this area. Points outside the fence are considered
216 outliers. Medians are represented with a gold star.

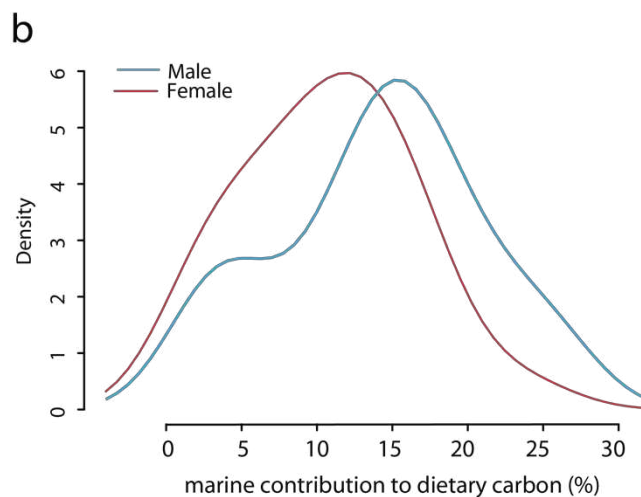
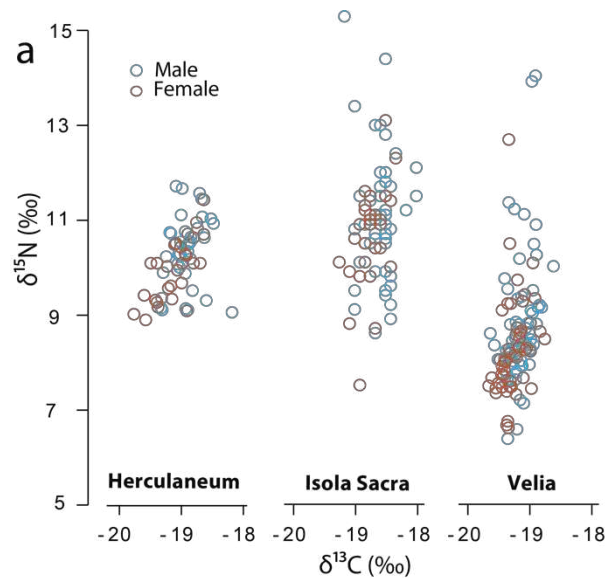
217 1.3.2. Variation by sex

218 The distribution of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ is significantly different between the sexes at Herculaneum
219 (Kruskal-Wallis, $\chi^2 = 4.6$, $p = 0.03$ and $\chi^2 = 5.1$, $p = 0.02$ for each isotope, respectively) with
220 males typically enriched in ^{15}N and ^{13}C compared to females (Fig. 3a). From these data, it is
221 proposed that males consumed more fish with relatively elevated $\delta^{15}\text{N}$ values. This is not to
222 suggest that other low trophic level species were not consumed at Herculaneum, either fresh
223 or as commodities such as garum. Indeed there are ample remains of small fish such as

224 sardine, anchovy, and marine shellfish from sewer deposits (Rowan, 2014) but these are
225 less likely to be distinguished isotopically.

226
227 At Herculaneum, since all the individuals died simultaneously (Mastrolorenzo *et al.*, 2001),
228 we can exploit differences in individual radiocarbon dates to independently quantify marine
229 food consumption with much more certainty. At this site it has been previously shown that
230 both carbon and nitrogen isotopes in human bone collagen are positively linearly correlated
231 with the amount of 'old' carbon derived from the marine reservoir (Craig *et al.*, 2013). On this
232 basis, it is estimated that across the Herculaneum sample a relatively small proportion (0-
233 30%) of the total carbon in bone collagen, broadly equivalent to the weight % or calorific
234 contribution to the diet, was derived from marine foods (Craig *et al.*, 2013). Given their richer
235 protein content, marine foods make a much greater contribution to total dietary protein
236 (nitrogen) which at Herculaneum is estimated to range between 20-50% (Craig *et al.*, 2013).
237 These estimates are also supported by the application of a Bayesian mixing model, which
238 takes into account the macronutrient composition of different food groups (Fernandes,
239 2015).

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241

242 **Fig 3: Stable isotope measurements of human remains from Herculaneum.** a.) - compared with
243 Isola Sacra and Velia; b.) - showing the Kernel density plot of all adults from Herculaneum by sex (F =
244 28; M = 37) against the estimation of % marine carbon to total dietary carbon.

245
246

247 Apart from fish, the remainder of the diet at Herculaneum - at least 70% by weight - was
248 made up of terrestrial foodstuffs of similar isotopic composition and of substantially less
249 protein content than fish. Although other low-protein terrestrial foods, even fatty meats or
250 legumes, cannot be ruled out (Fernandes *et al.*, 2014), the most likely contenders are
251 cereals. Carbonized remains of cereals, mainly naked wheats and barley, have been found
252 in abundance at Herculaneum and in the Villa dei Papiri nearby (Meyer, 1988; Ciarallo,
253 1994; Pagano, 1994). A cache of 117 wooden writing tablets (the 'Murecine Tablets') found
254 in a wicker basket just outside the walls of Pompeii and dating from the mid-first century (29-
255 61 AD) reveals that 'Alexandrian wheat' was stored in large quantities in warehouses at
256 Puteoli (Camodeca, 1999; Wolf, 2010). Overall, the high consumption of cereals with a
257 relatively low protein concentration, and variable contribution of marine foods, explains the
258 narrow range of $\delta^{13}\text{C}$ values compared with $\delta^{15}\text{N}$ values observed at Herculaneum and other
259 Italian Roman Imperial period coastal sites (Fig. 3a) (Craig *et al.*, 2013).

260

261 The observed isotopic differences between the sexes at Herculaneum could simply be a
262 matter of biology; the calorific requirements of males are known to be greater than those of
263 females, and the undertaking of hard labour would undoubtedly exacerbate such needs
264 leading to quantitative and qualitative dietary discrepancies. However, it is terrestrial
265 products - mainly cereals - that provided the majority of calories regardless of sex, so this is
266 less likely. Rather, it is the consumption of high trophic level marine fish that isotopically
267 distinguishes males from females. In Figure 3b we have used the $\delta^{15}\text{N}$ to indicate the %
268 contribution of marine foods to dietary carbon (an approximation to their weight contribution
269 to total diet) using equation 1 (above). The distributions (Fig. 3b) show that a small
270 proportion of the males obtained a slightly greater % of their total diet from marine foods.
271 The differences between males and females with respect to marine consumption is great
272 (typically <5% contribution to total diet) but the effect on their $\delta^{15}\text{N}$ values is much more
273 pronounced, since fish makes a disproportional contribution to dietary protein.

274

275 It is reasonable to suppose that occupation is a key variable which determines these sex-
276 related dietary differences. Men had primary access to marine foods in as much as fishing
277 and trade in fish products were male-dominated activities. In general, the uneven distribution
278 of power, which in a traditional society lay with males, and other social factors, would have
279 played a part in permitting or restricting access to fish, both within the families of fishermen,
280 and in the wider community (Garnsey 1999).

281

282 **1.3.3. Variation by Age**

283 When the sample is subdivided into specific age classes (15–20, 20–30, 30–40, 40–50, 50+
284 years) there are no significant differences in $\delta^{15}\text{N}$ values (Kruskal-Wallis $\chi^2 = 7.0$, $p = 0.13$)
285 or in $\delta^{13}\text{C}$ values (Kruskal-Wallis $\chi^2 = 6.4$, $p = 0.17$). If the data are first disaggregated by sex
286 and then compared by age, there are no significant differences between males and females
287 in any of the age classes, or between males and females of different age classes (Robust

288 ANOVA $\delta^{15}\text{N}$ interaction between age classes and sex $F = 2.6$, $p = 0.05$; Robust ANOVA
289 $\delta^{13}\text{C}$ interaction between age classes and sex $F = 1.1$, $p = 0.37$). Overall, the intra-
290 population stable isotopic variation at Herculaneum is related to sex but seems to be less
291 dependent on an individual's age at death. However, $\delta^{15}\text{N}$ values are significantly different
292 between adults less than 30 years old (i.e. 15-30) compared with those older than 30 years
293 (Wilcoxon rank sum test with continuity correction $W = 385.5$, $p = 0.04$). When testing for the
294 interaction with sex within these age classes, the robust ANOVA shows no significant
295 interaction for $\delta^{15}\text{N}$ ($F = 2.6$, $p = 0.05$). Boxplots in Figure 4 show that older males at
296 Herculaneum tended to have diets richer in marine foods. Conversely, females and younger
297 males have diets more similar to each other. There are no significant differences in $\delta^{13}\text{C}$
298 values between these broader (15-30, 30+ years) age ranges (Wilcoxon rank sum test with
299 continuity correction $W = 469.5$, $p = 0.30$).

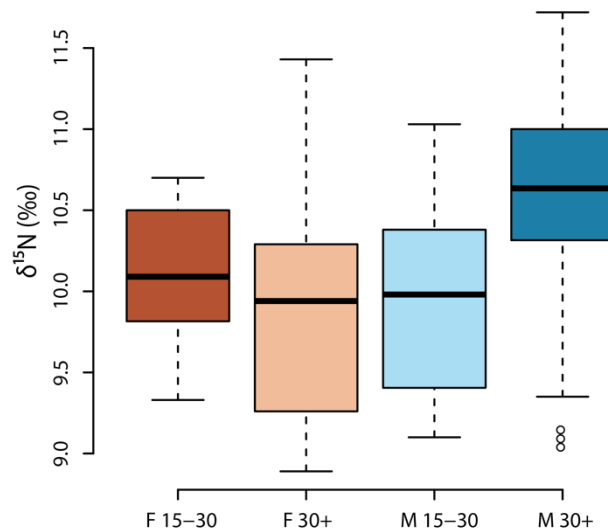
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301 Certainly, we would expect some age and sex related differences at Herculaneum. By 30
302 years of age, most men might be supposed to have received a boost in their disposable
303 income, allowing access to greater quantities of more expensive commodities such as fish.
304 By 30 years old most men would have entered into their first marriage (Saller, 1996; Aldrete,
305 2008; Garnsey and Saller, 2015) and most sons are likely to have lost their fathers,
306 becoming *sui iuris* ('of one's own right'), and had themselves inherited the role – including
307 the legal and financial independence - of the head of the household (*paterfamilias*). A
308 second consideration is the high prevalence of slaves and freedmen in the city.
309 Demographic estimates based on the Marble Album of Herculaneum suggest that a
310 significant proportion of the town's urban population (ca. 23%) were freedmen (de Ligt and
311 Garnsey, 2012). The study proposes that ca. 69% of the adult male citizen population were
312 ex-slaves, and that ca. 60% of the entire urban slave population at Herculaneum were
313 manumitted by the age of 30. With manumission came possible elevation to the rank of
314 Roman citizen in accordance with the laws passed in the time of Augustus. Freedmen were
315 normally involved *ipso facto* in a patronage relationship with their ex-masters, supposing the
316 latter were still alive – in which case the freedman might benefit from a legacy (Aldrete,
317 2008; Garnsey and Saller, 2015). In either eventuality, their standard of living and
318 subsistence is likely to have improved following manumission, again permitting access to
319 new foods. In comparison, female slaves were manumitted later in life, if at all. Furthermore
320 if, as seems probable, freedmen were involved in the processing and trade of fish (Curtis,
321 2005), they are also likely to have had preferential access to this resource, and be well-
322 represented among those in the sample with high $\delta^{15}\text{N}$ values.

323

324 A potential methodological explanation for the absence of strong isotopic differences by
325 narrower age classes at Herculaneum is that the measurements are of collagen which is
326 synthesised at different times within an individual's lifespan. As bone collagen turnover rate
327 is relatively slow, a substantial proportion of collagen derived from earlier in life will still be
328 present at death. For example, from studies of collagen turnover rates in femoral bone
329 (Hedges *et al.*, 2007) we estimate that 63% of collagen in a 45 year old male, or 53% in a
330 female of the same age, is derived from foods consumed before 30 years of age.
331 Furthermore, the rate of bone turnover slows dramatically following adolescence, meaning
332 that younger individuals' skeletons contain relatively more collagen synthesised from foods
333 consumed closer to the time of death than older individuals. A slightly faster turnover rate
334 may be anticipated in the rib samples analysed in this study, nevertheless, these
335 measurements are unlikely to reflect true differences between the age classes. Indeed, the

336 differences that we observed are probably underestimations of the true dietary differences
337 between the old and the younger adults at their time of death.
338



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340
341 **Fig 4: Boxplot of $\delta^{15}\text{N}$ values at Herculaneum by age in years and sex.**
342

343 Age related dietary differences were observed at Isola Sacra. Here, Prowse *et al.* (2005)
344 showed that age and $\delta^{15}\text{N}$ are positively correlated for both sexes. Explaining this
345 observation is far from straightforward as it is not possible to distinguish whether individuals
346 consumed a greater proportion of fish in later life or whether high fish consumers simply
347 lived longer. Given the difficulties in interpreting isotopic data from bone collagen due to its
348 slow turnover rate, and the lack of strong evidence of age related differences within the
349 'living population' at Herculaneum, we suggest that the latter explanation is more likely. At
350 Velia, there are no overall significant differences by age class (Craig *et al.*, 2009), however
351 one group of adult males ($n = 11$) are relatively enriched in ^{15}N (i.e. $> 9.6\text{‰}$) compared to the
352 rest of the population. Interestingly, 10 are over 30 years of age and also have a much
353 higher prevalence of external auricular exostosis (Crowe *et al.*, 2010), a pathology caused
354 by regular exposure to cold water which is most likely linked to sea-related occupations
355 (Crowe *et al.*, 2010).

356 **1.4. Conclusion**

357 Overall, the data from the catastrophic assemblage at Herculaneum emphasizes the
358 difficulty in interpreting intra-population isotopic variability in attritional cemetery populations,
359 as are commonly encountered in archaeological research. There is less overall variation in
360 $\delta^{15}\text{N}$ at Herculaneum compared to Velia and Isola Sacra regardless of sample size or
361 demographic composition. This result is most easily explained by the short-lived nature of
362 the population. Diets change over generations as the result of changes in the economy and
363 food supply, as well as cultural shifts. Therefore, the range of foods eaten by individuals
364 living contemporary lives may be considerably narrower than revealed through isotopic
365 analysis of individuals buried in cemeteries, which are also influenced by selective mortality

366 and selective burial. This has important implications for considering the *durée* of cemetery
367 populations before making comparisons of any osteological datasets. Despite these
368 interpretative issues, underlying trends are still observable between osteological and isotopic
369 datasets, for example due to occupation (Crowe *et al.*, 2010). However, we suggest that
370 these correlations are probably related to an individual's long-term diet rather than directly
371 attributable to specific periods of their life, given the attenuated dietary record represented
372 by adult bone collagen. At the very least, such direct associations need to be questioned.
373 Further comparison of stable isotope values of collagen from tissues with different turnover
374 rates is needed to help resolve these issues. Finally, we confirm there is clear differentiation
375 of diet by sex as observed in attritional Roman populations, related to differential access of
376 males and females to marine foods.
377

378

379 **Acknowledgements:** We thank Andrew Millard, University of Durham, for his most valuable
380 assistance with estimating collagen turnover rates, Dr. Pietro Guzzo and Dr. Teresa Elena
381 Cinquantaquattro of the former Soprintendenza Speciale per i Beni Archeologici di Napoli e
382 Pompei for their continued support and two anonymous referees for their valued thoughts
383 and comments.

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525 Supporting information, Table 1. Carbon and nitrogen stable isotope values, and estimated % dietary contribution of marine-
 526 derived carbon and nitrogen, of all sampled Herculaneum individuals. The 9 infant/juvenile individuals analysed here for the
 first time are marked with an asterix (*). The remaining data are the same as presented in Craig *et al.*, (2013).

Sample	Bone Element	Sex	Age at Death	%C	%N	Atom C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	Carbon offset	Marine carbon (%)	Nitrogen offset	Marine nitrogen (%)
F7I7	Rib	M	20-30	41.7	15.2	3.2	-19.27	10.07	50.84	13.0	45.06	11.6
F7I9*	Rib	-	00-05	34.2	11.6	3.4	-19.28	11.37	50.20	12.9	89.93	23.1
F7I10	Rib	M	30-40	42.7	15.6	3.2	-18.75	10.63	80.13	20.5	64.41	16.5
F7I11*	Rib	-	00-05	37.8	13.4	3.3	-20.18	8.93	0.18	0.0	6.08	1.6
F8I6	Rib	F	20-30	35.6	12.6	3.3	-19.92	9.41	14.54	3.7	22.70	5.8
F8I7	Rib	M	40-50	42.4	15.5	3.2	-18.88	10.83	72.78	18.7	71.25	18.3
F8I8	Rib	F	40-50	45.2	16.7	3.2	-18.90	10.95	71.88	18.4	75.30	19.3
F8I10	Rib	-	10-15	42.2	15.5	3.2	-19.77	9.50	22.82	5.9	25.67	6.6
F8I11	Rib	-	15-20	43.4	16.0	3.2	-19.81	8.17	20.55	5.3	-19.85	-5.1
F8I13	Rib	F	30-40	40.6	14.9	3.2	-19.45	9.56	40.83	10.5	27.83	7.1
F8I15	Rib	-	15-20	31.1	10.5	3.5	-20.17	8.99	0.35	0.1	8.02	2.1
F8I17*	Rib	-	00-05	34.8	12.4	3.3	-19.28	10.21	50.20	12.9	50.05	12.8
F8I18	Rib	F	20-30	43.5	15.9	3.2	-19.40	9.61	43.66	11.2	29.42	7.5
F8I21	Rib	F	30-40	42.9	15.7	3.2	-19.67	9.26	28.77	7.4	17.54	4.5
F8I22	Rib	M	40-50	27.9	9.5	3.4	-19.22	10.29	53.93	13.8	52.71	13.5
F8I23	Rib	M	20-30	42.0	15.4	3.2	-19.57	9.10	34.21	8.8	12.08	3.1
F9I6*	Rib	-	05-10	44.2	15.3	3.4	-20.16	9.17	1.30	0.3	14.16	3.6
F9I9	Rib	M	40-50	43.4	15.6	3.3	-18.80	11.45	77.32	19.8	92.54	23.7
F9I13	Rib	M	40-50	42.6	15.3	3.2	-19.12	10.76	59.37	15.2	68.87	17.7
F9I27*	Rib	-	05-10	44.7	15.3	3.4	-19.99	10.11	10.56	2.7	46.40	11.9
F10I1	Rib	M	30-40	41.7	14.6	3.3	-18.21	9.05	110.39	28.3	10.12	2.6
F10I2	Rib	M	15-20	43.1	15.6	3.2	-19.02	10.18	64.92	16.6	48.96	12.6
F10I6	Rib	M	30-40	42.6	15.1	3.3	-18.79	11.07	78.04	20.0	79.40	20.4

F10I10	Rib	M	30-40	38.9	13.4	3.4	-19.30	11.72	49.31	12.6	101.65	26.1
F10I11	Rib	F	30-40	41.9	14.7	3.3	-19.70	9.31	26.83	6.9	19.13	4.9
F10I12	Rib	M	30-40	42.2	15.0	3.3	-19.01	10.64	65.34	16.8	64.71	16.6
F10I13	Rib	M	30-40	42.4	15.4	3.2	-19.18	11.67	55.79	14.3	100.05	25.7
F10I14	Rib	M	30-40	42.2	15.3	3.2	-19.02	10.54	64.72	16.6	61.22	15.7
F10I15	Rib	F	20-30	42.9	15.7	3.2	-18.96	10.63	68.44	17.5	64.28	16.5
F10I16	Rib	F	30-40	43.7	15.3	3.3	-19.79	10.09	21.78	5.6	45.89	11.8
F10I17	Rib	M	30-40	41.4	15.2	3.2	-18.84	11.57	74.98	19.2	96.76	24.8
F10I18	Rib	F	30-40	44.0	16.1	3.2	-19.27	9.94	50.89	13.0	40.74	10.4
F10I19	Rib	M	30-40	42.0	15.3	3.2	-19.04	10.55	63.63	16.3	61.58	15.8
F10I20	Rib	M	40-50	43.1	15.6	3.2	-19.59	9.14	32.86	8.4	13.21	3.4
F10I22	Tarsal bone	M	20-30	43.1	15.8	3.2	-19.07	10.49	62.00	15.9	59.52	15.3
F10I23	Rib	M	30-40	42.2	15.2	3.2	-19.07	9.10	61.91	15.9	11.92	3.1
F10I24	Rib	F	40-50	40.2	14.4	3.3	-18.96	10.09	68.36	17.5	45.84	11.8
F10I25	Long bone	M	20-30	41.3	15.1	3.2	-18.98	9.51	67.36	17.3	26.12	6.7
F10I28	Rib	F	30-40	41.6	15.0	3.2	-19.65	9.16	29.64	7.6	13.99	3.6
F10I29	Rib	F	20-30	42.8	15.6	3.2	-19.32	10.49	48.16	12.3	59.46	15.2
F10I35	Tarsal bone	M	20-30	41.7	15.2	3.2	-19.12	9.87	59.60	15.3	38.47	9.9
F10IA	Rib	F	50+	40.9	15.3	3.1	-20.12	9.01	3.38	0.9	8.76	2.2
F10IB	Rib	-	-	40.9	15.1	3.2	-19.31	10.00	48.51	12.4	42.65	10.9
F11I1*	Rib	-	00-05	34.8	13.0	3.1	-19.09	9.68	60.99	15.6	31.69	8.1
F11I2*	Rib	-	10-15	40.8	15.2	3.1	-19.23	9.00	53.48	13.7	8.53	2.2
F11I3*	Rib	-	10-15	38.6	14.1	3.2	-19.53	8.80	36.62	9.4	1.47	0.4
F11I4	Rib	F	15-20	36.8	14.0	3.1	-19.10	10.25	60.71	15.6	51.20	13.1
F11I5	Long bone	M	15-20	35.8	13.3	3.2	-18.62	11.03	87.36	22.4	78.20	20.1
F11I6	Rib	F	40-50	32.7	12.4	3.1	-19.12	10.29	59.56	15.3	52.85	13.6
F11I7	Rib	F	40-50	42.6	16.2	3.1	-19.19	9.67	55.72	14.3	31.53	8.1
F11I8	Long bone	F	20-30	39.2	15.0	3.0	-18.76	10.70	79.68	20.4	66.81	17.1
F11I9	Rib	M	20-30	43.2	16.7	3.0	-18.71	9.30	82.45	21.1	18.65	4.8
F11I10	Rib	M	15-20	38.8	15.0	3.0	-19.11	9.13	59.90	15.4	13.06	3.3
F11I11*	Rib	-	10-15	39.2	14.9	3.1	-19.14	9.48	58.41	15.0	24.88	6.4

F11I14	Rib	M	30-40	41.1	15.8	3.0	-19.07	10.34	62.17	15.9	54.38	13.9
F11I15	Rib	F	15-20	39.8	15.0	3.1	-19.38	9.33	44.87	11.5	19.68	5.0
F11I16	Rib	M	Adult	36.0	13.2	3.2	-19.49	10.23	38.70	9.9	50.57	13.0
F11I18	Rib	M	40-50	40.3	15.2	3.1	-19.23	10.00	52.97	13.6	42.75	11.0
F11I19	Rib	-	15-20	39.6	15.1	3.1	-19.38	9.46	44.61	11.4	24.14	6.2
F11I20	Rib	F	20-30	39.7	15.1	3.1	-18.83	10.09	75.64	19.4	46.02	11.8
F11I21	Rib	F	30-40	36.8	13.9	3.1	-19.21	10.43	54.21	13.9	57.38	14.7
F11I22	Rib	-	15-20	34.2	11.6	3.4	-20.00	9.15	9.83	2.5	13.71	3.5
F11I23	Rib	-	-	38.6	13.9	3.2	-19.33	9.58	47.67	12.2	28.22	7.2
F12I2	Rib	F	20-30	41.3	14.9	3.2	-19.30	10.51	49.55	12.7	60.17	15.4
F12I3	Rib	F	20-30	43.8	15.5	3.3	-19.67	10.09	28.51	7.3	45.89	11.8
F12I4	Rib	M	20-30	41.9	15.1	3.2	-19.25	10.27	52.22	13.4	52.03	13.3
F12I5	Rib	M	15-20	43.5	15.7	3.2	-19.55	9.89	35.03	9.0	39.09	10.0
F12I7	Rib	M	15-20	43.1	15.5	3.2	-19.21	10.54	54.21	13.9	61.36	15.7
F12I8	Rib	M	30-40	43.8	15.8	3.2	-19.05	10.50	63.14	16.2	59.96	15.4
F12I9	Rib	F	20-30	41.4	15.1	3.2	-19.47	10.02	39.50	10.1	43.54	11.2
F12I11	Rib	M	50+	42.0	15.4	3.2	-19.33	10.48	47.72	12.2	59.22	15.2
F12I13	Rib	F	30-40	43.7	15.9	3.2	-19.18	10.09	55.99	14.4	46.06	11.8
F12I15	Rib	F	30-40	41.9	15.4	3.2	-18.76	11.43	79.47	20.4	91.92	23.6
F12I16	Rib	M	30-40	42.2	15.3	3.2	-19.40	10.72	43.75	11.2	67.61	17.3
F12I19	Rib	M	30-40	37.9	13.5	3.3	-19.42	10.74	42.64	10.9	68.35	17.5
F12I23	Rib	M	40-50	43.7	15.5	3.3	-18.57	10.93	90.22	23.1	74.70	19.2
F12I26	Rib	M	30-40	39.8	14.4	3.2	-19.20	11.11	55.13	14.1	80.79	20.7
F12I27	Rib	M	30-40	41.5	14.8	3.3	-19.58	9.35	33.46	8.6	20.66	5.3
F12I28	Rib	F	30-40	42.4	15.2	3.2	-19.89	8.89	16.17	4.1	4.73	1.2
F12I30	Long bone	F	30-40	42.6	15.5	3.2	-19.09	9.08	60.89	15.6	11.21	2.9
F12I31	Phalanx	F	30-40	40.6	14.8	3.2	-19.07	10.71	62.24	16.0	67.24	17.2