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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 ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) 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 $\delta^{13}C$ and $\delta^{15}N$ 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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(Meyer, 1980; Pagano, 1994; Reese, 2002; Rowan, 2014; Robinson and Rowan, 2015) provide specific information regarding the types of foods that were eaten but lack the resolution required to quantify dietary content, or to study dietary variability within societies. Such information is crucial if we are to make meaningful comparisons between Roman and other pre-modern and developing societies, and to clarify relationships between social status, health and nutrition.

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

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

1.2 Methods

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

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

(1) $y = 34.3 - 300x$, $R^2 = 9.1$ where y = ^{14}C offset (years) and x = $\delta^{15}N$ value (‰).

These 9 individuals are a sub-sample of the 81 individuals analysed for $\delta^{13}C$ and $\delta^{15}N$ in the current study.

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

The human osteological material was analysed according to the common standards reported in the literature (Krogman and İşcan, 1986; Buikstra and Ubelaker, 1994; White and Folkens, 2005). Sex determination in the adults was obtained by the application of the visual assessment of the morphological traits of skull and pelvis (Ferembach *et al.*, 1980; White and Folkens, 2005). Age at death was determined using multiple age indicators. For adult individuals, methods included: degenerative changes of the pubic symphysis (Todd, 1921), the auricular surface of the innominate (Buikstra and Ubelaker, 1994), and the sternal ends of ribs (Işcan *et al.*, 1984); ecto- and endo-cranial suture closure (Buikstra and Ubelaker, 1994). For individuals still growing at the time of death the following criteria were applied: stages of epiphyseal fusion (Scheuer *et al.*, 2010), long bone dimensions (Scheuer *et al.*, 2010), and the stages of formation and eruption of teeth (AlQahtani *et al.*, 2010). The analyses were independently performed by three observers (PP, LF, AS,) and cases of discrepancy were resolved by a fourth joint and consensual analysis (on the reliability of the age-at-death assessment see (Baccino *et al.*, 1999; Garvin and Passalacqua, 2012). The extraordinary preservation state of the skeletal and dental material allowed for the age at death to be determined by 5 year intervals for subadults and 10 year intervals for adult individuals (the last age class being 50+), thus permitting comparison with almost contemporaneous central Italian skeletal series (Prowse *et al.*, 2004; Prowse *et al.*, 2005; FitzGerald *et al.*, 2006; Craig *et al.*, 2009; Crowe *et al.*, 2010; Petrone *et al.*, 2011).

The Herculaneum sample set reported in this paper is composed of 81 individuals: 28 females, 37 males, 6 unsexed individuals older than 15 years and 10 individuals (<15 years) which were unsexed, see Supplementary Information, Table 1.

For the dietary reconstruction, we included the biological sub-adults (age 15-20, 5 males, 2 females, and 4 unsexed) within the analysis of the adult individuals on the grounds that they probably ate an adult diet, being classed ‘social’ adults in accordance with the trend of traditional Roman life (Treggiari, 1993).

1.3 Results and Discussion

1.3.1. Dietary variation at Herculaneum and other coastal Roman sites

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

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

It is noticeable, however, that that the δ^{15}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; x^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 δ^{15}N and δ^{13}C, and a much narrower distribution of δ^{15}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.

To test for inter-site differences in δ^{15}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 δ^{15}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 δ^{15}N values genuinely reflects greater dietary variation at the attritional assemblages, compared to Herculaneum. Interestingly the core distributions, containing 25% to 75% of the δ^{15}N data (Fig. 2), at each assemblage are comparable in terms of amplitude of variance. The main difference between the sites is that Velia and Isola Sacra have a greater number of outliers, particularly individuals with high marine protein diets (i.e. high $\delta^{15}N$ values).

Finally, the amplitude of variance in $\delta^{15}N$ between the sites is not easily explained by greater absolute differences in dietary end-points (plants and fish) as discussed previously (Craig *et al.*, 2009), although temporal variation in these, particularly changes in location of grain supply, would be interesting to check. The consumption of leguminous vegetables, thought to be integral to the Roman diet (Garnsey, 1999) and with ample evidence from Vesuvian cities (Meyer, 1980; Wolf, 2010), should also be explored. These may have a large effect on the isotopic endpoints since they are relatively depleted in ^{15}N. Finally, the presence in the Velia assemblage of a specific subset of individuals, possibly fishermen, has been observed (Crowe *et al.*, 2010) and contributes to the broad range of $\delta^{15}N$ for this site.

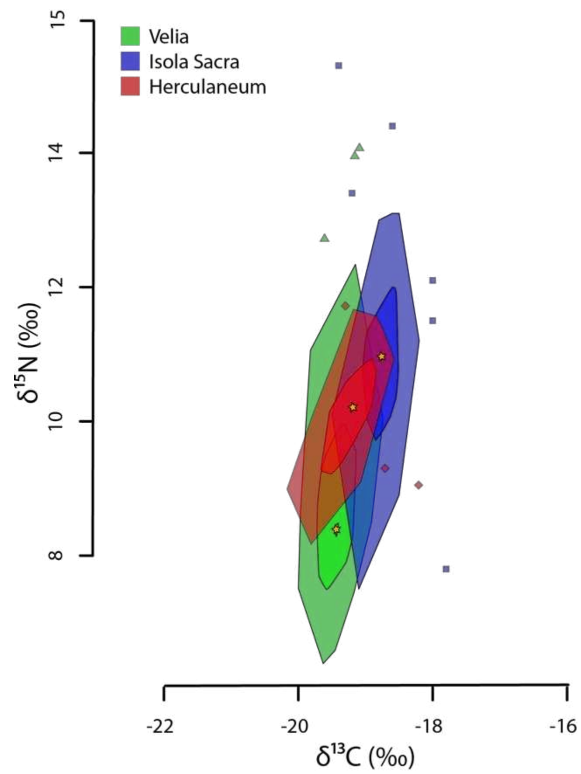

Fig. 2: Bagplot of three Roman Imperial period mortuary assemblages. Comparison of human stable isotope data between Velia (left) and Isola Sacra (middle) by means of bagplots. A bagplot is a bivariate generalization of the boxplot. The central darker shaded area contains 50% of all data points. The outer lighter shaded area is three times the area of the central part and is fenced by a line connecting data points that lie on the periphery of this area. Points outside the fence are considered outliers. Medians are represented with a gold star.

1.3.2. Variation by sex

The distribution of $\delta^{15}N$ and $\delta^{13}C$ is significantly different between the sexes at Herculaneum (Kruskal-Wallis, x^2 = 4.6, p = 0.03 and x^2 = 5.1, p = 0.02 for each isotope, respectively) with males typically enriched in ^{15}N and ^{13}C compared to females (Fig. 3a). From these data, it is proposed that males consumed more fish with relatively elevated $\delta^{15}N$ values. This is not to suggest that other low trophic level species were not consumed at Herculaneum, either fresh or as commodities such as garum. Indeed there are ample remains of small fish such as sardine, anchovy, and marine shellfish from sewer deposits (Rowan, 2014) but these are less likely to be distinguished isotopically.

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

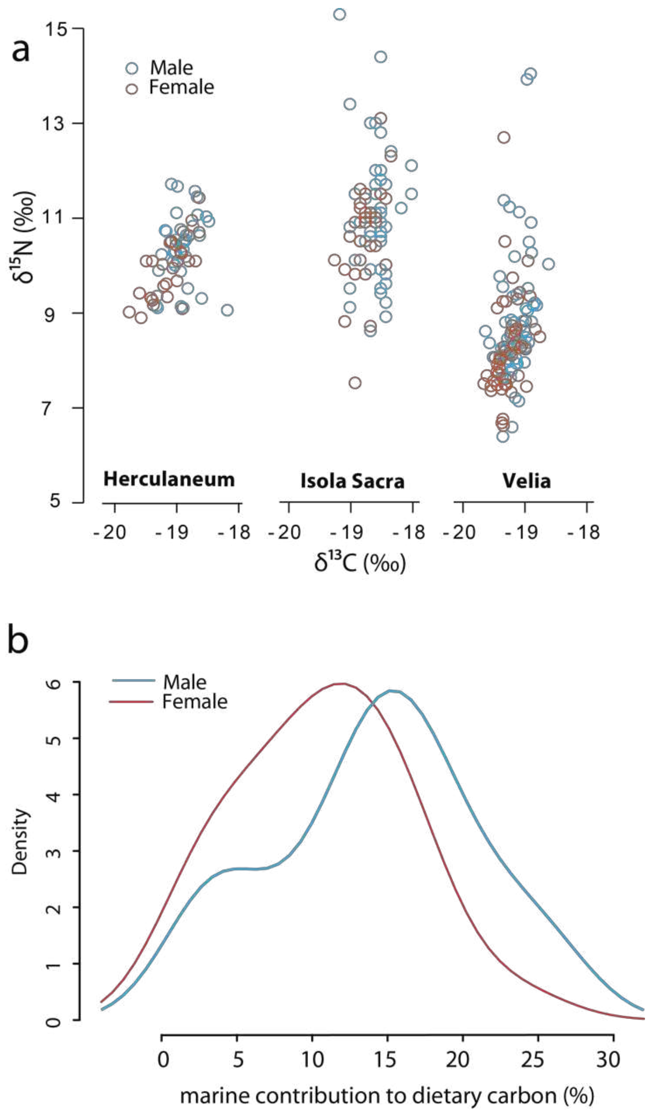

Fig 3: Stable isotope measurements of human remains from Herculaneum. *a.)* - compared with Isola Sacra and Velia; *b.)* - showing the Kernel density plot of all adults from Herculaneum by sex (F = 28; M = 37) against the estimation of % marine carbon to total dietary carbon.

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

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

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

1.3.3. Variation by Age

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

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

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

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

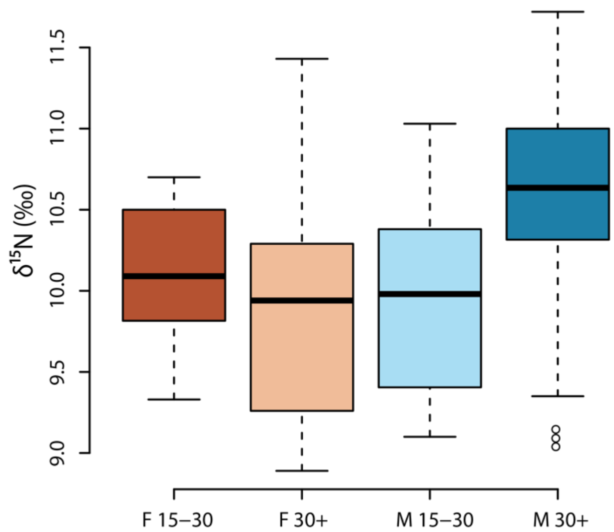

Fig 4: Boxplot of $\delta^{15}N$ values at Herculaneum by age in years and sex.

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

1.4. Conclusion

Overall, the data from the catastrophic assemblage at Herculaneum emphasizes the difficulty in interpreting intra-population isotopic variability in attritional cemetery populations, as are commonly encountered in archaeological research. There is less overall variation in $\delta^{15}N$ at Herculaneum compared to Velia and Isola Sacra regardless of sample size or demographic composition. This result is most easily explained by the short-lived nature of the population. Diets change over generations as the result of changes in the economy and food supply, as well as cultural shifts. Therefore, the range of foods eaten by individuals living contemporary lives may be considerably narrower than revealed through isotopic analysis of individuals buried in cemeteries, which are also influenced by selective mortality and selective burial. This has important implications for considering the *durée* of cemetery populations before making comparisons of any osteological datasets. Despite these interpretative issues, underlying trends are still observable between osteological and isotopic datasets, for example due to occupation (Crowe *et al.*, 2010). However, we suggest that these correlations are probably related to an individual's long-term diet rather than directly attributable to specific periods of their life, given the attenuated dietary record represented by adult bone collagen. At the very least, such direct associations need to be questioned. Further comparison of stable isotope values of collagen from tissues with different turnover rates is needed to help resolve these issues. Finally, we confirm there is clear differentiation of diet by sex as observed in attritional Roman populations, related to differential access of males and females to marine foods.

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Supporting information, Table 1. Carbon and nitrogen stable isotope values, and estimated % dietary contribution of marine-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	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	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

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