



Stable isotopes reveal dietary shifts associated with social change in Hellenistic, Roman and Late Antique Knossos

Anna C. Moles^{a,b,*}, Hazel Reade^b, Anne-Lise Jourdan^c, Rhiannon E. Stevens^b

^a Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, Netherlands

^b Institute of Archaeology, University College London, 31-34 Gordon Square, London WC1H 0PY, UK

^c Bloomsbury Environmental Isotope Facility, University College London, Gower Street, London WC1E 6BT, UK

ARTICLE INFO

Keywords:

Stable isotope analysis
Diet
Human remains
Social change
Knossos

ABSTRACT

Knossos was an important city on Crete and within Mediterranean networks in terms of trade and political status, though its status differed throughout the Hellenistic, Roman and Late Antique periods. This paper uses stable carbon and nitrogen isotope analysis to consider whether people at Knossos had differential diets due to the social, political, cultural, and economic changes across this time frame, factoring in age, sex and social status. Samples of human bone were selected to represent this range of time periods and variables.

In this initial study, a small but insignificant increase in $\delta^{13}\text{C}$ values was observed between the Hellenistic and Roman periods and there was a significant increase in $\delta^{15}\text{N}$ values for the Late Antique period. No relationship between $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ and age was observed and while the female and male means were similar, the females had wider ranging values. No significant differences were detected by social status as represented by tomb type but there were small sample sizes for several of the tomb types.

The results indicated a C3 terrestrial diet with meat or other animal products included for most individuals. The slight increase in $\delta^{13}\text{C}$ values in the Roman period may represent either the introduction of a small amount of C4 plant or marine food, or very low trophic level marine foods into some Roman diets. The higher $\delta^{13}\text{C}$ and, in particular, $\delta^{15}\text{N}$ values observed in the Late Antique samples, suggests an increased consumption of seafood, potentially linked to Christian dietary practices or advances in fishing technologies and preservation techniques. The wider spread values of females compared to males, indicating a more varied diet, could have resulted from differential participation in religious institutions connected to food or may have been caused by greater nutritional stress in females in relation to pregnancy and reproductive issues.

This study does not show a pattern of higher animal protein consumption in times of economic and cultural growth and prosperity but differences were detected between the different time periods in connection with the concurrent socio-economic changes.

1. Introduction

Knossos was a key centre within Cretan and wider Mediterranean networks throughout the Hellenistic (c.323–27 BC), Roman (c.27 BC–AD 300) and Late Antique (c.AD 300–700) periods (Fig. 1). These periods encompass a cycle of urban development and decline which involved major social, political, cultural and economic changes. These changes resulted in differing levels of prosperity and connectivity at the site, and different types of production and trade. It is not known to what extent these major social changes impacted the daily lives and health of individuals at Knossos, as the majority of studies investigating such

transitions do so on a macro socio-political scale, considering the implications for political systems, the fabric of the city, or the economy and trade relations. Recent studies in this region of the world have argued that higher animal protein consumption coincides with times of economic and cultural growth and prosperity (Papathanasiou & Richards, 2015) with some evidence coming from the elite classes of the Mycenaean civilisation (Iezzi, 2015; Papathanasiou, 2015; Richards & Hedges, 2008; Triantaphyllou, 2015; Vika, 2015) and at Classical Athens (Lagia, 2015). However, further data are needed to support this assertion (Papathanasiou and Richards 2015). Through reconstruction of human diet at Knossos via stable carbon and nitrogen isotope analysis,

* Corresponding author at: Groningen Institute of Archaeology, University of Groningen, Poststraat 6, 9712 ER Groningen, Netherlands.

E-mail addresses: a.c.moles@rug.nl (A.C. Moles), h.reade@ucl.ac.uk (H. Reade), a.jourdan@ucl.ac.uk (A.-L. Jourdan), rhiannon.stevens@ucl.ac.uk (R.E. Stevens).

<https://doi.org/10.1016/j.jasrep.2022.103609>

Received 16 June 2021; Received in revised form 24 June 2022; Accepted 18 August 2022

Available online 5 September 2022

2352-409X/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

this study examines the impact of social, political, cultural and economic changes at both the individual and population level. In particular, we examine whether there was differential access to resources due to social status and whether there was greater access to animal protein in times of perceived economic prosperity at Knossos.

2. Historical background

2.1. Hellenistic (c.323–27 BC)

Knossos was one of the leaders of the Hellenistic *koinon* (confederation of Cretan cities) and an important node along Hellenistic trade routes, evidenced by both exports, particularly of wine, and imports, including luxury commodities, coming from Attica, Delos, Knidos, Kos, Rhodes, Asia Minor, Cyprus and Egypt (Empereur et al. 1992, 640; Chaniotis 1999, 184; 2005, 107; Guizzi 1999; Cankardeş-Şenol 2007, 44–45; Gallimore 2015, 269–75). However, there were also frequent wars and disputes between the different cities (Ager, 1994; Callaghan, 1992; Carrier, 2018; Guarducci, 1935), which would have affected food supplies reaching the city at times. Supply and distribution systems were required for large urban communities to function, as a large proportion of the population needed to be relieved of agricultural duties in order to carry out urban building labour or administrative tasks (Bernard, 2016), therefore interruptions in the supply chain could have a significant impact.

Though luxury commodities are present in the archaeological record there is little evidence from the domestic or burial sphere for personal wealth at Hellenistic Knossos. There is generally a dearth of excavated domestic contexts for this period but from funerary contexts, only a very small proportion of known graves contained items such as gold jewellery, rosettes and wreaths, with the majority of graves containing no burial offerings or a single, poorly-fired *unguentarium* and all the graves were simple pit or tile graves (Moles, 2019). The existence of a small number of more lavish burial goods may suggest that, although personal

wealth was not widespread, it may have resulted in preferential access to foodstuffs for a limited elite. Alternatively, the universally simple grave types and the existence of the *syssitia* (communal dining institution) for men, women and children may indicate a relatively egalitarian society, as is suggested in some ancient sources though potentially refuted by the epigraphic record (Chaniotis, 2005; Aristotle Politics 2.1272a; Perlman, 1992, 2005). The frequency of this communal dining institution and whether it was inclusive of all members of society are uncertain but it could have ensured that there was adequate sustenance for all (Chaniotis, 1999). This study will examine the diets of different individuals and population groups and the widespread nature of certain diet types throughout the population.

2.2. Roman (c.27 BC- AD 300)

The invasion of Crete took almost three years (69–67 BC). Knossos was one of the last cities resisting the Romans, yet it became the only colony on Crete under the Roman Empire. By the second century, it was the subject of great investment in both the public and private spheres (Paton, 1994, 2004; Sweetman, 2007), demonstrating state wealth and an increased display of personal wealth for an elite group. This included the adoption of more monumental tomb forms and a greater diversity of different tomb types. During the Roman period, the economy on Crete changed as connections were amplified and the island's ports became increasingly integral within Mediterranean networks, with a particular focus on the mass export of wine (Gallimore, 2019; Marangou, 1999). This study aims to identify whether there was preferential access to dietary resources for individuals buried in more elaborate tombs and/or whether the intensified trade contacts played a role in dietary changes.

2.3. Late Antiquity (AD 300–700)

Knossos became a significant Christian bishopric in Late Antiquity and remained an important centre with continued evidence for imports



Fig. 1. Location of Knossos within the Eastern Mediterranean (base map: d-maps.com).

(Sweetman 2004b; 2004a; Gallimore 2016). However, from the later third century onwards there was a gradual decline in population and less evidence for large-scale trade and connectivity (Sweetman, 2004a; Trainor, 2019). There is little archaeological evidence for social structure with a lack of domestic contexts excavated and the majority of known burials being from communal osteothekes, often associated with churches, with few accompanying objects. The reduction in trade links with and exports to Italy and the Western Mediterranean (Gallimore, 2016) may have allowed for a more stable food supply and a return to small-scale subsistence, as individuals could choose to disperse land-holdings, diversify produce and store, rather than export, their food surplus (Garnsey, 1988, p. 48). Changes and differences detected isotopically in the diet may be able to add to the picture of the impact of these changing economic and subsistence conditions and of Christianity at Knossos.

2.4. Diet and subsistence at Knossos

Mixed farming has been common since the Neolithic in Greece and provided a more secure and less labour-intensive subsistence model than arable farming alone (Halstead, 2008, p. 244; Margaritis & Jones, 2009; Papathanasiou & Richards, 2015, p. 200). However, animal husbandry was an expensive use of land for food production compared to growing crops, and although intensive dairying supported livestock farming, meat remained a prestigious product (Sallares, 1991). Prehistoric plant remains found at Knossos show that a variety of cereals and pulses were cultivated, including free-threshing wheat, emmer, hulled barley, winged vetchling, lentil and celtic bean (Nitsch et al., 2019). Nitrogen isotope analysis of these plant remains indicates intensive cultivation strategies, including manuring and water management (Nitsch et al., 2019). While wheat, barley, several types of legumes, olive and grape would have been the core staple crops, many other plants are attested in the archaeobotanical record of Crete (Livarda, 2012, 2014; Livarda & Kotzamani, 2013).

The production of wine, honey and herbs was known from both written sources and the archaeological evidence to have been a major part of the economy of Crete in the Hellenistic period and increasingly so in the Roman period (Chanotis, 1999; Francis, 2016; Marangou, 1999). There is evidence at Knossos for beehives dating from the Hellenistic period through to the 7th century CE (Coldstream et al., 2001; Forster, 2009; Hayes, 1983, 2001). A late Hellenistic wine press serves as evidence for wine production (Carington Smith & Wall, 1994; Trainor, 2016), and there have also been discoveries of large numbers of local and imported transport amphorae for wine, olive oil and potentially other produce (Forster, 2009; Hayes, 1971, 1983, 2001; Sweetman & Grigoropoulos, 2010; Trainor, 2019). These are particularly abundant from the Roman period but are also plentiful within Hellenistic and Late Antique contexts.

Millet is known to have been a minority cereal crop at some sites in Greece since the beginning of the 2nd millennium BC (Valamoti, 2016, p. 52), and is attested in both the archaeological record and written sources throughout the Roman Empire, though generally regarded as a second-class crop for the poor or livestock (Dalby, 2003; Murphy, 2016). Other than in the phytolith record from the Middle Neolithic (Efstratiou et al., 2004) and the mention of a discovery by Evans from the store-rooms of the Bronze Age Palace (Evans, 1935; Livarda & Kotzamani, 2013), millet has not been identified in the – as yet limited – archaeobotanical record for other time periods at Knossos (Jones, 1984; Livarda, 2012; Nitsch et al., 2019; Warren, 1981), but there are no contemporary studies at Knossos for the time frame of the present project (none later than the Protogeometric period).

The majority of animal bone assemblages in Greece are dominated by the four major domestic taxa: cattle, pig, sheep and goat (Dibble, 2017). The Hellenistic animal bone assemblage from the wine-press excavation and the Knossos 'Unexplored Mansion' Roman animal bone assemblage indicate sheep/goat was the main meat source, though there

were also finds of pig, cattle, chicken, red deer, horse, dog, hare and fish (Bedwin, 1992; Carington Smith & Wall, 1994). Archaic law inscriptions from Crete indicate widespread grazing with treaties between city-states for access to upland grazing (Chanotis, 1999, pp. 192–197; Gagarin & Perlman, 2016, pp. 42, 104), which could result in varied diets amongst livestock.

3. Background to stable isotopes

Stable carbon and nitrogen isotope analysis of bone collagen has become a well-established method used in archaeology to investigate aspects of past diets (Ambrose, 1993; Bird et al., 2021; Makarewicz & Sealy, 2015; Papathanasiou et al., 2015). Carbon and nitrogen in bone collagen are primarily derived from dietary protein, though a minor part of the carbon can also come from carbohydrates and fats in the diet (Fernandes et al., 2012). Stable carbon isotope ratios ($\delta^{13}\text{C}$) in plants differ significantly based on whether the species utilises the C3 or C4 photosynthetic pathway, and these isotopic signatures are passed on to the animals which consume them. On Crete, and throughout Europe, at this time C3 plants with $\delta^{13}\text{C}$ values of approximately -35 to -22 ‰ (V-PDB) dominated while C4 plants, with $\delta^{13}\text{C}$ values commonly ranging from -12.7 to -11.4 ‰, were much rarer (Cerling et al., 1997; Knipper et al., 2020; Lightfoot et al., 2015). Millet, the most relevant C4 crop found in Europe, was attested at Knossos in earlier time periods (Efstratiou et al., 2004; Livarda & Kotzamani, 2013). The $\delta^{15}\text{N}$ values of the plants being consumed can be affected by environmental factors, including precipitation, temperature and salinity, and farming practices such as manuring (Bogaard et al., 2007). Fractionation with metabolism occurs throughout the food chain, with an increase in $\delta^{13}\text{C}$ values of c. 5 ‰ from plants to herbivore collagen and an increase of c. 0.8–1.3 ‰ for subsequent trophic levels (Bocherens & Drucker, 2003; Lee-Thorpe, 2008; van der Merwe & Vogel, 1978). There is also an increase in $\delta^{15}\text{N}$ values of 3–5 ‰ for each trophic level (Bocherens & Drucker, 2003; Hedges & Reynard, 2007; Schoeninger & DeNiro, 1984), though more recent work has demonstrated that this should be closer to c.6 ‰ (O'Connell et al., 2012). This trophic level enrichment along the food chain enables diets containing animal products, such as meat and dairy, to be identified from the human bone collagen. As animal products are more expensive to produce than crops, these are often considered to be prestige foodstuffs (Knipper et al., 2015; Privat et al., 2002; Sallares, 1991).

Consumption of marine resources can be distinguished from terrestrial diets due to the different carbon sources in the sea and the atmosphere. Carbon is available for marine organisms as dissolved carbonate, with a $\delta^{13}\text{C}$ value of 0 ‰, while atmospheric CO_2 is -7 ‰, resulting in marine fish and mammals with average $\delta^{13}\text{C}$ values of -13 to -10 ‰ (Cubas et al., 2019; Fuller et al., 2012; Garcia-Guixé et al., 2010). Longer food chains in marine environments result in marine mammals at the top of the food chain also having elevated $\delta^{15}\text{N}$ values (c.7–11 ‰) compared to most terrestrial carnivores (Lubell et al., 1994; Schoeninger & DeNiro, 1984). Therefore, there can also be a distinction between humans consuming shellfish and small fish compared to those eating larger fish further along the food chain. Freshwater resources have highly variable $\delta^{13}\text{C}$ values due to the range of sources the carbon can be obtained from, including atmospheric CO_2 , CO_2 in the water, carbonate from rocks and soils, and decomposition products or waste from plants and animals living in the water (Katzenberg, 2008, p. 427; Zohary et al., 1994).

Previous studies have suggested that a typical human C3 terrestrial consumer's bone collagen would have $\delta^{13}\text{C}$ values in the region of -21 ‰ (Schoeninger, 1989). A pure C4 plant diet would yield $\delta^{13}\text{C}$ values of around -7 ‰, while those consuming 50 % each of C3 and C4 plants would have values of c.-14 ‰ (Tykot, 2006). A population with a predominantly marine diet will have human collagen values around -12 ‰ (Richards & Hedges, 1999).

Stable carbon and nitrogen isotope analysis is therefore an appropriate method for the current study as it enables factors such as

differential access to meat and animal products and the introduction of new foods, such as millet, or new food technologies, such as fish preservation techniques allowing more widespread consumption of seafood, to be identified.

4. Methods

Bone samples ($n = 93$) were selected from across a range of archaeological contexts to represent the different time periods, burial locations, tomb forms, and demographic characteristics present at Knossos (Table 1). Sex determinations were made using the standard methods of the skull and pelvis morphology (Buikstra & Ubelaker, 1994). Age-at-death was estimated using standard methods of assessing the pubic symphysis (Brooks & Suchey, 1990), auricular surface (Lovejoy et al., 1985) and dental wear (Smith (1984), cross-referencing (Miles 1963; Lovejoy 1985; Brothwell 1989). These methods were used to assign individuals to an age group, which can be broadly equated to the following age ranges whilst acknowledging the difficulties of adult age-at-death determination (Moles, 2019): Adolescent > 12 to 20 years, Young Adult > 20–30 years, Middle Adult > 30–45 years, Old Adult > 45 years.

Long bones were preferentially selected for sampling when they could be securely associated with one or more age- and sex-able elements from the same individual. Long bone samples were the preferred element as the thick cortical bone provides the greatest chance of collagen preservation. However, due to the degree of fragmentation in the assemblage and the commingled nature of many of the burial contexts, some samples had to be taken from the skull or pelvis in order to obtain demographic information.

4.1. Collagen extraction and isotope analysis

Collagen extraction was carried out at the UCL Institute of Archaeology following a modified Longin method (1971). A dental drill with a small cutting wheel was used to take a small sample of bone (0.5–1.0 g) from each specimen. Samples were treated with 0.5 M hydrochloric acid (HCl) at 4 °C until fully demineralised and then thoroughly rinsed with ultrapure water. Samples were then heated in pH3 HCl solution at 75 °C for 48hrs and filtered using an Ezeefilter, with the supernatant being retained and freeze dried. Between 500 and 600 µg aliquots of freeze-dried collagen were weighed into tin capsules and analysed at UCL Bloomsbury Environmental Isotope Facility using a ThermoFisher Delta V Advantage stable isotope mass spectrometer coupled to a Flash EA 1112 flash combustion elemental analyser.

The results were calibrated against laboratory and international standards (IAEA-C6, IAEA-600, IAEA-N1, IAEA-N2, USGS40, USGS24, OEA alanine). For every 27 unknown samples, 23 reference materials were analysed. Results are reported as per mil (‰), in the conventional δ -notation, relative to the internationally accepted standards V-PDB and atmospheric N₂ (AIR), respectively. Measurement uncertainty was determined to be better than ± 0.3 ‰ for $\delta^{13}\text{C}$ and ± 0.2 ‰ for $\delta^{15}\text{N}$ on the basis of repeated measurements of OEA alanine. Each sample was analysed in duplicate with reproducibility better than or equal to ± 0.7 ‰ for $\delta^{13}\text{C}$, and ± 0.2 ‰ for $\delta^{15}\text{N}$.

5. Results

Of the 93 samples analysed for their stable carbon and nitrogen isotope composition, 74 samples¹ produced %C, %N and C:N atomic ratios indicative of suitably preserved collagen (13–47 %, 5–17 %, 2.9–3.6, respectively, (Ambrose, 1990; DeNiro, 1985)). Collagen yield ranged from 0.0 % to 13.7 %, with 22 samples falling below the 1 % threshold, though of these low-yield samples, 4 samples had acceptable %C, %N and C:N values and were included in the analysis. All results are reported in Supplementary Tables 1 and 2, with the following data discussion limited to those samples deemed to have produced acceptable results (Table 1).

The Knossos human $\delta^{13}\text{C}$ values ranged from -20.1 ‰ to -16.1 ‰ ($n = 68$, mean = -19.2 ‰, s.d. = 0.57) and $\delta^{15}\text{N}$ values range from 6.7 ‰ to 11.0 ‰ ($n = 68$, mean = 8.6 ‰, s.d. = 0.84).

5.1. Time period

The mean $\delta^{13}\text{C}$ was -19.4 ‰ ± 0.9 (range -20.1 ‰ to -16.1 ‰) for the Hellenistic period, -19.2 ‰ ± 0.4 (range -20.1 ‰ to -17.6 ‰) for the Roman period, and -19.1 ‰ ± 0.4 (range -19.7 ‰ to -18.4 ‰) for the Late Antique period (Fig. 2, Table 2). A small, but statistically insignificant, increase in mean $\delta^{13}\text{C}$ values occurs from the Hellenistic to Roman periods, using a Student's t -test ($t = 0.786$, $p = 0.436$). The Hellenistic sample S22 ($\delta^{13}\text{C} = -16.1$ ‰) and Roman sample S31 ($\delta^{13}\text{C} = -17.6$ ‰) had notably different $\delta^{13}\text{C}$ values to most other samples and may represent individuals with slightly atypical diets. A very small increase in mean $\delta^{13}\text{C}$ values is seen between the Roman and Late Antique period, but again this is not statistically significant ($t = 1.579$, $p = 0.121$).

The mean $\delta^{15}\text{N}$ value was 8.5 ‰ ± 0.8 (range 7.3 ‰ to 10.4 ‰) for the Hellenistic period, 8.5 ‰ ± 0.8 (range 6.7 ‰ to 11.0 ‰) for the Roman period, and 9.1 ‰ ± 0.8 (range 8.0 ‰ to 10.8 ‰) for the Late Antique period (Fig. 2, Table 2). $\delta^{15}\text{N}$ values were significantly higher by 0.6 ‰ in the Late Antique period ($t = 2.67$, $p = 0.009$) when compared to the Hellenistic and Roman periods (Table 2). A wider range of $\delta^{15}\text{N}$ values were observed in the Roman samples than in the Hellenistic samples. Only two Hellenistic samples have $\delta^{15}\text{N}$ values over 9.2 ‰, whereas this is five and seven for the Roman and Late Antique groups respectively. None of the Late Antique samples have $\delta^{15}\text{N}$ values lower than 8 ‰, unlike the Hellenistic and Roman periods which have five and six samples respectively below this value.

It was possible to assign some samples to more discrete time periods based on better dating information for some tombs, based on coins and pottery chronologies (Sweetman & Becker, 2005; unpublished reports in BSA archives), such that more detailed temporal differences could be investigated for these individuals (Table 3). It was not possible to do a temporal comparison within the Hellenistic period, as no samples could be attributed to the Early Hellenistic period with certainty and only three samples could be confidently assigned to the Late Hellenistic period. Considering the Hellenistic samples as a whole, there was no significant difference between them ($n = 21$) and Early Roman mean $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values. However, there was a slight drop in $\delta^{15}\text{N}$ values between the Hellenistic (8.5 ‰) and Early Roman (8.3 ‰) periods which demonstrates that the higher Late Roman values had masked the lower Early Roman $\delta^{15}\text{N}$ values when considering the samples at a more coarse chronological scale. This shows a pattern opposite to the general

¹ Six of these samples were of Subminoan date (1100–970 BCE) and were excluded from the present study due to being temporally distant but they are included in Fig. 6 and Supplementary Tables 1 and 2. These were selected to serve as an intermediary between the present study and that of Nafplioti (2016) for Bronze Age Knossos. From the time periods included in this study, 68 samples produced adequate collagen preservation and were included in this analysis.

Table 1

Summary of contextual and isotopic information for the samples presented in this study. Further context and details of each of the 93 bone samples originally collected for stable isotope analysis, including those lacking good enough collagen preservation, are presented in [Supplementary Tables 1 and 2](#).

No.	Sex	Age	Tomb type	Time period	Collagen yield	Mean %C	Mean %N	C:N	Mean $\delta^{13}\text{C}$ ‰	Mean $\delta^{15}\text{N}$ ‰
S2	Female	MA	Osteotheke	Late Antique	4.13	25.7	9.2	3.3	-19.3	8.1
S3	Male	Adult	Osteotheke	Late Antique	5.32	41.1	15.3	3.1	-18.9	9.3
S4	Male	MA	Osteotheke	Late Antique	7.68	43.1	15.9	3.2	-18.6	9.6
S5	Male	MA	Osteotheke	Late Antique	5.99	43.8	15.7	3.3	-18.8	9.6
S6	Female	Adol.	Osteotheke	Late Antique	4.00	26.1	9.4	3.3	-18.9	9.8
S8	Male	Adult	Chamber	Roman	1.45	42.8	15.2	3.3	-19.5	8.7
S9	Female	Adult	Chamber	Roman	4.40	37.7	13.4	3.3	-19.7	6.7
S10	Male	Adult	Chamber	Roman	2.25	41.9	14.7	3.3	-19.5	7.2
S11	Female	Adult	Chamber	Roman	4.72	43.3	16.0	3.2	-19.3	9.7
S18	Male	MA	Cist	Roman	3.31	43.1	15.9	3.2	-19.3	8.3
S20	Female	YA	Cist	Roman	4.31	34.5	12.5	3.2	-19.1	8.6
S22	Unknown	YA	Tile	Hellenistic	1.38	31.6	10.8	3.4	-16.1	9.9
S25	Female	Adult	Stone-lined	Roman	13.74	31.6	11.5	3.2	-19.4	8.4
S26	Female	YA	Stone-lined	Roman	4.53	43.9	16.1	3.2	-18.8	9.5
S27	Male	MA	Stone-lined	Roman	3.43	44.7	16.3	3.2	-19.2	8.9
S28	Female	MA	Pit	Roman	11.26	43.8	16.3	3.1	-19.1	9.4
S29	Male	YA	Built	Roman	7.02	42.5	15.6	3.2	-19.1	8.3
S30	Female	MA	Built	Roman	10.58	41.0	14.8	3.2	-19.3	8.3
S31	Female	YA	Chamber	Roman	9.51	42.7	15.9	3.1	-17.6	11.0
S32	Indet.	Adult	Chamber	Roman	1.49	42.4	15.3	3.2	-19.1	8.5
S33	Male	MA	Chamber	Roman	2.99	36.4	13.2	3.2	-19.3	8.0
S34	Female	Adol.	Chamber	Roman	5.99	43.3	16.0	3.2	-19.1	8.7
S35	Male	Adult	Chamber	Roman	1.04	35.2	12.7	3.2	-19.4	8.3
S41	Female	Adol.	Chamber	Roman	3.99	39.5	14.3	3.2	-19.1	7.7
S42	Male	MA	Chamber	Roman	2.51	41.5	15.5	3.1	-19.4	9.9
S43	Female	YA	Chamber	Roman	5.92	42.3	16.1	3.1	-19.1	9.1
S44	Male	Adult	Pit	Hellenistic	7.81	16.2	5.8	3.2	-19.5	7.6
S45	Female	YA	Pit	Hellenistic	6.46	38.7	14.1	3.2	-19.6	7.7
S46	Female	YA	Pit	Hellenistic	3.94	39.0	14.0	3.2	-20.1	7.7
S47	Male	MA	Pit	Hellenistic	8.78	40.9	15.1	3.2	-19.3	8.5
S48	Female	MA	Pit	Hellenistic	7.24	41.8	15.6	3.1	-19.8	8.7
S49	Female	OA	Pit	Hellenistic	7.24	42.0	15.8	3.1	-18.9	9.1
S50	Female	YA	Pit	Hellenistic	6.17	41.0	15.4	3.1	-19.3	8.6
S51	Female	Adult	Pit	Hellenistic	3.07	34.1	12.5	3.2	-19.2	8.3
S52	Female	YA	Pit	Hellenistic	4.34	43.0	15.4	3.3	-19.6	8.1
S53	Female	Adult	Pit	Hellenistic	6.94	41.6	15.3	3.2	-20.1	8.7
S54	Male	Adult	Pit	Hellenistic	3.70	41.5	15.3	3.2	-18.3	10.4
S55	Male	Adult	Pit	Hellenistic	2.03	38.2	14.0	3.2	-19.8	8.3
S56	Male	MA	Pit	Hellenistic	4.84	41.1	15.1	3.2	-19.3	8.6
S57	Female	YA	Tile	Hellenistic	5.76	40.6	15.1	3.1	-19.7	8.3
S58	Male	YA	Pit	Hellenistic	6.89	37.4	13.8	3.2	-19.6	9.1
S59	Unknown	YA	Pit	Hellenistic	4.69	41.4	15.7	3.1	-19.8	7.3
S60	Female	YA	Tile	Hellenistic	10.73	42.3	15.8	3.1	-19.8	8.2
S61	Male	MA	Pit	Hellenistic	6.31	39.7	14.5	3.2	-19.8	9.2
S62	Male	YA	Pit	Hellenistic	0.28	37.2	12.8	3.4	-19.7	8.3
S64	Female	Adol.	Pit	Hellenistic	1.96	39.1	14.1	3.2	-19.5	7.4
S65	Female	YA	Tile	Roman	5.62	40.6	15.0	3.2	-19.4	8.1
S66	Male	Adult	Built	Roman	5.91	43.0	15.4	3.3	-19.2	9.0
S67	Female	MA	Tile	Roman	5.28	41.0	15.2	3.1	-19.2	8.2
S68	Female	Adol.	Tile	Roman	2.03	38.4	13.9	3.2	-19.4	7.8
S71	Female	Adult	Cist	Late Antique	3.34	41.8	15.0	3.3	-18.4	10.1
S72	Female	MA	Osteotheke	Late Antique	4.34	42.1	15.7	3.1	-19.5	8.5
S73	Male	YA	Sarcophagus	Late Antique	4.49	43.0	16.2	3.1	-19.0	9.1
S74	Male	MA	Stone-lined	Late Antique	7.91	42.4	16.0	3.1	-18.8	8.9
S76	Female	MA	Osteotheke	Late Antique	1.45	33.0	11.6	3.3	-18.8	9.8
S77	Male	Adult	Stone-lined	Late Antique	11.16	21.4	7.9	3.1	-18.9	8.0
S78	Female	Adult	Osteotheke	Late Antique	0.31	33.2	10.9	3.5	-19.4	10.8
S79	Female	Adult	Osteotheke	Late Antique	7.17	43.7	15.9	3.2	-19.1	8.0
S82	Male	YA	Osteotheke	Late Antique	2.46	42.1	15.4	3.2	-19.3	8.6
S83	Male	Adult	Osteotheke	Late Antique	1.00	40.9	13.9	3.4	-19.5	8.2
S84	Male	YA	Osteotheke	Late Antique	0.54	21.2	7.2	3.4	-19.7	9.1
S85	Male	Adult	Built	Roman	1.70	37.1	14.1	3.1	-19.2	8.2
S86	Male	MA	Built	Roman	4.64	42.3	15.1	3.3	-19.0	8.5
S89	Female	MA	Built	Roman	1.03	41.9	15.8	3.1	-19.4	7.0
S90	Female	YA	Built	Roman	0.50	40.9	14.6	3.3	-19.3	8.5
S91	Unknown	Unknown	Chamber	Roman	11.88	42.4	15.5	3.2	-19.2	7.9
S92	Unknown	Unknown	Chamber	Roman	6.03	39.5	14.6	3.2	-19.5	8.2
S93	Unknown	Unknown	Chamber	Roman	0.64	21.7	7.1	3.6	-20.1	8.5

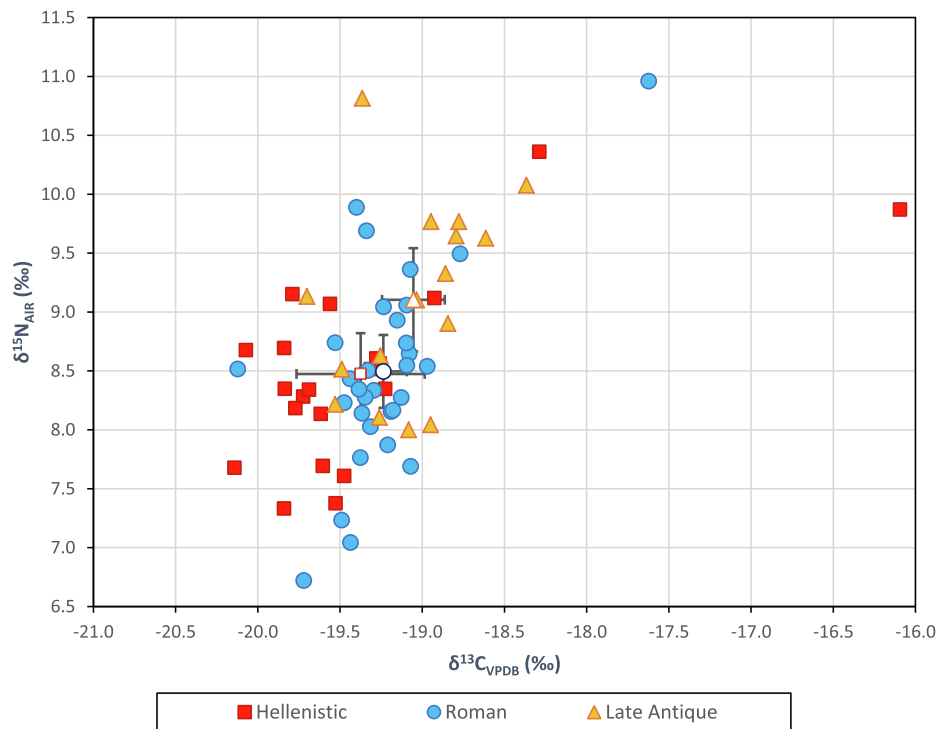


Fig. 2. Scatter plot of isotope values for each time period, including mean values with 95% confidence interval error bars.

Table 2

Summary of isotopic values for each time period.

	<i>n</i>	Mean $\delta^{13}\text{C}$ (‰)	Lowest $\delta^{13}\text{C}$ (‰)	Highest $\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ SD	Mean $\delta^{15}\text{N}$ (‰)	Lowest $\delta^{15}\text{N}$ (‰)	Highest $\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ SD
Hellenistic	21	-19.4	-20.1	-16.1	±0.9	8.5	7.3	10.4	±0.8
Roman	31	-19.2	-20.1	-17.6	±0.4	8.5	6.7	11.0	±0.8
Late Antique	16	-19.1	-19.7	-18.4	±0.4	9.1	8.0	10.8	±0.8

Table 3

Descriptive statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for each narrowly defined time period.

Time period	<i>n</i>	Mean $\delta^{13}\text{C}$ ‰	Lowest $\delta^{13}\text{C}$ ‰	Highest $\delta^{13}\text{C}$ ‰	$\delta^{13}\text{C}$ s.d.	Mean $\delta^{15}\text{N}$ ‰	Lowest $\delta^{15}\text{N}$ ‰	Highest $\delta^{15}\text{N}$ ‰	$\delta^{15}\text{N}$ s.d.
Early Hellenistic late 4th-3rd C. BC	0								
Late Hellenistic 2nd-1st C. BC	3	-18.2	-19.3	-16.1	±1.8	9.0	8.5	9.9	±0.8
Early Roman 1st- 2nd C. AD	15	-19.4	-20.1	-19.0	±0.3	8.3	6.7	9.9	±0.9
Late Roman 3rd-4th C. AD	8	-19.2	-19.4	-18.8	±0.2	8.7	8.3	9.5	±0.5
Earlier Late Antique 5th-early 6th C. AD	5	-19.3	-19.7	-18.8	±0.4	9.0	8.0	10.8	±1.1
Later Late Antique late 6th-7th C. AD	7	-19.0	-19.5	-18.6	±0.3	9.1	8.1	9.8	±0.7

temporal trend of increasing values that was observed for the broader time periods, but the sample size is small.

5.2. Age and sex

No relationship between $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values and age was observed (see section 3 of supplementary material). Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for females and males are almost identical, being -19.3 ‰ ± 0.5 and -19.2 ‰ ± 0.4 , and 8.6 ‰ ± 1.0 and 8.7 ‰ ± 0.7 respectively, with marginally higher mean values for males in each case (Fig. 3, Table 4). Most time-period-specific differences between the sexes are small. The only statistically significant difference for sex-specific changes over time was between the Hellenistic and Roman female $\delta^{13}\text{C}$ values ($t = 2.77$, p

$= 0.011$). The difference in mean $\delta^{15}\text{N}$ values between Hellenistic males and females is likely skewed by the male outlier (>1.5 times the interquartile range), S54 (10.4 ‰), and regardless, it is not a statistically significant difference ($t = 1.65$, $p = 0.117$). However, the female $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values have much broader ranges, demonstrating that across the sample, female diets were more variable. Notably, there are more females ($n = 7$) than males ($n = 2$) with $\delta^{15}\text{N}$ values less than 8.0 ‰, and there are also more females ($n = 3$) than males ($n = 1$) represented in those samples with $\delta^{15}\text{N}$ values >10.0 ‰.

5.3. Social status

Tomb types were employed as a proxy for social status. The

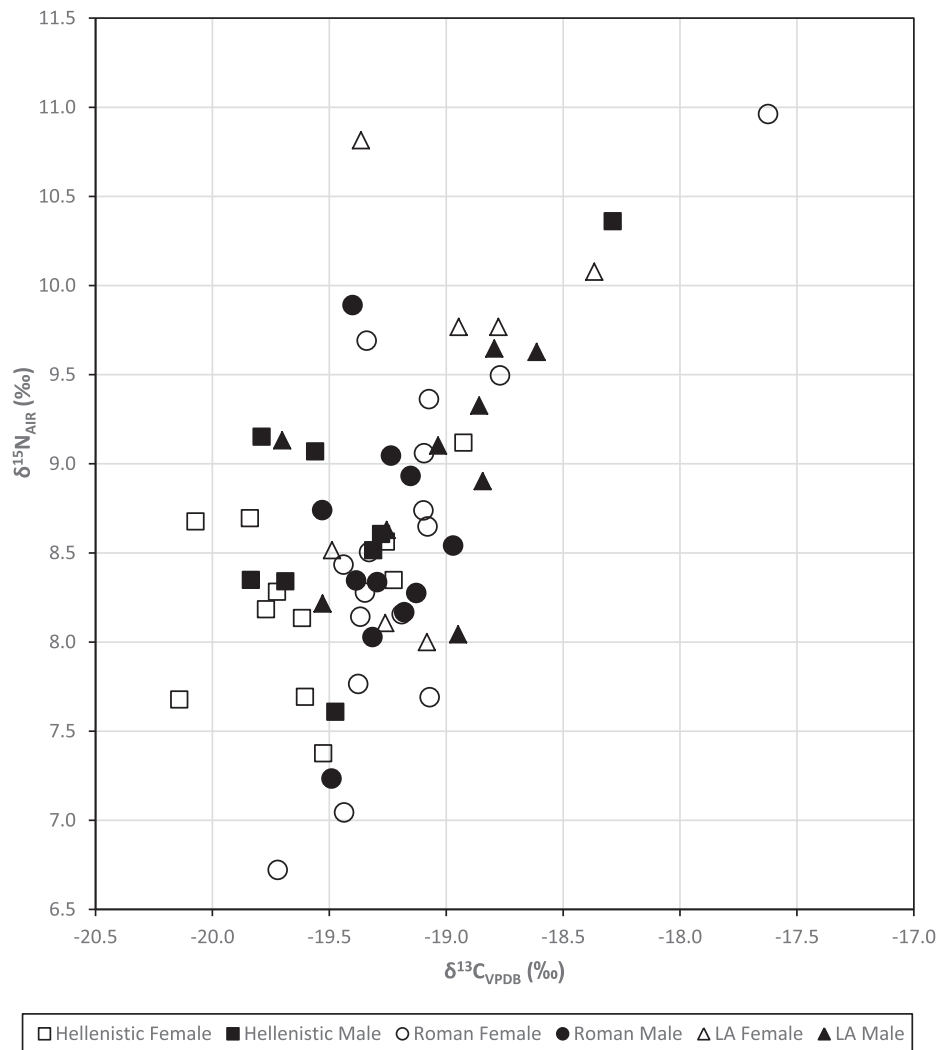


Fig. 3. Scatter plot of isotope values for the sexes in each time period (excluding those of unknown sex).

Table 4

Descriptive statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for females and males, and the breakdown of those categories within each time period.

	n	Mean $\delta^{13}\text{C}$ ‰	Lowest $\delta^{13}\text{C}$ ‰	Highest $\delta^{13}\text{C}$ ‰	$\delta^{13}\text{C}$ s.d.	Mean $\delta^{15}\text{N}$ ‰	Lowest $\delta^{15}\text{N}$ ‰	Highest $\delta^{15}\text{N}$ ‰	$\delta^{15}\text{N}$ s.d.
Female (all)	34	-19.3	-20.1	-17.6	±0.5	8.6	6.7	11.0	±1.0
Male (all)	28	-19.2	-19.8	-18.3	±0.4	8.7	7.2	10.4	±0.7
Hellenistic Females	11	-19.6	-20.1	-18.9	±0.4	8.3	7.4	9.1	±0.5
Hellenistic Males	8	-19.4	-19.8	-18.3	±0.5	8.8	7.6	10.4	±0.8
Roman Females	16	-19.1	-19.7	-17.6	±0.5	8.5	6.7	11.0	±1.0
Roman Males	11	-19.3	-19.5	-19.0	±0.2	8.5	7.2	9.9	±0.7
Late Antique Females	7	-19.0	-19.5	-18.4	±0.4	9.3	8.0	10.8	±1.1
Late Antique Males	9	-19.1	-19.7	-18.6	±0.4	9.0	8.0	9.6	±0.6

relationship between tomb types and social status is complex and reasons for burying any individual in a particular tomb may be different, complex or multifaceted. However, as there existed remarkably different types of tombs, in terms of investment and elaboration, particularly during the Roman period, it is likely these represent different social factors, whether these are related to status, emotion or other factors (for discussion of tomb terminology and the representation of society, see Moles 2019, 83-89, 124-128). Tomb type was used in preference to grave goods as a social indicator due to looting of many graves as well as the lack of differentiation between graves in general and an absence of grave goods in later Roman and Late Antique periods. Period specific summary values for all tomb types are presented in Table 5 and all samples are plotted as either ‘Lower’ (pit and tile graves) or ‘Higher’ (all

other, more elaborate tomb types) status by time period in Figs. 4 and 5.

The Hellenistic samples are all lower status, largely from pit graves, with a small number from tile graves (n = 3). There are not enough tile samples for any pattern to be determined and the pit samples have a wide range of values. However, as was observed in general for the Hellenistic period, the pit grave group generally has more samples with lower isotopic values, particularly $\delta^{13}\text{C}$ values.

The Roman period has both lower (n = 4) and higher (n = 27) status samples, but the sample size is heavily skewed. There was no significant difference between the higher and lower status $\delta^{13}\text{C}$ (higher: -19.2 ‰, lower: -19.3 ‰; t = 0.09, p = 0.932) or $\delta^{15}\text{N}$ (higher: 8.5 ‰, lower: 8.4 ‰; t = 0.35, p = 0.727) values. Within a single tomb type group the results can be highly variable, such as the large ranges ($\delta^{13}\text{C}$ 2.5 ‰, $\delta^{15}\text{N}$

Table 5
Descriptive statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for each tomb type within each time period.

Tomb Type	n	Mean $\delta^{13}\text{C}$ ‰	Lowest $\delta^{13}\text{C}$ ‰	Highest $\delta^{13}\text{C}$ ‰	$\delta^{13}\text{C}$ SD	Mean $\delta^{15}\text{N}$ ‰	Lowest $\delta^{15}\text{N}$ ‰	Highest $\delta^{15}\text{N}$ ‰	$\delta^{15}\text{N}$ SD
Hellenistic									
Pit	18	-19.5	-20.1	-18.3	± 0.4	8.4	7.3	10.4	± 0.7
Tile	3	-18.5	-19.8	-16.1	± 2.1	8.8	8.2	9.9	± 0.9
Roman									
Built	7	-19.2	-19.4	-19.0	± 0.2	8.3	7.0	9.0	± 0.6
Chamber	15	-19.3	-20.1	-17.6	± 0.5	8.6	6.7	11.0	± 1.1
Stone-lined	3	-19.1	-19.4	-18.8	± 0.3	9.0	8.4	9.5	± 0.5
Cist	2	-19.2	-19.3	-19.1	± 0.2	8.5	8.3	8.6	± 0.2
Tile	3	-19.3	-19.4	-19.2	± 0.1	8.0	7.8	8.2	± 0.2
Pit	1	-19.1				9.4			
Late Antique									
Osteotheke	12	-19.1	-19.7	-18.6	± 0.3	9.1	8.0	10.8	± 0.9
Stone-lined	2	-18.9	-18.9	-18.8	± 0.1	8.5	8.0	8.9	± 0.6
Sarcophagus	1	-19.0				9.1			
Cist	1	-18.4				10.1			

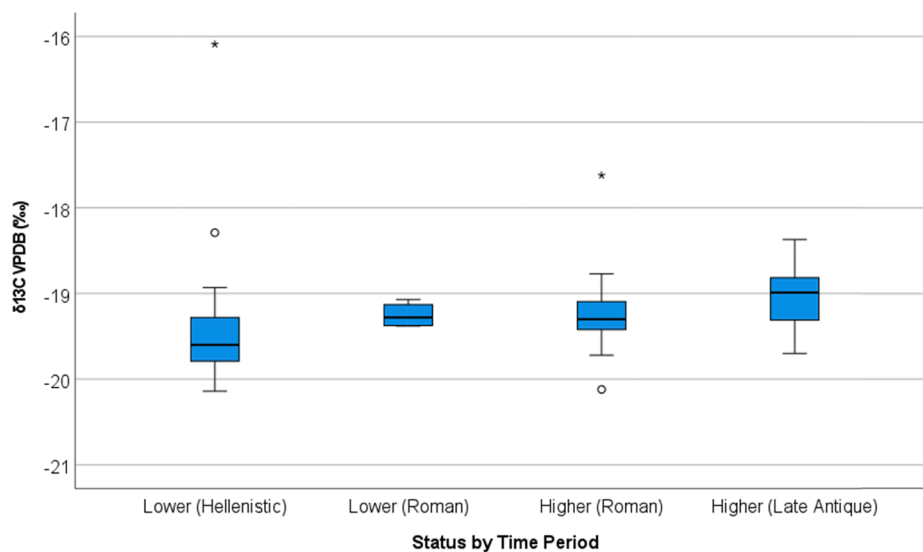


Fig. 4. Box plot of $\delta^{13}\text{C}$ values by social status as inferred from tomb type in each time period. This plot was created in SPSS, where potential outliers are shown as circles and extreme values are indicated by asterisks (*).

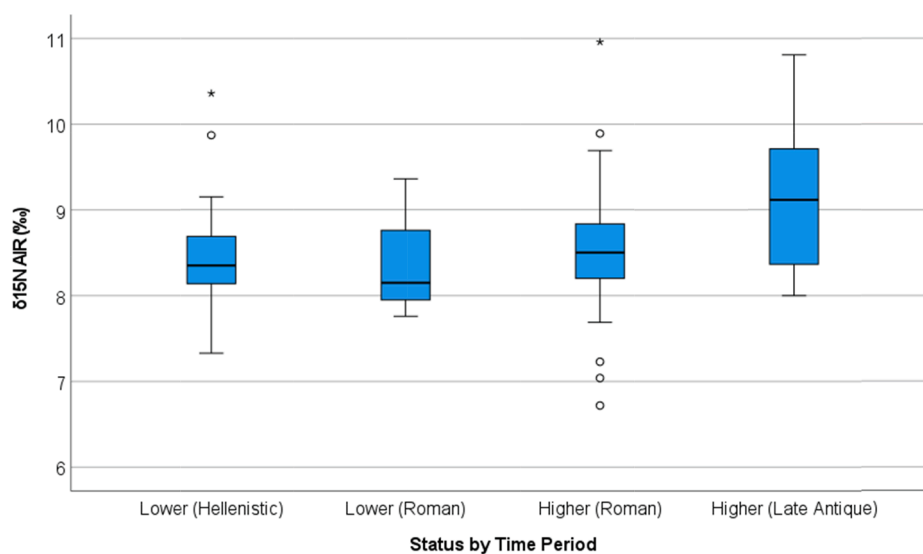


Fig. 5. Box plot of $\delta^{15}\text{N}$ values by social status as inferred from tomb type in each time period. This plot was created in SPSS, where potential outliers are shown as circles and extreme values are indicated by asterisks (*).

4.3 ‰) for the chamber tomb samples.

Despite only having three samples, the Roman stone-lined tomb samples (3rd-4th century CE Sanatorium Basilica cemetery) have noticeably higher mean isotope values, particularly for $\delta^{15}\text{N}$ at 9 ‰ (1 ‰ higher than the tile grave mean). The Late Antique samples are all from higher status tombs and there were no differences detected between the different tomb types, although samples sizes for three of the tomb types are very small.

6. Discussion

6.1. Knossian diets

Local isotopic baseline data are important for the interpretation of human carbon and nitrogen isotope data as plant and faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values can be influenced by climatic and environmental conditions.

Unfortunately, there is a scarcity of well-dated, excavated contexts that include animal bones from Knossos from contemporary time periods. Thus, at present it is not possible to establish a contemporary local faunal isotope baseline. However, plant (Nitsch et al., 2019) and animal (Nafplioti, 2016) isotope values are available from the Knossos vicinity, from Bronze Age contexts, in addition to faunal samples from 6th-7th century Eleutherna, Crete (Bourbou & Garvie-Lok, 2015), contemporary with the Late Antique human samples, and 11th century CE faunal isotope values from Kastella, Crete (Bourbou & Richards, 2007). We use these as a baseline against which the human values can be compared (Fig. 6), with the caveat that this local baseline may have changed over time. Fish bones saved from legacy excavations are even more rare and therefore data from the Mediterranean region are used as a baseline, with the caveat that local fish isotope values may have differed from the wider region. Thus, the interpretations of human palaeodiet are somewhat speculative, and may need to be revised if further excavations



Fig. 6. Scatter plot displaying carbon and nitrogen isotope values. Knossos human values are plotted by time period, including Nafplioti's Bronze Age human samples and the additional Subminoan sample analysed for this study as an intermediate example. Also included are terrestrial fauna from Bronze Age Knossos, 11th century CE Kastella and 6th-7th century CE Eleutherna, Neolithic/Bronze Age charred plant samples from Knossos, and Mediterranean fish remains of various time periods from the Mesolithic (Croatia) to Roman (Velia) to Modern time periods (see section 2 of supplementary material).

provide material and baseline isotope data that differ from the baseline we use here. The human $\delta^{15}\text{N}$ values are more elevated than the faunal values, ranging from +3.2‰ to +7.5‰ above the mean faunal value of 3.5‰, and +2.1‰ to +6.4‰ over the maximum faunal $\delta^{15}\text{N}$ value of 4.6‰. The mean human $\delta^{13}\text{C}$ value of -19.2‰ is also 1.4‰ higher than the mean faunal $\delta^{13}\text{C}$ value of -20.6‰.

The isotopic signatures for most of the studied individuals indicate C3 terrestrial diets with meat or secondary animal products included. However, if an intensive cultivation strategy, known to have elevated plant $\delta^{15}\text{N}$ values in earlier times at the site (Nitsch et al., 2019), existed during these periods, some of the lower $\delta^{15}\text{N}$ values of the present study's human samples may indicate individuals with relatively little animal protein in their diets. The Late Bronze Age terrestrial faunal values (Nafplioti, 2016) largely have lower $\delta^{15}\text{N}$ values than the contemporary cereals, indicating that most of this sample of livestock was not raised on manured cereals. The wide-ranging animal bone stable isotope values may account for some of the variability in the human values. If the Hellenistic, Roman and Late Antique livestock values were similar to these, the human isotope values in the present sample would indicate that most individuals had some terrestrial animal foods in their diets.

The results suggest that even the individuals with lower $\delta^{15}\text{N}$ values still had occasional access to animal products but are likely to have subsisted off a largely vegetarian diet much of the time. This demonstrates that animal products were not a very rare feature in any diet within the sample, despite the fact that meat was generally a prestigious product, as even the lowest human $\delta^{15}\text{N}$ value ($\delta^{15}\text{N}$ 6.7‰) is 3.2‰ higher than the mean faunal $\delta^{15}\text{N}$ value. Written accounts and the archaeological record for most premodern, agricultural populations (as well as ethnographic studies of subsistence farming in developing countries) suggest that the amount of animal products would have been fairly modest (compared to modern Western expectations of meat consumption) and staple crops, such as wheat and barley, would have provided the bulk of the diet (Dewey, 1979; Erdkamp & Holleran, 2019; Foxhall & Forbes, 1982; Garnsey, 1988, 1999).

The higher $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values in some samples, above the expectations of a terrestrial food chain (those above approximately $\delta^{13}\text{C}$ -19‰ and $\delta^{15}\text{N}$ 9.5‰), indicate some marine food consumption, as marine food chains are much longer and result in more elevated $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (Craig et al., 2006; Richards & Hedges, 1999; Vander Zanden & Fetzer, 2007). As no site-specific fish or seafood isotope data exist, we compare the results to other stable isotope values available for Mediterranean sea and river fish (Craig et al., 2009; Garvie-Lok, 2001; Lightfoot et al., 2011; Vika & Theodoropoulou, 2012), which demonstrate very wide-ranging isotope values. None of the $\delta^{15}\text{N}$ values in the present study reach the 11.5‰ marine-terrestrial boundary recommended by Salamon et al. (2008) but other studies have discussed the wide range of marine organism values and the difficulty in detecting low trophic level fish in the diet (Lightfoot et al., 2012; Vika & Theodoropoulou, 2012). Additionally, 10‰ is the cut-off that Papatheanasiou and Richards (2015) have used for identifying a significant marine component in the diet. This indicates the importance of having local faunal values as a site-specific indicator of where terrestrial human values would be expected to lie.

6.2. Time periods

The slight increase in $\delta^{13}\text{C}$ values between the Hellenistic and Roman period may represent either the introduction of a small amount of C4 plant (likely millet), a small amount of marine food, or very low trophic level marine foods into some Roman diets, all archaeologically credible explanations. Millet could be grown in dry conditions that would not have suited wheat; therefore, with the shift towards a drier climate during the Roman period, millet may have been introduced as a secondary crop. Millet is known to have been cultivated in Campania (Spurr, 1983) and it could have been transferred to the 'Capuan

territories' as a back-up crop at the time this land to the south of Knossos was granted to Capua by Augustus (Baldwin Bowsky, 1997). While millet is known at Roman sites in Greece, including Sparta (Waywell et al., 1997) and Corinth (Willett, 2012), archaeobotanical studies at most sites have not been extensive enough to track a detailed history of the spread of millet in Greece. Despite a distinct lack of thoroughly excavated (involving fine sieving of soil) domestic contexts at Knossos or zooarchaeological studies, fish bones and shells of marine molluscs and crustaceans have been reported from Roman contexts at Knossos (Bedwin, 1992; Reese, 1992). Such finds are attested throughout Crete in addition to the evidence of Roman rock-cut fish tanks (Davaras, 1974; Francis, 2010; Mylona, 2003a, 2003b).

For the Early Roman period specifically, the presence of lower $\delta^{15}\text{N}$ values may suggest the consumption of less animal protein. If this assemblage only represented the years following the Roman invasion, such a result might be explicable in terms of economic hardship but as it represents more than two centuries of relative prosperity after the foundation of the colony, it seems more likely that this is a product of the small sample size and that meat consumption did not change significantly in the early Roman period. Meat, offal, milk and other animal products are attested in Roman literary sources to have played important roles in both daily diet and ritual contexts and similar types of animal bone assemblages are found in neighbourhoods of different social standing in Roman urban contexts (Halstead, 2019).

The higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values observed in the Late Antique samples, compared to the earlier time periods, suggest a small but consistent change in diet. The isotope data indicates a greater animal protein component in the diet and it is likely that this involved an increased (though still modest) amount of seafood. This elevation in values was a gradual process starting in the 3rd or 4th century CE. This suggests that the shift in dietary habits may have been influenced by Christian asceticism. The later Roman and Late Antique graves are largely considered to be Christian graves due to either their association with a basilica church or their orientation, treatment of the body, grave architecture and lack of grave goods (Frend & Johnston, 1962; Sweetman & Becker, 2005). There are other possible reasons for increased fish consumption, such as developments in fish preservation techniques, changes in attitudes towards the sea and sea life, or new trading partners or networks, as has been attested at other Roman and Medieval sites across the Mediterranean and Europe (McCormick, 2001; Salamon et al., 2008; Van Neer & Eryvynck, 2004). However, the widespread adoption of Christianity and its fasting calendar coincides with the phenomenon at a number of sites in Crete, around the Mediterranean and across Europe (Bourbou, 2010; Bourbou et al., 2011; Bourbou & Richards, 2007; Garvie-Lok, 2001; McConnan Borstad et al., 2018; Polet & Katzenberg, 2003; Reitsema et al., 2016; Rutgers et al., 2009). Changes in diet at this time could also have been due to the easing of pressure on resources or on the administration and distribution of food due to the reduction in settlement and population size.

The suggestion of a fall in protein consumption in the Early Roman period is also seen in a sample from Athens (Lagia, 2015), which is a useful comparison as another large urban centre that was well-connected within Mediterranean networks. The increase in carbon and nitrogen isotope values from the Late Roman period onwards demonstrates that Knossos does not fit the trend of having increased protein consumption in times of economic and cultural growth and prosperity, which appear to be in decline throughout the Late Roman and Late Antique periods, as indicated by the reduction of population, lack of building projects and relative lack and diversity of artefacts.

6.3. Sex and age

The lack of sex-based isotopically-identifiable dietary differences at Knossos is similar to that found at other comparable sites, such as Late Roman Leptiminus in Tunisia and Classical to Roman Athens in Greece (Keenleyside et al., 2009; Lagia, 2015). However, this does not

necessarily mean that dietary differences did not exist as it is not possible for isotope data to discern between different cuts of meat or between meat and other animal products. The Roman and Late Antique females did have a wider range of $\delta^{15}\text{N}$ values compared to the males, which indicates that the women had access to different resources and a more varied diet than men. The greater involvement of men in religious festivals and ritual institutions surrounding food may account for the greater homogeneity of male $\delta^{15}\text{N}$ results compared to the females. It could also indicate that women were more likely to experience periods of nutritional stress, linked to their reproductive status, which could impact $\delta^{15}\text{N}$ values (Fuller et al., 2004; Nitsch et al., 2010). The two highest Late Antique $\delta^{15}\text{N}$ values (S71: $\delta^{13}\text{C} = -18.1\text{‰}$, $\delta^{15}\text{N} = 10.1\text{‰}$, S78: $\delta^{13}\text{C} = -19.4\text{‰}$, $\delta^{15}\text{N} = 10.8\text{‰}$) were both females and these elevated $\delta^{15}\text{N}$ values may be attributed to such nutritional stress or to fish consumption. The same pattern was not detected for the Hellenistic period with both males and females having comparatively narrow ranging values, other than two outliers (one male and one of unknown sex), suggesting a more homogenous diet.

There were no isotopically detectable differences between the diets of individuals from different age groups, which is not an uncommon finding for the period and wider region. However, at both Athens and Isola Sacra it was observed that older adults had more elevated $\delta^{15}\text{N}$ values (Lagia, 2015; Prowse et al., 2005), demonstrating that significant differences have been detected between adults of different ages in comparable populations.

6.4. Status

The Roman samples that came from the higher status tombs did not portray individuals with superior diets in the form of greater access to protein or the inclusion of fish. The stone-lined tombs had the samples with the most elevated values. This may simply be due to the time period and associated social changes as discussed in section 6.2 but may also represent a particular social group being buried in association with two of the basilica churches at the site (Frend & Johnston, 1962; Sweetman & Becker, 2005).

Two outlier values (S22 and S31) are particularly likely to indicate some fish consumption considering the level of elevation in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ over the terrestrial faunal values. The individual with the most elevated carbon signal (S22: $\delta^{13}\text{C} = -16.1\text{‰}$, $\delta^{15}\text{N} = 9.9\text{‰}$), was a Young Adult of Unknown sex, buried in a Late Hellenistic tile grave. This is one of the simplest grave types, unlikely to represent a higher status individual. This sample, as well as S54 (a Hellenistic Adult Male from a pit grave: $\delta^{13}\text{C} = -18.3\text{‰}$, $\delta^{15}\text{N} = 10.4\text{‰}$), suggest that fish was a dietary option in the Hellenistic period but that it was not widely available throughout the population. S31 ($\delta^{13}\text{C} = -17.6\text{‰}$, $\delta^{15}\text{N} = 11.0\text{‰}$), was a Roman Young Adult Female, buried in a more elaborate rock-cut chamber tomb. Four other samples from individuals in the same tomb had remarkably different values to this outlier, implying C3 terrestrial diets that included meat consumption but with no significant contribution from marine resources. The fact that only one out of five analysed individuals, buried in this tomb, had fish in her diet, suggests that it was unlikely to be social status that allowed her access to seafood, or at least not solely so. For both these outliers, seafood consumption may have been personal preference, occupation related, or a result of migration from somewhere where seafood played a greater role in the diet.

7. Conclusion

The Knossian diet in all time periods was based on C3 plants and usually included some C3 animal products, though conclusions remain tentative due to the lack of contemporary animal bone comparatives at the site. Fish consumption appears limited in most diets but there was a slight increase in marine organism consumption in the later Roman and Late Antique periods. While this may be linked to economic changes, the

widespread pattern across Europe of increased fish consumption being linked to Christian fasting rules is likely the primary factor for this change.

The most significant differences in diets at Knossos are between the different time periods due to the socio-economic changes that were occurring. The data do not fit with the pattern of higher animal protein consumption in times of economic and cultural growth and prosperity. The greater dietary variability observed in female samples from the Roman and Late Antique periods suggests that female diets may have been less regulated by cultural or religious practices relating to food consumption when compared to men. Any differentiation by social status that existed was not manifest in the diet (or is not detectable isotopically), or the present sample represents a homogeneous social group within each time period.

Knossos was a well-connected centre in wider Mediterranean networks and these connections intensified in the Roman period when Knossos became a colony. Future investigations into the place of origin of individuals at Knossos using strontium and oxygen stable isotope analyses would enable the importance of incoming populations, external connections and colonialism to be assessed in these differences in diet.

CRediT authorship contribution statement

Anna C. Moles: Conceptualization, Funding acquisition, Formal analysis, Methodology, Visualization. **Hazel Reade:** Supervision, Formal analysis, Methodology, Visualization. **Anne-Lise Jourdan:** Supervision, Formal analysis, Methodology, Visualization. **Rhiannon E. Stevens:** Supervision, Formal analysis, Methodology, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This article derives from a chapter of the primary author's PhD thesis. Simon Hillson, Todd Whitelaw, Julia Beaumont, Dan Stewart and Rebecca Sweetman are thanked for their advice on this research. Thanks go to the Heraklion Ephoreia and Heraklion Museum for the sampling permission, and to the British School at Athens for the permission to study and publish the skeletal material, in particular Kostis Christakis, Tania Gerousi, Amalia Kakissis and Matthew Haysom.

Funding

Anna Moles was funded by a London Arts and Humanities Partnership AHRC Studentship (Award ref. 1459301), the Richard Bradford McConnell Studentship at the British School at Athens, and an Onassis Foundation Fellowship.

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2022.103609>.

References

- Ager, S.L., 1994. Hellenistic Crete and KOINOΔΙΚION. *J. Hellenic Stud.* 114, 1–18. <https://doi.org/10.2307/632730>.
- Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *J. Archaeol. Sci.* 17 (4), 431–451. [https://doi.org/10.1016/0305-4403\(90\)90007-R](https://doi.org/10.1016/0305-4403(90)90007-R).
- Ambrose, S.H., 1993. Diet reconstruction with stable isotopes. In: Standford, M.K. (Ed.), *Investigations of Ancient Human Tissue Chemical Analysis in Anthropology*. Gordon and Breach, pp. 59–130.

- Baldwin Bowsky, M.W., 1997. Knossos and Campanian the Critical Connection. In: Preliminary Publication XI International Congress of Greek and Latin Epigraphy, Rome, 18-24 September 1997, 479-487.
- Bedwin, O., 1992. Appendix I: The Animal Bones. In: Sackett, L.H. (Ed.), Knossos: from Greek City to Roman Colony. Excavations at the Unexplored Mansion II (pp. 491-492). British School at Athens; Thames and Hudson; Alden Press.
- Bernard, S.G., 2016. Food Distributions and Immigration in Imperial Rome. In: Lo Cascio, E., Tacoma, L.E. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, pp. 50-71. https://doi.org/10.1163/9789004307377_005.
- Bird, M.I., Crabtree, S.A., Haig, J., Ulm, S., Wurster, C.M., 2021. A global carbon and nitrogen isotope perspective on modern and ancient human diet. *Proc. Natl. Acad. Sci.* 118 (19), e2024642118 <https://doi.org/10.1073/pnas.2024642118>.
- Bocherens, H., Drucker, D., 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *Int. J. Osteoarchaeol.* 13 (1-2), 46-53. <https://doi.org/10.1002/oa.662>.
- Bogaard, A., Heaton, T.H.E., Poulton, P., Merbach, I., 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *J. Archaeol. Sci.* 34 (3), 335-343. <https://doi.org/10.1016/j.jas.2006.04.009>.
- Bourbou, C., 2010. Health and Disease in Byzantine Crete (7th-12th Centuries AD). Ashgate Publishing.
- Bourbou, C., Fuller, B.T., Garvie-Lok, S.J., Richards, M.P., 2011. Reconstructing the Diets of Greek Byzantine Populations (6th-15th Centuries AD) Using Carbon and Nitrogen Stable Isotope Ratios. *Am. J. Phys. Anthropol.* 146 (4), 569-581. <https://doi.org/10.1002/ajpa.21601>.
- Bourbou, C., Garvie-Lok, S., 2015. Bread, oil, wine, and milk : feeding infants and adults in Byzantine Greece. In: Papanthasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction From Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 171-194.
- Bourbou, C., Richards, M.P., 2007. The Middle Byzantine menu: palaeodietary information from isotopic analysis of humans and fauna from Kastella, Crete. *Int. J. Osteoarchaeol.* 17 (1), 63-72. <https://doi.org/10.1002/oa.855>.
- Brooks, S., Suchey, J.M., 1990. Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. *Hum. Evol.* 5 (3), 227-238. <https://doi.org/10.1007/BF02437238>.
- Brothwell, D.R., 1989. The Relationship of Tooth Wear to Ageing. In: İşcan, M.Y. (Ed.), *Age Markers in the Human Skeleton*. Charles C. Thomas, pp. 303-316.
- Buikstra, J.E., Ubelaker, D.H., 1994. Standards for Data Collection from Human Skeletal Remains. *Arkansas Archeol. Survey Res. Ser. No.* 44.
- Callaghan, P.J., 1992. Archaic to Hellenistic Pottery. In: Sackett, L.H. (Ed.), *Knossos: From Greek City to Roman Colony*. Excavations at the Unexplored Mansion II. British School at Athens, pp. 89-136.
- Cankardeş-Şenol, G., 2007. Stamped Amphora Handles Found in the Rescue Excavations of CEAlex in Alexandria. In S. Marchand & A. Marangou (Eds.), *Amphores D'Égypte. De La Basse époque à L'époque Arabe* (pp. 33-56). Institut français d'archéologie orientale.
- Carlington Smith, J., Wall, S., 1994. A late hellenistic wine press at knossos. *Ann. Brit. School Athens* 89, 359-376.
- Carrier, C., 2018. Knossos De L'époque Classique À L'époque Impériale (Ve siècle avant J.-C - Ier siècle après J.-C.). Université Paris-Sorbonne PhD thesis.
- Cerling, T.E., Harris, J.M., MacFadden, B.J., Leakey, M.G., Quade, J., Eisenmann, V., Ehleringer, J.R., 1997. Global vegetation change through the Miocene/Pliocene boundary. *Nature* 389 (6647), 153-158. <https://doi.org/10.1038/38229>.
- Chaniotis, A., 1999. Milking the Mountains: Economic Activities on the Cretan Uplands in the Classical and Hellenistic Period. In: Chaniotis, A. (Ed.), *From Minoan Farmers to Roman Traders: Sidelines on the Economy of Ancient Crete*. FranzSteiner Verlag, pp. 181-220.
- Chaniotis, A., 2005. Inscribed instrumenta domestica and the economy of Hellenistic and Roman Crete. In: Archibald, Z.H., Davies, J.K., Gabrielsen, V. (Eds.), *Making, moving, and managing. The new world of ancient economies* (pp. 92-116). Oxbow.
- Coldstream, J.N., Eiring, L.J., Forster, G., 2001. Knossos Pottery Handbook: Greek and Roman. British School at Athens.
- Craig, O.E., Biazzo, M., Tafuri, M.A., 2006. Palaeodietary records of Coastal Mediterranean populations. *J. Mediterranean Stud.* 16, 63-77.
- Craig, O.E., Biazzo, M., O'Connell, T.C., Garnsey, P., Martinez-Labarga, C., Lelli, R., Salvadei, L., Tartaglia, G., Nava, A., Renò, L., Fiammenghi, A., Rickards, O., Bondioli, L., 2009. Stable isotopic evidence for diet at the Imperial Roman coastal site of Velia (1st and 2nd Centuries AD) in Southern Italy. *Am. J. Phys. Anthropol.* 139 (4), 572-583. <https://doi.org/10.1002/ajpa.21021>.
- Cubas, M., Peyroteo-Stjerna, R., Fontanals-Coll, M., Llorente-Rodríguez, L., Lucquin, A., Craig, O.E., Colonese, A.C., 2019. Long-term dietary change in Atlantic and Mediterranean Iberia with the introduction of agriculture: a stable isotope perspective. *Archaeol. Anthropol. Sci.* 11 (8), 3825-3836. <https://doi.org/10.1007/s12520-018-0752-1>.
- Dalby, A., 2003. *Food in the Ancient World from A to Z*. Routledge.
- Davaras, C., 1974. Rock-cut fish tanks in eastern crete. *Ann. Brit. School Athens* 69, 87-93.
- DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317 (6040), 806-809. <https://doi.org/10.1038/317806a0>.
- Dewey, K.G., 1979. Agricultural Development, Diet and Nutrition. *Ecol. Food Nutr.* 8 (4), 265-273. <https://doi.org/10.1080/03670244.1979.9990576>.
- Dibble, F., 2017. *Politika Zoa: Animals and Social Change in Ancient Greece (1600-300 B.C.)*. University of Cincinnati. PhD thesis.
- Efstratiou, N., Karetso, A., Banou, E.S., Margomenou, D., 2004. The Neolithic settlement of Knossos: new light on an old picture. In: Cadogan, G., Hatzaki, E., Vasilakis, A. (Eds.), *Palace, City, State*. British School at Athens Studies, Vol. 12. British School at Athens, pp. 39-49.
- Empereur, J.-Y., Marangou, A.A., Papadakis, N., 1992. Recherches sur les amphores crétoises (III). *Bulletin de Correspondance Hellénique*, 116(2), 633-648. <https://doi.org/10.3406/bch.1992.4670>.
- Erdkamp, P., Holleran, C., 2019. *The Routledge Handbook of Diet and Nutrition in the Roman World*. Routledge.
- Evans, A.J., 1935. The Palace of Minos: a comparative account of the successive stages of the early Cretan civilization as illustrated by the discoveries at Knossos Vol. 4 (2).
- Fernandes, R., Nadeau, M.-J., Grootes, P.M., 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. *Archaeol. Anthropol. Sci.* 4 (4), 291-301. <https://doi.org/10.1007/s12520-012-0102-7>.
- Forster, G., 2009. Roman Knossos: the Pottery in Context. A Presentation of Ceramic Evidence Provided by the Knossos 2000 Project (1993-95). PhD thesis, University of Birmingham.
- Foxhall, L., Forbes, H.A., 1982. Sitometreia: the role of grain as a staple food in classical antiquity. *Chiron* 12, 41-90.
- Francis, J.E., 2010. A re-evaluation of rock-cut fish installations in roman crete. *Creta Antica* 11, 255-277.
- Francis, J.E., 2016. Apiculture in Roman Crete. In: Francis, J.E., Kouremenos, A. (Eds.), *Roman Crete: New Perspectives*. Oxbow, pp. 83-100.
- Friend, W.H.C., Johnston, D.E., 1962. The Byzantine basilica church at Knossos. *Ann. Brit. School Athens* 57, 186-238.
- Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., Hedges, R.E.M., 2004. Nitrogen balance and $\delta^{15}N$: why you're not what you eat during pregnancy. *Rapid Commun. Mass Spectrom.* 18, 2889-2896.
- Fuller, B.T., Müldner, G., Van Neer, W., Ervynck, A., Richards, M.P., 2012. Carbon and nitrogen stable isotope ratio analysis of freshwater, brackish and marine fish from Belgian archaeological sites (1st and 2nd millennium AD). *J. Anal. At. Spectrom.* 27 (5), 807-820. <https://doi.org/10.1039/C2JA10366D>.
- Gagarin, M., Perlman, P.J., 2016. *The Laws of Ancient Crete c.650-400 BCE*. (Oxford). Oxford University Press.
- Gallimore, S., 2015. *An Island Economy: Hellenistic and Roman Pottery from Hierapytna*. Peter Lang, Crete.
- Gallimore, S., 2016. Crete's economic transformation in the late Roman Empire. In: Francis, J.E., Kouremenos, A. (Eds.), *Roman Crete: New Perspectives*. Oxbow, pp. 175-188.
- Gallimore, S., 2019. An island in crisis? Reconsidering the formation of roman crete. *Am. J. Archaeol.* 123 (4), 589. <https://doi.org/10.3764/aja.123.4.0589>.
- García-Guixé, E., Subirà, M.E., Marlasca, R., Richards, M.P., 2010. $\delta^{13}C$ and $\delta^{15}N$ in ancient and recent fish bones from the Mediterranean Sea. *J. Nordic Archaeol. Sci.* 17, 83-92.
- Garnsey, P., 1988. *Famine and Food Supply in the Graeco-Roman World*. Cambridge University Press.
- Garnsey, P., 1999. *Food and Society in Classical Antiquity*. Cambridge University Press.
- Garvie-Lok, S.J., 2001. *Loaves and Fishes: A Stable Isotope Reconstruction of Diet in Medieval Greece*. University of Calgary. PhD thesis.
- Guarducci, M. (Ed.), 1935. *Cnosos. In: Inscriptiones Creticae I. Opera et consilio Friderici Halbherr collectae* (pp. 45-82). La Libreria dello Stato.
- Guizzi, F., 1999. Private economic activities in Hellenistic Crete: the evidence of the isopoliteia treaties. In: Chaniotis, A. (Ed.), *From Minoan Farmers to Roman Traders: Sidelines on the Economy of Ancient Crete*. F. Steiner, pp. 235-245.
- Halstead, P., 2008. Between a Rock and a Hard Place: Coping with Marginal Colonisation in the Later Neolithic and Early Bronze Age of Crete and the Aegean. In: Isaakidou, V., Tompkins, P.D. (Eds.), *Escaping the Labyrinth: The Cretan Neolithic in Context*. Oxbow Books.
- Halstead, P., 2019. The Contribution of Zooarchaeology. In: Erdkamp, P., Holleran, C. (Eds.), *The Routledge Handbook of Diet and Nutrition in the Roman World*. Routledge, pp. 64-76. <https://doi.org/10.4324/9781351107334-6>.
- Hayes, J.W., 1971. Four early roman groups from knossos. *Ann. Brit. School Athens* 66, 249-275. <https://doi.org/10.1017/S0068245400019183>.
- Hayes, J.W., 1983. The villa dionysos excavations, knossos: the pottery. *Ann. Brit. School Athens* 78, 97-169.
- Hayes, J.W., 2001. Early christian pottery from knossos: the 1978-1981 finds from the knossos medical faculty site. *Ann. Brit. School Athens* 96, 431-454. <https://doi.org/10.1017/S0068245400005372>.
- Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J. Archaeol. Sci.* 34 (8), 1240-1251. <https://doi.org/10.1016/j.jas.2006.10.015>.
- Iezzi, C.A., 2015. Existence and subsistence in Mycenaean era East Lokris: the isotopic evidence. In: Papanthasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction From Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 89-104.
- Jones, G., 1984. Appendix 1: The LM II Plant Remains. In: Popham, M.R., Bett, J.H., Cameron, M., Catling, H.W., Evely, D., Higgins, R.A., Smyth, D. (Eds.), *The Minoan Unexplored Mansion at Knossos* (pp. 303-306). The British School at Athens. Supplementary Volumes, No. 17.
- Katzenberg, M.A., 2008. Stable isotope analysis: a tool for studying past diet, demography, and life history. In: Katzenberg, M.A., Saunders, S.R. (Eds.), *Biological Anthropology of the Human Skeleton*, (2nd ed.). John Wiley & Sons, pp. 413-442.
- 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. *J. Archaeol. Sci.* 36 (1), 51-63. <https://doi.org/10.1016/j.jas.2008.07.008>.
- Knipper, C., Held, P., Fecher, M., Nicklisch, N., Meyer, C., Schreiber, H., Zich, B., Metzner-Nebelsick, C., Hubensack, V., Hansen, L., Nieveler, E., Alt, K.W., 2015. Superior in Life—Superior in death: dietary distinction of central european

- prehistoric and medieval elites. *Curr. Anthropol.* 56 (4), 579–589. <https://doi.org/10.1086/682083>.
- Knipper, C., Rihuete-Herrada, C., Voltas, J., Held, P., Lull, V., Micó, R., Risch, R., Alt, K. W., 2020. Reconstructing Bronze Age diets and farming strategies at the early Bronze Age sites of La Bastida and Gatas (southeast Iberia) using stable isotope analysis. *PLoS ONE* 15 (3), e0229398.
- Lagia, A., 2015. Diet and the Polis: An Isotopic Study of Diet in Athens and Laurion during the Classical, Hellenistic, and Imperial Roman Periods. In: Papatathanasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 119–146.
- Lee-Thorpe, J.A., 2008. On Isotopes and Old Bones. *Archaeometry* 50 (6), 925–950. <https://doi.org/10.1111/j.1475-4754.2008.00441.x>.
- Lightfoot, E., Boneva, B., Miracle, P.T., Slaus, M., O'Connell, T.C., 2011. Exploring the Mesolithic and Neolithic transition in Croatia through isotopic investigations. *Antiquity* 85 (327), 73–86. <https://doi.org/10.1017/S0003598X00067442>.
- Lightfoot, E., Slaus, M., O'Connell, T.C., 2012. Changing cultures, changing cuisines: cultural transitions and dietary change in iron age, roman, and early medieval croatia. *Am. J. Phys. Anthropol.* 148 (4), 543–556. <https://doi.org/10.1002/ajpa.22070>.
- Lightfoot, E., Slaus, M., Šikanjić, P.R., O'Connell, T.C., 2015. Metals and millets: Bronze and Iron Age diet in inland and coastal Croatia seen through stable isotope analysis. *Archaeol. Anthropol. Sci.* 7 (3), 375–386. <https://doi.org/10.1007/s12520-014-0194-3>.
- Livarda, A., 2012. The archaeobotanical evidence of the late bronze age and protohistoric occupation under the villa diionysus, knossos, crete, and an overview of the protohistoric data of Greece. *Ann. Brit. School Athens* 107, 189–209. <https://doi.org/10.1017/S0068245412000068>.
- Livarda, A., 2014. Archaeobotany in Greece. *Archaeol. Rep.* 60, 106–116. <https://doi.org/10.1017/S057060841400012X>.
- Livarda, A., Kotzamani, G., 2013. The Archaeobotany of Neolithic and Bronze Age Crete: Synthesis and Prospects. *Ann. Brit. School Athens* 108, 1–29.
- Lovejoy, C.O., 1985. Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. *Am. J. Phys. Anthropol.* 68 (1), 47–56. <https://doi.org/10.1002/ajpa.1330680105>.
- Lovejoy, C.O., Meindl, R.S., Pryzbeck, T.R., Mensforth, R.P., 1985. Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. *Am. J. Phys. Anthropol.* 68 (1), 15–28. <https://doi.org/10.1002/ajpa.1330680103>.
- Lubell, D., Jackes, M., Schwarcz, H., Knyf, M., Meiklejohn, C., 1994. The mesolithic-neolithic transition in Portugal: isotopic and dental evidence of diet. *J. Archaeol. Sci.* 21 (2), 201–216. <https://doi.org/10.1006/jasc.1994.1022>.
- Makarewicz, C.A., Sealy, J.C., 2015. Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: Expanding the prospects of stable isotope research in archaeology. *J. Archaeol. Sci.* 56, 146–158.
- Marangou, A., 1999. Wine in the Cretan Economy. In: Chaniotis, A. (Ed.), *From Minoan Farmers to Roman Traders: Sidelines on the Economy of Ancient Crete*. Franz Steiner Verlag, pp. 269–278.
- Margaritis, E., Jones, M.K., 2009. Greek and Roman Agriculture. In: Oleson, J.P. (Ed.), *The Oxford Handbook of Engineering and Technology in the Classical World*. Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780199734856.013.0008>.
- McConnan Borstad, C., Garvie-Lok, S., Katsonopoulou, D., 2018. Diet at ancient Helike, Achaia, Greece based on stable isotope analysis: From the Hellenistic to the Roman and Byzantine periods. *J. Archaeol. Sci. Rep.* 18, 1–10. <https://doi.org/10.1016/j.jasrep.2017.12.007>.
- McCormick, M., 2001. Origins of the European economy. *Communications and Commerce*. A.D. 300–900. Cambridge University Press.
- Miles, A.E.W., 1963. Dentition in the estimation of age. *J. Dent. Res.* 42 (1), 255–263. <https://doi.org/10.1177/00220345630420012701>.
- Moles, A.C., 2019. Urbanism and its impact on human health: a long-term study at Knossos, Crete. University College London. PhD thesis.
- Murphy, C., 2016. Finding millet in the Roman world. *Archaeol. Anthropol. Sci.* 8 (1), 65–78. <https://doi.org/10.1007/s12520-015-0237-4>.
- Mylona, D., 2003a. Archaeological fish remains in Greece: general trends of the research and a gazetteer of sites. In *British School at Athens Studies* (Vol. 9, pp. 193–200). British School at Athens. <https://doi.org/10.2307/40960346>.
- Mylona, D., 2003b. Fishing in late antiquity: the case of Itanos, Crete. In: *British School at Athens Studies* (Vol. 9, pp. 103–110). British School at Athens. <https://doi.org/10.2307/40960337>.
- Nafplioti, A., 2016. Eating in prosperity: first stable isotope evidence of diet from Palatial Knossos. *J. Archaeol. Sci. Rep.* 6, 42–52. <https://doi.org/10.1016/j.jasrep.2016.01.017>.
- Nitsch, E.K., Humphrey, L.T., Hedges, R.E.M., 2010. The effect of parity status on $\delta^{15}N$: looking for the “pregnancy effect” in 18th and 19th century London. *J. Archaeol. Sci.* 37 (12), 3191–3199. <https://doi.org/10.1016/j.jas.2010.07.019>.
- Nitsch, E.K., Jones, G., Sarpaki, A., Hald, M., Bogaard, A.M., 2019. Farming Practice and Land Management at Knossos, Crete: New Insights from $\delta^{13}C$ and $\delta^{15}N$ Analysis of Neolithic and Bronze Age Crop Remains. In: Garcia, D., Orgelet, R., Pomadere, M., Zurbach, J. (Eds.), *Country in the City: Agricultural Functions of Protohistoric Urban Settlements (Aegean and Western Mediterranean)*. Archaeopress, pp. 159–174.
- O'Connell, T.C., Kneale, C.J., Tasevska, N., Kuhnle, G.G.C., 2012. The diet-body offset in human nitrogen isotopic values: A controlled dietary study. *Am. J. Phys. Anthropol.* 149 (3), 426–434. <https://doi.org/10.1002/ajpa.22140>.
- Papathanasiou, A., 2015. Stable isotope analyses in Neolithic and Bronze Age Greece: an overview. In: Papatathanasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 25–56.
- Papathanasiou, A., Richards, M.P., 2015. Patterns in the carbon and nitrogen isotope data through time. In: Papatathanasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 195–204.
- Papathanasiou, A., Richards, M.P., Fox, S.C., 2015. Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis. In *Hesperia Supplement 49*. American School of Classical Studies at Athens.
- Paton, S., 1994. Roman Knossos and the Colonia Julia Nobilis Cnossus. In: Evely, D., Hughes-Brock, H., Momigliano, N. (Eds.), *Knossos, a labyrinth of history : papers presented in honour of Sinclair Hood*. British School at Athens, pp. 141–154.
- Paton, S. (2004). Knossos: an imperial renaissance. In G. Cadogan, E. Hatzaki, & A. Vasilakis (Eds.), *Knossos: Palace, City, State* (Issue 12, pp. 451–455). British School at Athens.
- Perlman, P., 1992. One Hundred-Cityed Crete and the “Cretan ΠΟΛΙΤΕΙΑ”. In *Classical Philology* Vol. 87, 193–205.
- The Imaginary Polis Issue 7, 2005, 282–334.
- Polet, C., Katzenberg, M.A., 2003. Reconstruction of the diet in a mediaeval monastic community from the coast of Belgium. *J. Archaeol. Sci.* 30 (5), 525–533. [https://doi.org/10.1016/S0305-4403\(02\)00183-8](https://doi.org/10.1016/S0305-4403(02)00183-8).
- Privat, K.L., O'Connell, T.C., Richards, M.P., 2002. Stable isotope analysis of human and faunal remains from the anglo-saxon cemetery at berinsfield, oxfordshire: dietary and social implications. *J. Archaeol. Sci.* 29 (7), 779–790. <https://doi.org/10.1006/jasc.2001.0785>.
- Prowse, T.L., Schwarz, H.P., Saunders, S.R., Macchiarelli, R., Bondioli, L., 2005. Isotopic evidence for age-related variation in diet from Isola Sacra, Italy. *Am. J. Phys. Anthropol.* 128 (1), 2–13. <https://doi.org/10.1002/ajpa.20094>.
- Reese, D.S., 1992. Appendix 2: Recent and Fossil Marine Invertebrates. In: Sackett, L.H. (Ed.), *Knossos: from Greek City to Roman Colony*. British School at Athens, pp. 493–496.
- Reitsema, L.J., Vercellotti, G., Boano, R., 2016. Subadult dietary variation at Trino Vercellese, Italy, and its relationship to adult diet and mortality. *Am. J. Phys. Anthropol.* 160 (4), 653–664. <https://doi.org/10.1002/ajpa.22995>.
- Richards, M.P., Hedges, R.E.M., 1999. Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe. *J. Archaeol. Sci.* 26 (6), 717–722. <https://doi.org/10.1006/jasc.1998.0387>.
- Richards, M.P., Hedges, R.E.M., 2008. Stable Isotope Evidence of Past Human Diet at the Sites of the Neolithic Cave of Gerani, the Late Minoan III cemetery of Armenoi, Grave Circles A and B at the Palace Site of Mycenae; and the Late Helladic Chamber Tombs. In: Tzedakis, Y., Martlew, H., Jones, M. (Eds.), *Archaeology Meets Science: Biomolecular Investigations in Bronze Age Greece*. Oxbow, pp. 220–230.
- Rutgers, L.V.V., 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. *J. Archaeol. Sci.* 36 (5), 1127–1134. <https://doi.org/10.1016/j.jas.2008.12.015>.
- Salamon, M., Coppa, A., McCormick, M., Rubini, M., Vargiu, R., Tuross, N., 2008. The consilience of historical and isotopic approaches in reconstructing the medieval Mediterranean diet. *J. Archaeol. Sci.* 35 (6), 1667–1672. <https://doi.org/10.1016/j.jas.2007.11.015>.
- Sallares, R., 1991. *The Ecology of the Ancient Greek World*. Cornell University Press.
- Schoeninger, M.J., 1989. Prehistoric human diet. In: Price, T.D. (Ed.), *Chemistry of Prehistoric Human Bone*. Cambridge University Press, pp. 38–67.
- Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim. Cosmochim. Acta* 48 (4), 625–639. [https://doi.org/10.1016/0016-7037\(84\)90091-7](https://doi.org/10.1016/0016-7037(84)90091-7).
- Smith, B.H., 1984. Patterns of molar wear in hunter-gatherers and agriculturalists. *Am. J. Phys. Anthropol.* 63, 39–56.
- Spurr, M.S., 1983. The Cultivation of Millet in Roman Italy. *Papers Brit. School Rome* 51, 1–15.
- Sweetman, R.J., 2004a. Late Antique Knossos. Understanding the city: evidence of mosaics and religious architecture. *Ann. Brit. School Athens* 99, 339–354.
- Sweetman, R.J., 2004b. The changing nature of Knossos: Roman to Late Antique – some problems. In: Cadogan, G., Hatzaki, E., Vasilakis, A. (Eds.), *Knossos: Palace, City, State*. British School at Athens, pp. 481–488.
- Sweetman, R.J., 2007. Roman Knossos: the nature of a Globalized city. *Am. J. Archaeol.* 111 (1), 61–82.
- Sweetman, R.J., Becker, M.J., 2005. Knossos medical faculty site: late antique graves and other remains. *Ann. Brit. School Athens* 100, 331–386.
- Sweetman, R.J., Grigoropoulos, D., 2010. Roman knossos: discovering the city through the evidence of rescue excavations. *Ann. Brit. School Athens* 105, 339–379.
- Trainor, C., 2016. Daily Life at Hellenistic Knossos: A View from the KWW77 Excavations. *The Enigma of Late Hellenistic and Roman Crete: Unanswered Questions*. University of Nottingham, Roman Crete.
- Trainor, C., 2019. Polis, colony and beyond: urban Knossos from Archaic to Late Antique times. In: *Proceedings of the 12th International Congress of Cretan Studies* (Heraklion, 21-25 September 2016), p. A1.
- Triantaphyllou, S., 2015. A stable isotope analysis of skeletal assemblages from prehistoric Northern Greece. In: Papatathanasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis* (Hesperia S, pp. 57–76). American School of Classical Studies at Athens.
- Tykot, R.H., 2006. Isotope Analyses and the Histories of Maize. In: Staller, J.E., Tykot, R. H., Benz, B.F. (Eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize*. Elsevier Academic Press, pp. 129–141.

- Valamoti, S.M., 2016. Millet, the late comer: on the tracks of *Panicum miliaceum* in prehistoric Greece. *Archaeol. Anthropol. Sci.* 8 (1), 51–63. <https://doi.org/10.1007/s12520-013-0152-5>.
- van der Merwe, N.J., Vogel, J.C., 1978. $\delta^{13}\text{C}$ Content of human collagen as a measure of prehistoric diet in woodland North America. *Nature* 276 (5690), 815–816. <https://doi.org/10.1038/276815a0>.
- Van Neer, W., Ervynck, A., 2004. Remains of traded fish in archaeological sites: indicators of status, or bulk food? In: Jones O'Day, S., Van Neer, W., Ervynck, A. (Eds.), *Behaviour Behind Bones: the Zooarchaeology of Ritual, Religion, Status and Identity*. Oxbow Books, pp. 203–214.
- Vander Zanden, M.J., Fetzner, W.W., 2007. Global patterns of aquatic food chain length. *Oikos* 116 (8), 1378–1388.
- Vika, E., 2015. Temporal and spatial variations in diet in prehistoric Thebes: the case of the Bronze Age mass burial. In: Papathanasiou, A., Richards, M.P., Fox, S.C. (Eds.), *Archaeodiet in the Greek World: Dietary Reconstruction from Stable Isotope Analysis*. American School of Classical Studies at Athens, pp. 77–88.
- Vika, E., Theodoropoulou, T., 2012. Re-investigating fish consumption in Greek antiquity: results from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis from fish bone collagen. *J. Archaeol. Sci.* 39 (5), 1618–1627. <https://doi.org/10.1016/j.jas.2012.01.016>.
- Warren, P., 1981. Knossos: stratigraphical museum excavations. Part I. *Archaeol. Rep.* 27, 73–92. <https://doi.org/10.2307/581077>.
- Waywell, G.B., Wilkes, J.J., Bland, R., Sidell, E.J., Wilkinson, K.N., Chandler, G.M., 1997. Excavations at Sparta: The Roman Stoa, 1988–91 Part 3. *Ann. Brit. School Athens* 92, 401–434.
- Willet, R., 2012. Whirlwind of numbers - Demographic experiments for Roman Corinth. *Ancient Soc.* 42, 127–158.
- Zohary, T., Erez, J., Gophen, M., Berman-Frank, I., Stiller, M., 1994. Seasonality of stable carbon isotopes within the pelagic food web of Lake Kinneret. *Limnol. Oceanogr.* 39 (5), 1030–1043. <https://doi.org/10.4319/lo.1994.39.5.1030>.