



# Eating in prosperity: First stable isotope evidence of diet from Palatial Knossos

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## ABSTRACT

This paper discusses the first stable isotope evidence of diet from Protopalatial to Neopalatial Knossos on Crete to reconstruct individual long-term dietary records for people from the site, spanning the period circa 1900 to 1600 BC. The aim is to shed light onto the lifeways and social organization of the respective communities, and to investigate people's everyday life for evidence of the site's politico-economic supremacy in the Neopalatial period.

Eighty-one human and 12 animal individuals from two Palatial cemeteries at Knossos were sampled for cortical bone and the extracted collagen was analyzed for stable carbon and nitrogen isotope ratios to trace relative proportions of (broad categories of) foodstuffs that they consumed on a day-to-day basis. The human collagen stable isotope signatures follow a broad distribution that reflects a range of diets, where animal protein, including marine in addition to terrestrial, was consumed at different levels. Faunal isotope values from the site are consistent with a terrestrial C<sub>3</sub> trophic context with apparently no C<sub>4</sub> protein input.

The observed dietary variation in the human stable isotope ratios shows no clear sex-, tomb-, or cemetery-pattern; it rather follows a temporal trend that is in tune with contemporary socio-economic and political developments and the increasing prosperity of Knossos in the period investigated. Moreover, the study yielded the first positive human palaeodietary evidence for marine food consumption in Prehistoric Crete.

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## 1. Introduction

This paper builds on extensive scholarship concerning the affluence and politico-economic growth of the major site of Minoan Knossos on Crete (Fig. 1) that peaked over the course of the Neopalatial period (MMIII–LMIB<sup>1</sup> or circa 1700 to 1490/1470 BC) (e.g. Whitelaw, 2012, 2004; MacDonald, 2013, 2005). It offers new insights to the actual life conditions of Palatial Knossos' inhabitants. This study presents the first results of stable isotope ratio analysis on archeological bone collagen from human remains found at this site. These results allow reconstruction of individual long-term dietary records for these people by tracing relative proportions of (broad categories of) foodstuffs that they consumed on a day-to-day basis (Horn et al., 2009; Lee-Thorp, 2008; DeNiro and Epstein, 1981, 1978). This study thus offers, for the first time, a more tangible measure of the site's untested heyday. In other words, it investigates how living at Palatial Knossos translated into people's everyday diet. Although none of the burials from either of the two cemeteries examined, Ailias and Lower Gypsades, can be taken to represent the 'royal' family of Palatial Knossos, the quality of some of the rare burial furnishings recovered from Ailias may be interpreted as evidence that the people buried there were of elevated status.

Moreover, this paper explores the biological correlates of identity and social structure by examining patterns of dietary variation in relation to sex-, tomb- and cemetery-affiliation. It also discusses Knossos in the palaeodietary isotopic context that is available to date for Bronze Age Crete and compares the MMII–LMI Knossos isotopic data to the LMIIIA–B site of Armenoi (Richards and Hedges, 2007) in north-central Crete (some 70 km west of Knossos). Despite post-dating the last interments at Ailias or Lower Gypsades by more than 200 years, Armenoi offers the nearest temporal parallel from the island to contextualize the human dietary reconstruction of Palatial Knossos.

## 2. Archeological background

### 2.1. Palatial Knossos: production and consumption

Knossos grew rapidly from Prepalatial to Protopalatial and more dramatically during Neopalatial times, by which point it was closely involved in networks of contacts, interactions and trade operating in the Aegean and the Asia Minor, and maintained a preeminent role in a trade for metals stretching as far as the eastern Mediterranean. Thus the Neopalatial period at Knossos was a time of increased affluence, architectural and artistic developments, with political and/or economic control extending over much of the island (e.g. Whitelaw, 2012, 2004;

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<sup>1</sup> Abbreviations: MM = Middle Minoan, LM = Late Minoan.



Fig. 1. Map of the Aegean; marked on it are the sites mentioned in this article.

MacDonald, 2010; Wiener, 2007; Adams, 2006; Rehak and Younger, 2001).

Built structures for storage and storage vessels (large jars or pithoi) at the Knossos palace attest to a large scale production of cereals, legumes, fruits, or oil, wine, etc., available for consumption by the palatial elite and officials, the dependant personnel, and probably, to some extent, by the remainder of the community (Hamilakis, 1996). Dating from LMIIIA onwards, Linear B tablets from Knossos supplement evidence for the operation of an extensive farming and herding system monitored by the palace (Hallager, 2010, 1977; Killen, 2004; Killen, 1994; Popham, 1970). Study of zooarchaeological remains shows that in the Bronze Age the four principal domestic species, i.e. sheep, goats, pigs and cows, as well as game such as fallow deer, were consumed at the site (e.g. Isaakidou, 2004, 2007a, 2007b). Material culture associated with tasks pertinent to herding practices and the associated by-products give further insights into the specific consumption and management practices. Moreover, published archaeobotanical evidence and specialized pottery lipid residue analysis from the site offer direct evidence for specific grains, legumes, nuts and fruits consumed, albeit not directly relevant in chronological terms to the period that this paper examines (e.g. Sarpaki, 2012, 2013; Livarda, 2012, for the Neolithic, the Late Bronze Age and Protogeometric Knossos respectively). Fish and other marine food consumption must also have been available to the people of Knossos because of its proximity to the sea. This is a common assumption for population groups living on or close to the coast that, in the Aegean, is corroborated by evidence for fishing activities from frescoes and pictorial vases in addition to the actual fishing equipment and fish bones recovered from Bronze Age sites (Papathanasiou et al., 2013; Gerontakou, 2010; Macgillivray and Sackett, 2010; Hadjianastasiou, 1996; Powell, 1996, 1992; Bintliff, 1977).

Zooarchaeological evidence, however, may be compromised by excavation practices and a bias towards the preservation of skeletal remains from larger-sized mammals compared to smaller ones or to fish bones (e.g. soil sieving and floatation will yield remains of smaller/younger animals otherwise not retrieved) (Craig et al., 2006). Likewise,

plant remains may be underrepresented owing to inappropriate excavation techniques or due to factors controlling preservation by charring (Papathanasiou et al., 2013). Moreover, archaeological animal bone, archaeobotanical records or pertinent material culture evidence, albeit potentially very informative about past human population dietary records, cannot directly reconstruct actual dietary practices if examined in isolation. They constitute evidence for production, preparation and generally the availability of certain food resources at a certain site, but they cannot address what was actually consumed or by whom. Individual dietary records are instead more directly reflected in the chemical profile of people's bones. Further insights into individual dietary records are also available through macroscopic analysis of people's skeletal remains and the recording of frequencies of diet-related skeletal and dental pathologies (e.g. dietary deficiencies such as scurvy, rickets, anemia, or dental caries, calculus and hypoplasia).

## 2.2. The cemetery sites examined

A total of eighty-one human individuals from Knossos were sampled for stable carbon and nitrogen isotope analysis for the purposes of this study. They derive from two roughly contemporary cemeteries situated near the palace and less than two km distant from each other: the Ailias MMII–LMI chamber tombs and the Lower Gypsades MMIII–LMI tholos (vaulted) tomb and ossuary that span the period during which Knossos flourished (Fig. 2) (Hood and Smyth, 1981: 7, 11; Hood, 1957; Hood and Boardman, 1955; Cook and Boardman, 1954). Excavations at both sites, undertaken in the 1950s under the directorship of Dr. Sinclair Hood of the British School at Athens, yielded substantial, well-preserved and meticulously-documented human skeletal material.<sup>2</sup>

<sup>2</sup> The author has studied both these skeletal collections for their full publication (Nafplioti, in preparation), and also sampled them for <sup>87</sup>Sr/<sup>86</sup>Sr as part of a broader residential mobility research project (Nafplioti, 2012, 2011, 2008, 2007).

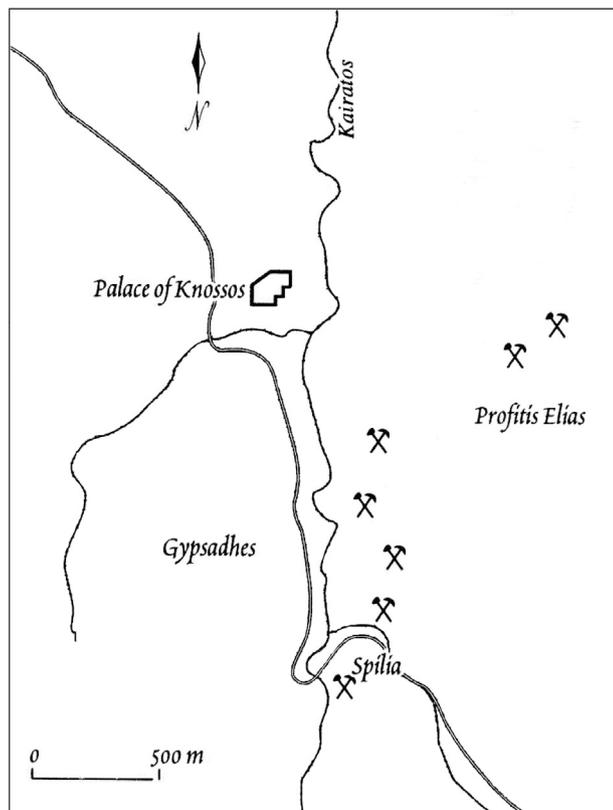


Fig. 2. Map of Knossos on Crete with the cemetery sites of Gypsades and Ailias (Profitis Elias) sampled for stable isotopes. Adapted from Higgins and Higgins (1996: Fig. 16.4).  $\overline{X}$  = quarry.

### 2.2.1. Ailias

The six chamber tombs (Tombs I, V–IX) excavated in the cemetery at Ailias yielded a total of more than two hundred individuals. All tombs were sampled for this isotopic study. Tombs I and VI are the earliest: Tomb I probably dates from MM IB (the earliest burials) to MM II; it was therefore the earliest in the cemetery and also the first to go out of use. Tomb VI, like Tomb I, also held remains of some early burials and was not in use after the end of MM II. Due to the circular shape of the burial chamber, Hood (personal communication) interpreted Tombs I and VI as substitutes for built ‘tholos’ tombs like those of the Mesara plain (Branigan, 1970, 1993). By contrast, the latter four Ailias chamber tombs (Tombs V, VII, VIII, IX) with the characteristic irregular group of chambers had broken away from any such tradition (for the Cretan–Minoan type, multi-chamber tomb see Alberti, 2004; Preston, 2004; Popham, 1994). Despite some evidence for a MM IB use of Tomb I, the main use of the cemetery dates to the MM II–MIII period, with some burials clearly as late as LM IA.

During MM II, burials were mainly made in large jars (pithoi) that appear to have been made for storage use rather than being specifically destined for burials. By contrast during the MMIII, large, mainly oval in shape, specialized clay coffins (larnakes) were used for burials. Nevertheless, contracted or extended inhumations made directly on the floor of the tombs were not uncommon either. Moreover, there is evidence from all six tombs that, at some point after their first use, they had been cleared of earlier burials: remains of these had been stuffed in pits dug into the tomb floor, pushed towards sidewalls, or collected in piles in isolated compartments created by erecting walls within the tomb (Hood, 2010).

Pottery was abundant among the burial furnishings at Ailias, and was normally placed on the floor beside the burial pithoi or larnakes. There is no evidence for contemporary plundering. However, rare grave goods, such as seals (27 in total), jewelry (e.g. gold rings and a unique large bead of gold and ivory, beads and pendants made of

precious/semi-precious stones, including artifacts probably of foreign origin), or other trinkets had probably been subject to looting over the course of use of these tombs – for example, during the frequent revisits of the tombs for the purposes of new interments and the performance of post-depositional mortuary rituals supported by the abundance of small red saucers (i.e. miniature clay trays) among the pottery from Tombs VI and VII (Hood, 2010).

### 2.2.2. Lower Gypsades

A minimum of sixty individuals is represented in the human skeletal material from the round built tholos and the associated ossuary excavated at this site. This study sampled bones from both these burial contexts. The material culture associated with the dead was not elaborate and largely comprised a few stone and principally clay vases. Although currently unpublished, the pottery from the tholos and ossuary suggests that the tomb was probably in use as early as MMIB, but mainly through MM III and into LM I (the date of the latest burials in the tholos) (Hood, personal communication). The Lower Gypsades burials were thus roughly contemporary with the Ailias burials examined in this paper.

### 2.2.3. Inter-site variation

Despite the nearness in time and space, the two cemeteries principally vary in terms of (a) the funerary architecture (single- and mainly multi-chamber rock-cut tombs at Ailias, versus a built circular tomb at Lower Gypsades); (b) associated ossuaries for depositing the remains of earlier burials (spaces and features within the actual tomb in use at Ailias, versus a separate built rectangular structure in front of the tomb at Lower Gypsades); (c) the range, wealth and rarity of grave goods (jewelry, sealstones or other trinkets in addition to pottery at Ailias, versus mainly clay and some stone vases at Lower Gypsades), and (d) mortuary practices, i.e. mode of original disposal of the deceased and secondary treatment of their remains at a later stage of the mortuary ritual/s performed (Hood, 2010, and unpublished data).

## 3. Background to stable carbon and nitrogen isotope analyses

### 3.1. Principles of analyses

The technique of isotopic analysis is based on the principle that ‘you are what you eat’, i.e. that molecules consumed as food or water are synthesized into consumer’s body tissues. As early as the 1970s, experimental laboratory work (e.g. DeNiro and Epstein, 1978) demonstrated that the consumers’ stable isotope profile is linked in a predictable manner to that of their diet, and that isotopic analysis of consumers’ tissues can measure a chemical ‘fingerprint’ within their remains, which can directly be linked to food and water ingested in vivo by the respective individuals. When organic matter is passed in the food chain from lower to higher trophic levels, a stepwise shift occurs in carbon and nitrogen isotopic signatures: this is the so-called ‘trophic level effect’ that is generally more pronounced for the nitrogen shifts (Schoeninger, 1985; Schoeninger and DeNiro, 1984). It describes the process by which consumers are enriched in  $\delta^{15}\text{N}$  by approximately +3 to +5‰ relative to their diet. As for the  $\delta^{13}\text{C}$  signatures, this difference is in the order of +0.5 to +2‰, between bone collagen from carnivores and herbivores, whilst it is higher between the collagen of herbivores and omnivores on the one hand and their diet on the other, i.e. approximately +5‰ (Bocherens and Drucker, 2003; Howland et al., 2003; van Klinken et al., 2000; DeNiro and Epstein, 1981).<sup>3</sup>

<sup>3</sup> The stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope ratios are measured as the ratio of the heavier isotope to the lighter isotope, and are reported relative to the VPDB and to the AIR standards respectively, using the delta ( $\delta$ ) notation in parts per thousand (‰), as follows:

$\delta^{\text{X}} = (\text{R}_{\text{sample}}/\text{R}_{\text{standard}} - 1) \times 1000$  (‰), where X stands for carbon or nitrogen, E stands for 13 or 15, respectively, and R for the isotopic ratios  $^{13}\text{C}/^{12}\text{C}$  and  $^{15}\text{N}/^{14}\text{N}$ , respectively.

Bone is constantly turned-over – turnover rate depends on the age of the individual – such that its isotope composition derives from the average diet consumed over a period of time. This may be as short as a few weeks in infants. After full maturity though, cortical bone collagen largely reflects the last 10 to 15 years of life with some adolescent collagen present even in old adult bones; albeit, less with increasing age (Hedges et al., 2007; Sealy et al., 1995). In diets with sufficient protein levels, collagen carbon values represent more the protein sources rather than the overall diet. Collagen nitrogen values on the other hand exclusively reflect protein sources since protein is the sole source of nitrogen (van Klinken et al., 2000; Ambrose, 1993; Ambrose and Norr, 1993). Hence, there is a bias towards overrepresentation of the protein component of the diet reconstructed. In essence, stable isotope analyses of human bone collagen reveal the relative proportions of plant versus animal, and terrestrial versus marine protein in diet, and can be used for reconstructions of long-term dietary records (e.g. Pearson et al., 2013; Lightfoot et al., 2012; Hakenbeck et al., 2010).

### 3.2. Stable carbon isotope variation in human bone collagen

Carbon isotopes principally vary according to the type of ecosystem from which the individuals obtained their food, though further environmental factors may impact on this variability.  $\delta^{13}\text{C}$  collagen values are effectively used to discriminate between (a) terrestrial  $\text{C}_3$  and  $\text{C}_4$  ecosystems, i.e. ecosystems wherein plants follow different photosynthetic pathways, and (b) terrestrial  $\text{C}_3$  and marine ecosystems (Lee-Thorp, 2008; van Klinken et al., 2000; Ambrose, 1993). Marine ecosystems are enriched in  $^{13}\text{C}$ , resulting in a shift towards more positive  $\delta^{13}\text{C}$  values compared to terrestrial  $\text{C}_3$  ecosystems:  $\delta^{13}\text{C}$  human collagen values up to  $-11\%$  may occur (Richards and Hedges, 1999; Schoeninger, 1989; Schoeninger et al., 1983; Schoeninger and DeNiro, 1984). By contrast, a pure terrestrial  $\text{C}_3$  plant-based diet is represented by human collagen carbon values around  $-21$  to  $-20\%$  (van der Merwe et al., 2000).  $\text{C}_4$  plants, such as millet, maize and sugarcane, are also enriched in  $^{13}\text{C}$  compared to  $\text{C}_3$  plants (Cadwallader et al., 2012; Sharp, 2007). Although their  $\delta^{13}\text{C}$  values can overlap to some extent with marine foods, they are generally more positive (Cadwallader et al., 2012), and a pure  $\text{C}_4$  plant diet can be represented by human collagen carbon values up to  $-4\%$  (Sharp, 2007; van der Merwe et al., 2000, 27). The corresponding  $\delta^{15}\text{N}$  values, and relevant data from other isotope systems, such as sulfur isotopes (Horn et al., 2009), can help distinguish protein inputs between  $\text{C}_4$  plants and marine foods, and thus achieve a more unequivocal dietary reconstruction.

### 3.3. Stable nitrogen isotope variation in human bone collagen

Acknowledging the effects of climate and physiology (Vaiglova et al., 2014; Reitsema, 2013; van Klinken et al., 2000; Ambrose, 1991), nitrogen isotopes in human bone collagen principally vary with the trophic level of the ingested protein: consumers'  $\delta^{15}\text{N}$  collagen signatures normally fall in the range of  $+3$  to  $+5\%$  above dietary protein (e.g. Hedges and Reynard, 2007; Bocherens and Drucker, 2003; van Klinken et al., 2000; Schoeninger and DeNiro, 1984; DeNiro and Schoeninger, 1983); more recently, O'Connell et al. (2012) report a wider spacing. As a result, the higher the consumer's trophic level, the more enriched in  $^{15}\text{N}$  his/her bone collagen is. Moreover, because marine and freshwater ecosystems tend to have food chains that are longer compared to the terrestrial ones,  $\delta^{15}\text{N}$  collagen signatures can also be used to distinguish between aquatic and terrestrial diets (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984).

Nonetheless, when stable nitrogen isotope data are interpreted in relation to past diets, certain limitations apply. For instance, protein contents differ between foods: they vary between plants and animal foods, or even between different plants. Because protein levels are significantly lower for plants, large amounts of plants will have to be consumed to have an impact on consumers' collagen isotopic values;

otherwise they will be obscured by animal source protein (Cadwallader et al., 2012; van Klinken et al., 2000). Moreover, collagen  $\delta^{15}\text{N}$  values cannot be used to distinguish between different types of animal protein sources, i.e. between meat, milk or cheese; or, in the case of a principally single-source protein input, between different consumption levels, i.e. 100 g to 500 g animal protein (van Klinken et al., 2000). Also, the practice of manuring can result in  $^{15}\text{N}$  enrichment of soils and the cultivated crops by up to  $+10\%$  (Vaiglova et al., 2014; Bogaard, 2012); hence potentially in  $\delta^{15}\text{N}$  crop signatures above those from herbivores and omnivores from the site investigated. Moreover, certain complications may also result from pathological conditions and starvation that can be accounted for increases in body  $\delta^{15}\text{N}$  signatures (D'Ortenzio et al., 2015; Mekota et al., 2006).

## 4. Materials and methods

A total of 81 human individuals were sampled for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  analysis. For 35 of the individuals sampled a single postcranial cortical bone sample was extracted mainly from the femur ( $N = 35$ ). The tibia, humerus, radius and clavicle substituted for the femur in nine cases ( $N = 9$ ), where the femur was not available for the particular individual analyzed. When postcranial remains from the Ailias collection could not be confidently associated with a cranium, samples were taken from the cranium ( $N = 37$ ); intact crania were not sampled. All 12 non-human cortical bone samples that were analyzed to provide baseline isotope signatures for Knossos come from the postcranial skeleton of sheep/goat, pig and cow individuals. These had been deposited within the Lower Gypsades Tholos tomb most likely as offerings to the dead.

Subperiosteal or ectocranial surface preservation for the majority of the bone samples ranged between moderate and good: none of the extracted samples was severely weathered, nor did they show any alterations suggestive of contact with fire and possible thermal alteration of its chemical profile. Additionally, none of the specimens had been treated with preservatives. Cortical bone was preferred because it is considered to be more resistant to contamination/degradation compared to trabecular bone (Jørkov et al., 2007: 1828). Experimentation with one of the cranial bone samples (DAN 28) included in this study confirmed the above observation: two subsamples from the same cranial fragment representing a) parts of cortical and trabecular bone, and b) cortical bone only, were separately analyzed. The collagen the latter subsample yielded met the criteria for good-quality collagen described below, unlike that yielded from the former, which showed signs of collagen degradation.

Collagen extraction and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  analysis was carried out by the author at the National Oceanography Centre in Southampton, UK. Bone samples were cleaned in an ultra-sonic bath with ultra pure water and the outer surface on all four sides of the sample was removed using a dremel tool fitted with a diamond cutting disk (cleaned between samples). Collagen was extracted from bone fragments of 500–700 mg using the method described in Richards and Hedges (1999), with the following modifications. Bone chunks, rather than bone powder, were immersed in 0.5 M HCl and left to demineralise at  $5\text{ }^\circ\text{C}$  for 10 to 15 days (Jørkov et al., 2007; Schoeninger et al., 1989; Ambrose, 1990: 448). It was observed that bone samples did not normally completely demineralise in 2–5 days as reported in earlier relevant literature (e.g. Honch et al., 2006; Richards and Hedges, 1999). A longer demineralization period was necessary as for example in Sealy et al. (2014) and in studies reported by Pestle et al. (2014); in some cases, depending on the size of the bone chunk and the density of the bone, up to 15 days. The 0.5 M HCl was replaced with fresh after 1 week.

Following complete demineralization, i.e. the bone chunks appeared flexible, translucent and floating in the 0.5 M HCl within the test tubes, the samples were rinsed three times in ultra pure water using centrifugation at 2500 rpm. Then pH 3 water was added and the samples were heated to  $75\text{ }^\circ\text{C}$  for 48 to 72 h in sealed test tubes. The gelatinous

solution was then filtered through an Ezee filter and the liquid fraction was transferred to clean test tubes. Samples were finally frozen and freeze-dried for 48 h. Ten of the 81 human bone samples yielded meager, macroscopically poor-quality residues that were suspected to represent severely degraded collagen and/or non-collagenous material and were therefore not analyzed for isotope ratios (Ambrose et al., 2003; Ambrose, 1990). For isotopic analysis, collagen samples of 500–550 µg from the remaining 71 human bone collagen samples and the 12 animal ones were weighed in tin capsules and analyzed in duplicate or triplicate using a GV Instruments Isoprime continuous flow stable isotope ratio mass spectrometer coupled to a EuroVector elemental analyzer. Analytical errors of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements varied slightly between different runs. Repeated measurements on five tyrosine standards before and after every set of 15 bone collagen samples showed that maximum errors for either of the two measurements were consistently lower than  $\pm 0.2\%$ . The average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements and brief contextual information for each sample included in this study are reported in Tables 1 and 2.

## 5. Results

Post-mortem diagenetic alteration (degradation) and contamination of bone collagen were assessed using measurements of the collagen concentrations for carbon (weight % C in collagen) and nitrogen (weight % N in collagen), as well as the calculated C:N atomic ratio (van Klinken, 1999; Ambrose, 1990; Schoeninger et al., 1989; DeNiro, 1985). Of the 71 human bone collagen samples that were isotopically analyzed, eight fell outside the acceptable ranges for intact bone collagen for at least one of the above parameters examined, i.e., wt % C (approximately  $34.8 \pm 8.8$ ), wt % N (11–16), and/or higher C:N atomic ratio (3.1–3.6). These were eliminated from the dataset and not considered any further in this study. All animal bone samples yielded collagen of good quality.

### 5.1. Animal samples

The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values measured from the twelve archeological animal bone collagen samples (4 sheep/goats, 4 cows, 4 pigs) analyzed are reported in Table 1. The average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values measured from all three species are  $-20.6 \pm 0.6\%$  and  $+3.5 \pm 0.8\%$ . Actual  $\delta^{13}\text{C}$  values range between  $-21.9$  and  $-19.8\%$  and are consistent with a temperate terrestrial  $\text{C}_3$  ecosystem with no  $\text{C}_4$  protein input to their diet (Sharp, 2007; van der Merwe et al., 2000: 27).  $\delta^{15}\text{N}$  values range between  $+2.0\%$  and  $+4.6\%$ .

Regarding each species separately:  $\delta^{13}\text{C}$  values for the sheep/goat average at  $-20.5 \pm 1.0\%$  and range between  $-21.9$  and  $-19.8\%$ . Cow and pig carbon values average at  $-20.8 \pm 0.2\%$  and  $-20.6 \pm 0.5\%$ , respectively; they are less variable than the sheep/goat ones and range between  $-20.9$  and  $-20.6\%$ , and between  $-21.3$  and  $-20.3\%$  for the cow and pig, respectively.

**Table 1**  
Stable isotope results of animal bone collagen samples from Lower Gypsades at Knossos.

Sample name	Context <sup>a</sup>	Element	Species	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C:N
DAN 60	LGI, Tholos, Larnax	PELVIS	Pig	-20.3	3.2	46.0	15.6	3.4
DAN 61	LGI, Trench C12	HUMERUS	Pig	-21.3	2.6	45.3	15.9	3.3
DAN62	LGI, Trench C12	RADIUS	Sheep/goat	-20.1	2.0	42.6	14.9	3.4
DAN63	LGI, Rectangular Enclosure, F7	METATARSAL	Cow	-21.0	3.8	42.3	15.8	3.1
DAN64	LGI, Rectangular Enclosure, F7	RADIUS	Sheep/goat	-19.8	3.5	44.7	15.8	3.3
DAN65	LGI, Rectangular Enclosure, F5	HUMERUS	Sheep/goat	-20.3	4.6	43.6	14.8	3.5
DAN66	LGI, Rectangular Enclosure, F5	METACARPAL	Cow	-20.8	3.8	38.3	12.6	3.5
DAN67	LGI, Rectangular Enclosure, F5	HUMERUS	Pig	-20.4	3.2	42.5	15.0	3.3
DAN68	LGI, Rectangular Enclosure, Balk A-F	LONG BONE SHAFT	Cow-size	-20.6	4.3	46.7	15.8	3.5
DAN69	LGI, Rectangular Enclosure, F7	HUMERUS	Cow-size	-20.7	4.5	46.2	15.7	3.4
DAN70	LGI, Tholos, Trench E7	HUMERUS	Sheep/goat	-21.9	2.8	37.5	12.0	3.6
DAN71	LGI, Trench C12	TIBIA	Pig	-20.3	4.0	45.2	15.4	3.4

<sup>a</sup> LGI = Lower Gypsades Tomb I.

$\delta^{15}\text{N}$  values measured from sheep/goat individuals average at  $+3.2 \pm 1.1\%$  and range between  $+2.0$  and  $+4.6\%$ . The  $\delta^{15}\text{N}$  values for the cow and pig average at  $+4.1 \pm 0.4\%$  and  $+3.2 \pm 0.6\%$ , and follow a narrower distribution, i.e. cow:  $+3.8$  to  $+4.5\%$ , pig:  $+2.6$  to  $+4.0\%$ . Although pigs are generally considered omnivorous, their collagen  $\delta^{15}\text{N}$  signatures are very similar to the  $\delta^{15}\text{N}$  values measured from the herbivores (sheep/goat and cow) analyzed, and thus compatible with a pure  $\text{C}_3$  plant protein-based diet.

Among the three species examined, isotopic variability for the cow is a comparatively low. Conversely, sheep/goat collagen isotope values show a comparatively higher variation for both carbon and nitrogen. Acknowledging the low sample size, this result most likely reflects a higher dietary variability and a wider geographical/environmental range for the sheep/goat individuals analyzed.

### 5.2. Human samples

Forty-six of the Ailias human bone samples yielded collagen of good quality and the results of the carbon and nitrogen isotope analyses are summarized in Table 2. The average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  signatures from Ailias are  $-19.7 \pm 0.99\%$  and  $+8.0 \pm 0.99\%$ , respectively. The Ailias human bone average  $\delta^{13}\text{C}$  is very close to the average  $\delta^{13}\text{C}$  for the Knossos archeological animals (baseline data) discussed above, as well as to similar data reported for terrestrial  $\text{C}_3$  ecosystems from the central Mediterranean or elsewhere in the Aegean (e.g. Petrousa and Manolis, 2009; Triantafyllou et al., 2008; Craig et al., 2006). Individual  $\delta^{13}\text{C}$  values range between  $-21.4$  and  $-17.4\%$ , while corresponding  $\delta^{15}\text{N}$  values from the same samples range from  $+6.2$  to  $+9.8\%$ . A first observation that can readily be made when comparing the Ailias human data against the Knossos baseline isotopic signatures (Table 2) is that the Ailias human  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  data follow a comparatively broad distribution that suggests a range of dietary sources.

Fig. 3 plots all the Ailias human and Knossos animal isotopic signatures. The Ailias human  $\delta^{15}\text{N}$  signatures are higher than the Knossos animal ones and reflect varying combinations of plant and animal dietary protein. The gray horizontal band on the graph marks the range of 3–5% above the highest Knossos archeological animal  $\delta^{15}\text{N}$  value ( $+4.6\%$ ). Human  $\delta^{15}\text{N}$  values within this range reflect a high consumption of  $\text{C}_3$  herbivore protein, whilst  $\delta^{15}\text{N}$  values that are lower than this range suggest a comparatively strong dietary input from plant protein. With reference to the  $\delta^{13}\text{C}$  data, the more positive  $\delta^{13}\text{C}$  values from nine Ailias individuals (20% Ailias humans) range between  $-18.4$  and  $-17.4\%$  (mean carbon human-animal isotopic offset of 2.7% for this group) and point to consumption of marine protein (Group A in Fig. 3). This is supported by the corresponding  $\delta^{15}\text{N}$  values ( $+8.1$  to  $+9.8\%$ ) that cluster towards the higher end of the  $\delta^{15}\text{N}$  range for the Ailias humans (mean nitrogen human-animal isotopic offset of 5.4% for this group). Group A consumed marine protein in combination with terrestrial  $\text{C}_3$  plant and animal proteins.

Table 2

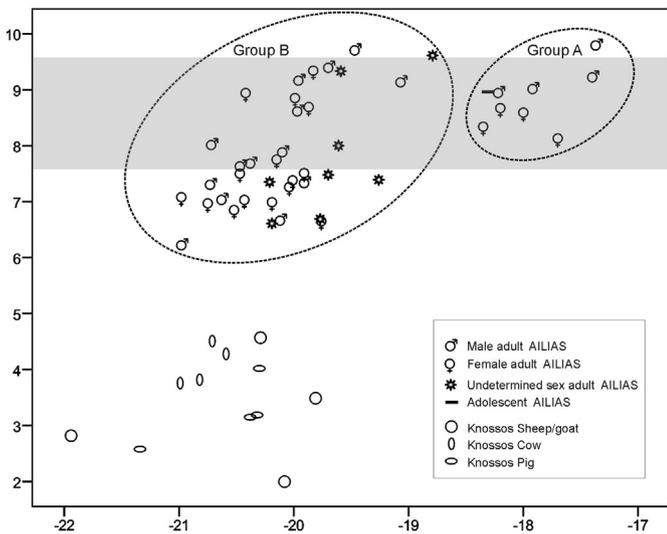
Stable isotope results of human bone collagen samples from Ailias and Lower Gypsades at Knossos; samples of good collagen preservation only.

Sample name	Context <sup>a</sup>	Element <sup>b</sup>	Age <sup>c</sup> (in years)	Sex <sup>d</sup>	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C:N
DAN1	LGI, Tholos, Larnax	CLAVICLE L	20–35	F	−19.8	8.1	43.0	15.3	3.3
DAN2	LGI, Tholos, Larnax, Individual A	FEMUR L	20–35	M	−19.5	9.8	40.7	14.8	3.2
DAN3	LGI, Tholos Larnax, Individual B	TIBIA R	<35	F	−19.6	8.7	42.8	15.7	3.2
DAN4	LGI, Tholos, Larnax main burial	FEMUR R	25–35	F	−19.9	8.4	39.9	13.4	3.5
DAN5	LGI, Tholos, Doorway of Tholos	HUMERUS L	<30	F	−20.3	9.1	42.6	15.3	3.2
DAN6	LGI, Tholos, Burial above original floor	TIBIA R	A	F	−17.8	8.7	42.1	15.6	3.1
CNS1	LGI, Larnax burial	LONG BONE SHAFT	A	U	−18.0	7.7	40.3	14.3	3.3
DAN7	LGI, Rectangular Enclosure, F7	FEMUR R	ADOL	U	−17.8	8.9	34.5	13.1	3.1
DAN8	LGI, Rectangular Enclosure, F8	FEMUR R	ADOL	U	−17.7	7.3	40.9	14.4	3.3
DAN9	LGI, Rectangular Enclosure, F9	FEMUR R	A	M	−17.6	9.2	34.7	12.4	3.3
DAN10	LGI, Rectangular Enclosure, F10	FEMUR R	A	F	−18.1	8.8	39.0	13.8	3.3
DAN11	LGI, Rectangular Enclosure, F11	FEMUR R	A	F	−18.0	8.7	39.7	14.0	3.3
DAN12	LGI, Rectangular Enclosure, F5	FEMUR R	A	M	−17.4	9.4	39.8	14.7	3.2
DAN13	LGI, Rectangular Enclosure, F5	FEMUR R	A	M	−17.4	9.0	39.5	14.3	3.2
DAN14	LGI, Rectangular Enclosure, F5	FEMUR R	A	F	−17.7	9.3	43.3	14.6	3.5
DAN15	LGI, Rectangular Enclosure, F5	FEMUR R	A	M	−17.7	8.9	35.0	13.3	3.1
DAN16	Ailias Tomb I, T95	CRANIUM	25–30	F	−18.4	8.3	38.3	12.9	3.5
DAN18	Ailias Tomb I, T97	CRANIUM	>40	F	−18.0	8.6	37.8	12.6	3.5
DAN19	Ailias Tomb V, T165	CRANIUM	>45	F	−18.2	8.7	37.7	12.8	3.4
DAN21	Ailias Tomb V, T166	CRANIUM	25–30	F	−20.2	7.8	39.3	13.1	3.5
DAN23	Ailias Tomb V, T171	CRANIUM	<25	F	−19.9	8.7	41.6	14.4	3.4
DAN25	Ailias Tomb V, T174	CRANIUM	>25	F	−20.4	8.9	41.0	14.3	3.4
DAN26	Ailias Tomb V, T74	CRANIUM	>25	F	−19.8	9.3	35.3	12.5	3.3
DAN27	Ailias Tomb V, T69	CRANIUM	<25	M	−19.7	9.4	42.1	14.9	3.3
DAN28	Ailias Tomb V, T72	CRANIUM	25–30	M	−20.0	9.2	39.5	13.6	3.4
DAN29	Ailias Tomb V, T78	CRANIUM	>45	M	−19.1	9.1	37.3	12.1	3.5
DAN30	Ailias Tomb V, T68	CRANIUM	20–35	M	−18.2	8.9	37.8	13.4	3.3
DAN34	Ailias Tomb VI, T9	TIBIA R	35–45	M	−17.9	9.0	40.0	14.2	3.3
DAN39	Ailias, AIL45	FEMUR R	ADOL	U	−18.3	9.0	41.6	14.6	3.3
DAN40	Ailias Tomb VI, T26	FEMUR R	25–35	M	−17.4	9.8	36.2	13.0	3.3
DAN41	Ailias Tomb VI, T29	TIBIA L	25–30	F?	−17.7	8.1	40.9	14.5	3.3
DAN43	Ailias Tomb VI, T106	FEMUR L	35–40	M	−17.4	9.2	35.7	14.5	2.9
DAN22	Ailias Tomb V, T172	CRANIUM	<25	F	−20.0	8.9	30.0	10.5	3.3
DAN44	Ailias Tomb VI, T107	FEMUR R	>45	F	−20.0	7.4	40.7	14.4	3.3
DAN48	Ailias Tomb VI, T160	FEMUR L	25–30	F	−19.8	6.7	38.5	13.6	3.3
DAN49	Ailias Tomb, T222	RADIUS R	A	U	−19.6	9.3	44.5	14.8	3.5
DAN50	Ailias Tomb, T220	FEMUR R	A	U	−19.7	7.5	27.4	9.8	3.3
DAN51	Ailias Tomb VI, T152	FEMUR R	A	F	−19.9	7.5	41.1	14.5	3.3
DAN52	Ailias Tomb VI, T159	FEMUR R	A	U	−19.8	6.7	42.6	14.7	3.4
DAN53	Ailias Tomb VI, T138	FEMUR R	20–30	F	−20.0	7.3	38.3	14.8	3.0
DAN54	Ailias Tomb VI, T154	FEMUR R	25–30	F	−20.4	7.0	42.1	14.7	3.3
DAN55	Ailias Tomb, Burial I, T281	FEMUR R	A	U	−18.8	9.6	36.3	13.1	3.2
DAN56	Ailias Tomb, T201	TIBIA R	A	U	−19.3	7.4	43.2	15.4	3.3
DAN57	Ailias Tomb, T156	FEMUR L	A	U	−20.2	7.4	44.7	15.3	3.4
DAN58	Ailias Tomb, T215	FEMUR L	A	U	−19.6	8.0	40.9	14.3	3.3
DAN46	Ailias Tomb VI, T103	FEMUR L	>35	F	−20.2	7.0	34.1	11.6	3.4
DAN72	Ailias Tomb VI, T108	CRANIUM	<25	F	−21.0	7.1	42.1	13.9	3.5
DAN75	Ailias Tomb VII, T92	CRANIUM	30–35	M	−20.0	8.6	43.5	14.6	3.5
DAN76	Ailias Tomb VII, T93	CRANIUM	35–45	M	−20.4	7.7	44.4	14.9	3.5
DAN78	Ailias Tomb VII, T95	CRANIUM	35–40	M	−20.1	6.7	46.4	15.2	3.6
DAN74	Ailias Tomb VI, T30	CRANIUM	35–45	M	−20.6	7.0	40.0	13.5	3.4
DAN77	Ailias Tomb VII, T94	CRANIUM	>45	M	−19.5	9.7	41.0	14.6	3.3
DAN81	Ailias Tomb IX, T87	CRANIUM	35–45	M	−20.7	8.0	41.3	13.8	3.5
DAN82	Ailias Tomb IX, T89	CRANIUM	25–35	M	−21.0	6.2	39.2	13.3	3.4
DAN84	Ailias Tomb IX, T91	CRANIUM	25–30	F	−20.5	6.9	41.6	14.3	3.4
DAN85	Ailias Tomb IX, XXIII	CRANIUM	A	U	−20.2	6.6	41.1	14.5	3.3
DAN86	Ailias Tomb V, T167	CRANIUM	25–35	F	−20.5	7.5	41.4	14.6	3.3
DAN87	Ailias Tomb V, T74	CRANIUM	25–35	M	−20.5	7.6	42.6	14.8	3.4
DAN88	Ailias Tomb V, T70	CRANIUM	25–35	M	−20.1	7.9	42.1	15.1	3.3
DAN89	Ailias Tomb V, T79	CRANIUM	25–35	M	−20.7	7.3	35.6	12.4	3.3
DAN90	Ailias Tomb VI, T8	CRANIUM	35–45	M	−19.9	7.3	39.2	13.9	3.3
DAN92	Ailias Tomb VI, T112	CRANIUM	25–35	F	−20.8	7.0	38.4	13.0	3.4

<sup>a</sup> LGI = Lower Gypsades Tomb I.<sup>b</sup> L = Left, R = Right.<sup>c</sup> ADOL = Adolescent, A = Adult.<sup>d</sup> F = Female, M = Male, U = Unknown.

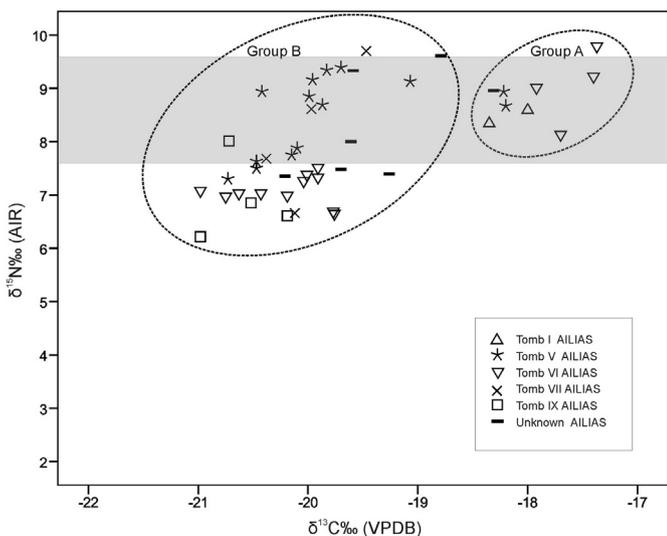
The remainder (80%) of the Ailias individuals (Group B in Fig. 3), whose diet did not include any marine protein, or, at least, not enough to impact their carbon isotope ratios, largely consumed a mixture of terrestrial  $\text{C}_3$  plant and animal proteins. In this group, the highest  $\delta^{15}\text{N}$  values ( $>+8.6\text{‰}$ , i.e. higher than  $+4\text{‰}$  above the highest archeological animal  $\delta^{15}\text{N}$  value) are probably linked to a very high reliance on herbivore animal protein, and potentially also to consumption of protein

from higher trophic levels, such as suckling animals or freshwater fish; clearly not as a staple, but rather a dietary supplement. Conversely, assuming that the plants regularly consumed by the humans at Knossos had lower  $\delta^{15}\text{N}$  values compared to the herbivores tested, the lowest  $\delta^{15}\text{N}$  values ( $<+7.6\text{‰}$ , i.e. below the gray horizontal band on the graph) point to a significant plant protein dietary input for nearly half of this group.



**Fig. 3.** Bone collagen carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotopic values of all Ailias individuals plotted by sex. Data are plotted with comparable isotopic signatures from contemporary animals at the site of Knossos; the gray horizontal band marks the range of +3 to +5‰ above the highest  $\delta^{15}\text{N}$  value obtained from the Knossos animals.

Isotopic data for males ( $N = 18$ ) and females ( $N = 19$ ) from Ailias are examined separately in order to explore sex-specific dietary practices and differential sex-based access to protein resources. The mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  for males ( $-19.6\%$  and  $+8.3\%$ , respectively) and females ( $-19.8\%$  and  $+7.8\%$ , respectively) are similar. Variation of mean carbon and nitrogen isotope values by sex was not found to be statistically significant (independent samples t-test:  $p = 0.672$  for carbon;  $p = 0.173$  for nitrogen). In Fig. 3, the two sexes are plotted separately to observe the variation of the individual isotope values. The graph shows high isotopic variation for both sexes, which is compatible with a range of diets with varying amounts and types of animal protein. Males and females had equal access to marine protein; they are represented in Group A discussed above by four individuals each. Also in Group B, the highest  $\delta^{15}\text{N}$  values ( $>+8.6\%$ ) belong to individuals from both sexes (4 males and 4 females) and suggest equal access to very high amounts of herbivore animal protein or to supplementary higher trophic level food resources. Females outnumber males in terms of the lowest  $\delta^{15}\text{N}$  values ( $<+7.6\%$ ) of the group that point to consumption of a very high proportion of  $\text{C}_3$  plant protein.



**Fig. 4.** Ailias  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values plotted by tomb. The gray horizontal band marks the range of +3 to +5‰ above the highest  $\delta^{15}\text{N}$  value obtained from the Knossos animals.

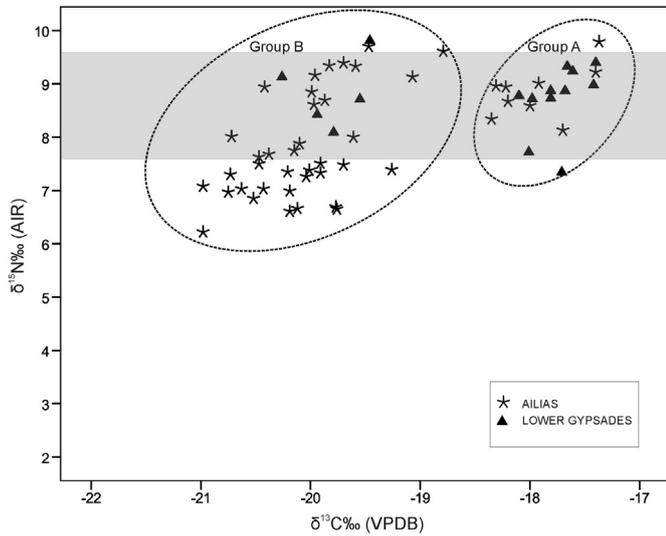
Isotopic variation for the Ailias humans was examined among different tombs (Fig. 4). Except for Tomb I that is underrepresented, isotopic signatures from all other tombs (V, VI, VII and IX) do not tightly cluster within either end of the range of the Ailias human carbon and nitrogen isotopic values; as such, data do not suggest uniformly different protein sources between different tombs. They rather reflect intra-tomb variation and a range of diets, which were discussed above, for the individuals from each tomb. Because Tombs I, VII and IX are represented in the data by less than five individuals (Table 2), it was decided that the inter-tomb isotopic variation would not be statistically analyzed.

An interesting pattern emerges when temporal trends in the isotopic variation are explored. Tombs V and VI, which are better represented in the isotopic data, date to MMIII and MMII respectively. Both tombs are represented in Group A that had access to marine resources. The majority of the individuals from both tombs however lived on a diet with varying amounts of terrestrial  $\text{C}_3$  plant and animal proteins (Group B). In Group B, the data suggests that the individuals from Tomb V consumed proportionally more herbivore protein compared to the Tomb VI individuals, and that some of them probably also consumed protein from higher trophic levels. In this group,  $\delta^{15}\text{N}$  values from 83% of the Tomb V individuals cluster within or higher than the range of 3–5‰ above the highest Knossos baseline  $\delta^{15}\text{N}$  signature. By contrast, all the Tomb VI individuals cluster below this range. Nitrogen isotope values were found to be significantly different between the two tombs (independent samples t-test:  $p = 0.481$  for carbon;  $p = 0.009$  for nitrogen). Because Tomb VI dates to MMII, and together with Tomb I they are the earliest in the cemetery, while Tomb V dates to MMIII, patterning of the data in this graph (Fig. 4) may reflect a temporal trend in the intra-population dietary variation at Knossos with an increase in the input of dietary terrestrial herbivore or other higher trophic level protein from MMII to MMIII times.

Further relevant to the discussion of a probable temporal trend in the isotopic variation from Palatial Knossos, are the data from Lower Gypsades (the Tholos tomb and the associated ossuary). The shift towards more positive  $\delta^{13}\text{C}$  values for some of the Ailias humans is clearer for the individuals from Lower Gypsades.  $\delta^{13}\text{C}$  values from Lower Gypsades range between  $-20.3$  to  $-17.4\%$  with an average of  $-18.4 \pm 1.0\%$ . Corresponding  $\delta^{15}\text{N}$  values range between  $+7.3$  and  $+9.8\%$  with an average of  $8.8 \pm 0.6\%$ . The mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for males are  $-17.9$  and  $+9.3\%$ . For females mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  are lower at  $-18.9$  and  $+8.7\%$ , respectively. The difference for the nitrogen values was found to be statistically significant (independent samples t-test:  $p = 0.122$  for carbon;  $p = 0.035$  for nitrogen), which suggests proportionally more herbivore protein or protein from higher trophic levels for males than females. Nevertheless, individual  $\delta^{15}\text{N}$  values for females range between  $+8.1$  and  $+9.3\%$  and are very high compared with the baseline Knossos data (Table 2).

Fig. 5 plots human Lower Gypsades isotopic data along with Ailias data to explore inter-site variation. Lower Gypsades datapoints on this graph cluster tightly together and appear to follow a narrower distribution for nitrogen isotope ratios compared to Ailias. Sixty-nine percent (4 males, 4 females, 1 adult of unknown sex, 2 adolescents) of these people have  $\delta^{13}\text{C}$  values on the order of  $-18.1$  to  $-17.4\%$  and fall in Group A that had some protein input from marine resources. In Group B, all Lower Gypsades individuals (1 male, 4 females) consumed a very high proportion of herbivore protein, whilst more than half of them probably supplemented their diet with food resources from higher trophic levels.

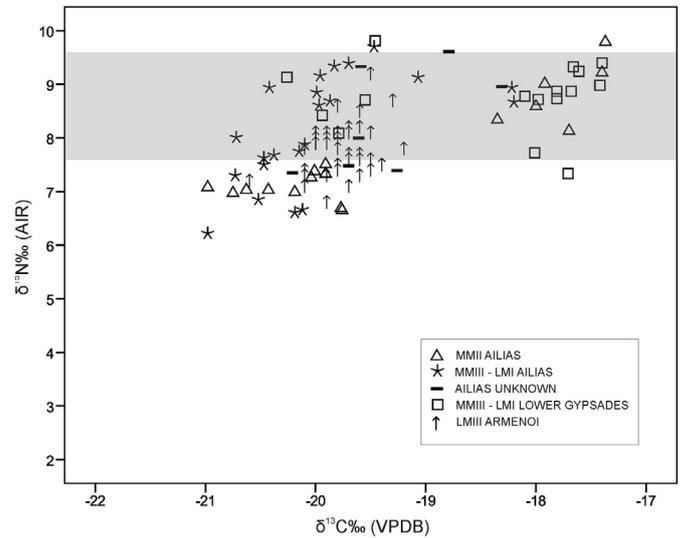
Although the two cemeteries are roughly contemporary, use of the Lower Gypsades Tholos and ossuary largely took place in MM III to LM IA period, not earlier. The isotopic data from Lower Gypsades thereby appear to corroborate a temporal trend in dietary variation from MM II (Protopalatial) to MM III–LMI (Neopalatial) times at Knossos that was observed from the Ailias data (see Fig. 6, where Ailias MM II and MM III–LM I burials are plotted separately, along with MMIII–LMI Lower Gypsades): during the Neopalatial period, non-marine food



**Fig. 5.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of all Lower Gypsades and Ailias individuals. The gray horizontal band marks the range of +3 to +5‰ above the highest  $\delta^{15}\text{N}$  value obtained from the Knossos animals.

consumers appear to rely comparatively more on herbivore animal protein, as well as to supplement their diet with food from higher trophic levels, such as lactating animals or freshwater fish. For non-marine food consumers – Ailias and Lower Gypsades data pooled – differences in  $\delta^{15}\text{N}$  values between samples from Protopalatial and Neopalatial times are statistically significant (independent samples t-test:  $p = 0.413$  for carbon;  $p < 0.001$  for nitrogen). Conversely, the proportion of marine consumers in the Knossos population is similar between Protopalatial and Neopalatial times; approximately one third of the population. Nonetheless, marine consumers in the Neopalatial group largely represent Lower Gypsades (eleven out of thirteen individuals) rather than contemporary Ailias (two out of thirteen) (Fig. 6).

Finally, the Knossos isotopic data are compared to data from the LMIIIA–B site of Armenoi on north-central Crete (Richards and Hedges, 2007) (Fig. 7). Although Armenoi postdates by over 200 years the last use of the two Knossos cemeteries and baseline isotopic signatures are different between the two sites, the following can readily be observed: a) the carbon and nitrogen isotope ratio values from Knossos



**Fig. 7.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from Ailias and Lower Gypsades at MMII–LMIA Knossos, and LMIIIA–B Armenoi (data come from Richards and Hedges, 2007). The gray horizontal band marks the range of +3 to +5‰ above the highest  $\delta^{15}\text{N}$  value obtained from the Knossos animals.

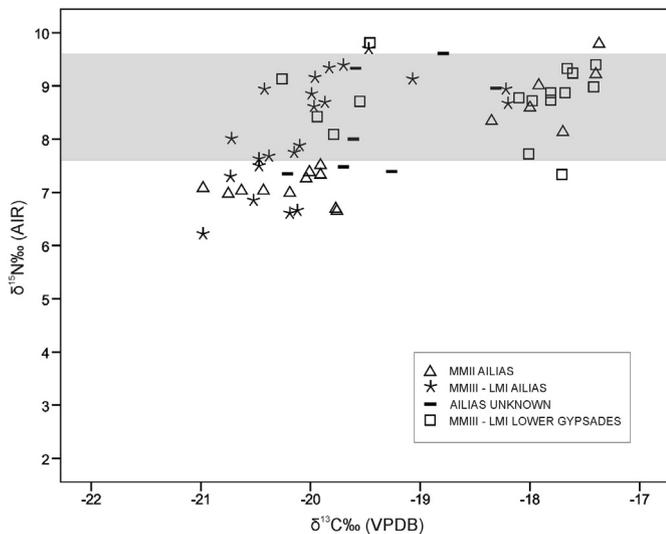
are more variable compared to Armenoi and reflect a broader range of diets in terms of the different types of protein consumed and the proportional contribution of the various protein sources, and b) part of the Palatial Knossos population consumed marine protein that appears to be insignificant or even lacking from the diet of the Armenoi population (Richards and Hedges, 2007).

## 6. Discussion

Acknowledging the low sample size, the stable carbon isotope data from archeological animals from Palatial Knossos with an average of  $-20.6 \pm 0.6\text{‰}$  indicate a terrestrial  $\text{C}_3$  ecosystem, with no  $\text{C}_4$  protein input. Similar  $\delta^{13}\text{C}$  values with an average of  $-20.3 \pm 0.9\text{‰}$  were reported by Craig et al. (2006) for archeological herbivores from the central Mediterranean. Thus data from this project agree with current knowledge about a late (i.e. not before historical times), first introduction of  $\text{C}_4$  plants to Cretan diet (Vika and Theodoropoulou, 2012). Inter-species variation in the corresponding nitrogen isotope ratios probably reflects dietary variation and different herding practices for the three species analyzed (Vaiglova et al., 2014: 210). Wider feeding territories, and hence wider geographical/environmental ranges, for the sheep/goat compared to cow and pig, were also deduced from the variation of  $^{87}\text{Sr}/^{86}\text{Sr}$  signatures from archeological animals from this site (Nafplioti, 2011: 1567).

The human carbon and nitrogen isotope ratios show a range of diets with varying amounts and types of protein for the Palatial Knossos population. Two main dietary groups can be distinguished. In Group A, individuals consumed marine protein in combination with terrestrial  $\text{C}_3$  plant and most probably animal proteins. Individuals from Group B either did not consume any marine protein, or most probably not enough to make an impact on their isotope signatures, and largely subsisted on a mixture of terrestrial plant and (herbivore) animal proteins. Some individuals from this group appear to have supplemented their diet with higher trophic level food resources, such as lactating animals or freshwater fish (Balasse and Tresset, 2002; Wright and Schwarcz, 1999). Consumption of freshwater fish, however, seems less likely, because today there are no perennial rivers or lakes near Knossos on Crete.

These data represent the first positive human stable isotope evidence for marine food consumption in Prehistoric Crete. In a terrestrial  $\text{C}_3$  ecosystem as reconstructed for Palatial Knossos, human carbon isotope ratios between  $-18.4$  and  $-17.4\text{‰}$  for approximately one third of the people analyzed clearly indicate consumption of marine protein.



**Fig. 6.** Ailias and Lower Gypsades  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values grouped by dating to Protopalatial (MMII Ailias) and Neopalatial periods (MMIII–LMIA Ailias and Lower Gypsades). The gray horizontal band marks the range of +3 to +5‰ above the highest  $\delta^{15}\text{N}$  value obtained from the Knossos animals.

The corresponding nitrogen isotope ratio values are high and cluster towards the higher end of the Knossos human range (up to +9.8‰). These values with a mean of  $+8.8 \pm 0.6\%$  are at least one trophic level above those from the Knossos archeological animals with a mean of  $+3.5 \pm 0.8\%$ . Hence the alternative theory of a C<sub>4</sub> plant protein consumption restricted to humans to account for the more positive human carbon isotope ratios can be rejected. Unless C<sub>4</sub> crops were highly manured, which could have elevated crops'  $\delta^{15}\text{N}$  signatures up to above those from herbivores from the site. However, such a high level of manuring does not seem plausible. Moreover, as domesticated pigs are generally thought to have lived on human by-products such as table scraps, crop wastes etc. (Bentley, 2006), it would have been unlikely to miss such a C<sub>4</sub> plant protein signal from their carbon isotope values.

The human nitrogen isotope ratios associated with marine consumption at Knossos fall below the ranges that Richards and Hedges (1999) and Craig et al. (2006) reported for marine fish consumption in other parts of Europe; these studies have linked the latter with human collagen nitrogen isotope ratios higher than +10‰. However, the comparatively lower nitrogen ratios for the marine consumers from Knossos are not surprising in the light of the data that Vika and Theodoropoulou (2012) recently published for the Aegean. Although their dataset is not extensive and Crete or other parts of the south Aegean are not represented, what is important is that nitrogen isotope ratio values from archeological fish (marine, freshwater and euryhaline species) in the north Aegean are overall comparatively low: in the range of +4 to +12‰, with corresponding carbon values between –20 and –7‰.

Although human enamel  $^{87}\text{Sr}/^{86}\text{Sr}$  data can in theory give complementary insights to palaeodietary reconstructions in relation to marine food consumption, the local bioavailable strontium isotopic signatures at Knossos and for the broader region of northern Crete average 0.7089 ( $\pm 0.0001$ ) and 0.7090 ( $\pm 0.0001$ ) (Nafplioti, 2011), respectively, and are similar to the modern seawater signature of 0.7092 (Veizer, 1989). Thus, it is not possible to use human enamel/bone  $^{87}\text{Sr}/^{86}\text{Sr}$  signatures from Knossos to indicate consumption of marine resources (Sealy et al., 1995). Therefore, the human  $^{87}\text{Sr}/^{86}\text{Sr}$  data published for Ailias and Lower Gypsades (Nafplioti, 2012, 2008, 2007) are inconclusive in this respect.

Isotopic variation between males and females from Ailias and Lower Gypsades does not suggest sex-specific access to certain foods. Both sexes span the entire range of diets observed; they both had access to marine foods, to high amounts of herbivore protein and to resources from higher trophic levels. Similarly, assuming that the five Ailias tombs examined were used by different, broadly contemporary, family/social groups, the data presented in this paper gave no evidence for social differentiation at Knossos through everyday dietary practices and differential access to food resources. Despite the lack of impressive/rare grave goods from the Lower Gypsades burials contrary to the Ailias burials, there is no evidence that the former had less access to foods from higher trophic levels; in fact, the opposite was observed.

Instead the variation in the human isotope data for Palatial Knossos can be better explained in temporal terms. The isotope data for Neopalatial Lower Gypsades confirmed the isotopic variation observed between the Protopalatial and Neopalatial Ailias tombs. In Neopalatial times, part of the population continued to consume marine protein, whilst most of the non-marine food consumers who subsisted on a mixture of terrestrial plant and animal proteins, relied more heavily on animal protein than before. It is very likely that some of them had also added foods from higher trophic level into their diet. These isotope data largely showed an increased availability of animal protein to the Knossos population over the course of the Middle Bronze Age. Access to this was wide; it was not conditioned either by the sex or the family/social group-affiliation of the individuals. It would seem that the dietary variation and the everyday subsistence practices of the Knossos people mirror the political and economic transformations at the site,

as well as in the rest of the island, during Protopalatial to Neopalatial times, and the uncontested supremacy of Knossos in the latter period.

## 7. Conclusions

Palatial Knossos is a known major politico-economic centre in Bronze Age Crete, the Aegean and beyond. Although the relevant scholarship is extensive, most of the evidence available to date rarely reflects people's lifeways and their actual day-to-day practices. The carbon and nitrogen isotope ratio data discussed in this paper constitute the first evidence of individual long-term dietary records for Knossos; they show a range of diets with varying types and amounts of proteins that were widely accessible to people from this site with no evidence of dietary differentiation based on membership to a particular group, either by sex-, tomb- or cemetery-affiliation. These data also offer the first positive evidence for early (i.e. Bronze Age) marine food consumption on Crete. Comparison with human isotope data from LM IIIA–B Armenoi corroborates the conclusion that there was nothing ordinary about living and eating at Palatial Knossos. In Neopalatial times in particular, people at Knossos lived on a diet that was comparatively rich in terms of the different types of protein consumed and the proportional contribution of animal protein. The higher availability of animal protein over the course of the Middle Bronze Age is broadly coincidental with socio-economic and political developments and the supremacy of the site during Neopalatial times. A more nuanced understanding of everyday life at Palatial Knossos has thus been made possible. Significant further advances in this direction are anticipated through the complete publication of the two human skeletal collections analyzed in this paper (Nafplioti, in preparation), as well as a future program of systematic stable isotope ratio analysis of archaeobotanical and zooarchaeological (fish and other species not included in this study) remains from the site.

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