AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 000:000–000 (2012)

Isotopic Reconstruction of Human Diet and Animal Husbandry Practices During the Classical-Hellenistic, Imperial, and Byzantine Periods at Sagalassos, Turkey

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KEY WORDS stable isotopes; diachronic; herding; grazing; C4 plants; Roman

ABSTRACT An isotopic reconstruction of human dietary patterns and livestock management practices (herding, grazing, foddering, etc.) is presented here from the sites of Düzen Tepe and Sagalassos in southwestern Turkey. Carbon and nitrogen stable isotope ratios were determined from bone collagen extracted from humans (n = 49) and animals (n = 454) from five distinct time periods: Classical-Hellenistic (400–200 BC), Early to Middle Imperial (25 BC–300 AD), Late Imperial (300–450 AD), Early Byzantine (450–600 AD), and Middle Byzantine (800–1200 AD). The humans had protein sources that were based on C_3 plants and terrestrial animals. During the Classical-Hellenistic period, all of the domestic animals had $\delta^{13}C$ and $\delta^{15}N$ signatures that clustered together; evidence that the animals were herded in the same area or kept in enclosures and fed on similar foods. The diachronic analysis of the isotopic trends in the dogs, cattle, pigs, sheep, and goats highlighted subtle but distinct variations in these animals. The $\delta^{13}C$ values of the dogs and cattle increased (reflecting C_4 plant consumption) during the Imperial and Byzantine periods, but the pigs and the goats displayed little change and a constant C_3 plant-based diet. The sheep had a variable $\delta^{13}C$ pattern reflecting periods of greater and lesser consumption of C_4 plants in the diet. In addition, the $\delta^{15}N$ values of the dogs, pigs, cattle, and sheep increase substantially from the Classical-Hellenistic to the Imperial periods reflecting increased animal protein consumption, but the goats showed a decrease. Finally, these isotopic results are discussed in the context of zooarcheological, archeobotanical, and trace element evidence. Am J Phys Anthropol 000:000–000, 2012. ©2012 Wiley Periodicals, Inc.

The reconstruction of human and animal dietary practices with carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratio analysis of bone collagen is an established method in the field of scientific archeology that has revealed important information about dietary, migration, and health patterns in past populations from a variety of time periods and locations (e.g., van der Merwe and Vogel, 1978; Schoeninger and DeNiro, 1984; Sealy et al., 1987; Katzenberg et al., 1995; Katzenberg and Weber, 1999; Richards et al., 2000; Valentin et al., 2006; Choy et al., 2010). Isotopic results are semiquantitative and mainly reflect the origin of the protein portion of the diet averaged over the entire lifetime of an individual including a significant amount of collagen from the period of adolescence (Stenhouse and Baxter, 1979; Hedges et al., 2007). Stable isotope results are analyzed as the ratio of the heavier isotope to the lighter isotope ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) and reported as δ values in parts per 1,000 or "per mil" (‰) relative to internationally defined standards for carbon (Vienna Pee Dee Belemnite, VPDB) and nitrogen (Ambient Inhalable Reservoir, AIR) (Schwarcz and Schoeninger, 1991). A detailed discussion about how stable isotope ratios can be used to reconstruct dietary pattern in archeological populations is beyond the scope of the work, and the reader is directed to the following excellent reviews (Schwarcz and Schoeninger, 1991; Schoeninger, 1995; Katzenberg, 2000; Lee Thorp, 2008).

Roman and Byzantine/medieval populations, which were socially stratified and known from historical accounts to have diverse diets, have been increasingly

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Grant sponsor: Belgian Program on Interuniversity Poles of Attraction; Grant number: IAP 6/22; Grant sponsor: Research Fund of the K.U. Leuven; Grant number: BOF-GOA 07/02; Grant sponsor: Fund for Scientific Research, Flanders (FWO); Grant number: G.0421.06; Grant sponsors: J.-J. Hublin; the Max Planck Society; Methusalem Grant of the Flemish Government.

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Received 7 October 2011; accepted 30 April 2012

DOI 10.1002/ajpa.22100
Published online in Wiley Online Library (wileyonlinelibrary.com).

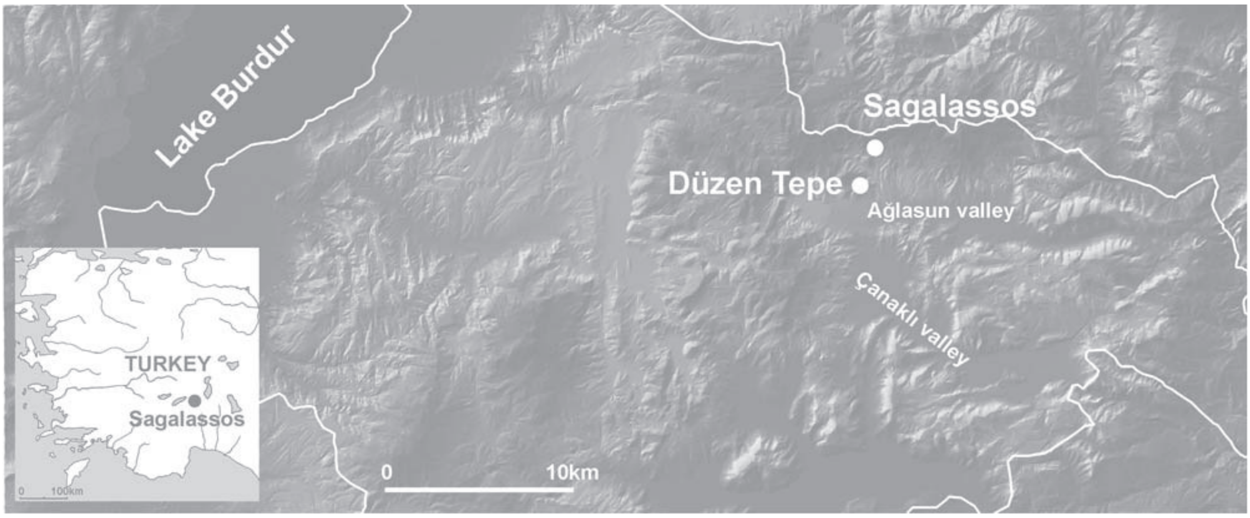

Fig. 1. Map showing the locations of Düzen Tepe and Sagalassos, Turkey.

studied with δ^{13}C and δ^{15}N results over the last decade. However, the isotopic analysis of animal husbandry practices from the Roman and Byzantine/medieval periods have not been the focus of extensive investigation. Previous work on humans from these time periods has been centered on sites in Europe, especially Britain (Richards et al., 1998; Fuller et al., 2006; Müldner and Richards, 2005, 2007; Cummings, 2009; Lightfoot et al., 2009; Chenery et al., 2010, 2011; Redfern et al., 2010; Müldner et al., 2011), Italy (Prowse et al., 2004, 2005, 2007, 2008; Craig et al., 2009; Rutgers et al., 2009; Crowe et al., 2010), Spain (Garcia et al., 2004; Fuller et al., 2010), and Greece (Bourbou and Richards, 2007; Bourbou et al., 2011). In addition, a few studies have isotopically examined Roman and Byzantine populations from North Africa, specifically Egypt (White et al., 1999; Dupras and Schwarcz, 2001; Dupras et al., 2001; Dupras and Tocheri, 2007; Williams et al., 2011), and Tunisia (Keenleyside et al., 2009). Apart from the analysis of Neolithic sites (Richards et al., 2003; Lösch et al., 2006; Pearson et al., 2007; Henton et al., 2010; Pearson et al., 2010), little isotopic work has been conducted on skeletal populations from Turkey and none from the Classical-Hellenistic, Roman or Byzantine periods from that region.

The focus of the research presented here is to examine human dietary habits and animal husbandry and feeding practices at the closely related sites of Sagalassos and Düzen Tepe, in southwest Turkey. The skeletal material selected for isotopic analysis is from five specific periods of occupation: Classical-Hellenistic (400–200 BC), Early to Middle Imperial (25 BC–300 AD), Late Imperial (300–450 AD), Early Byzantine (450–600 AD), and Middle Byzantine (800–1200 AD) and represents the largest isotopic study of faunal samples from these periods to date. One of the main aims of this project is to determine if carbon and nitrogen stable isotope ratios in bone collagen can be used to detect changes in diet that can be linked to herding and animal management practices through time. In addition, as many previous studies of classical and medieval populations analyzed no or relatively few faunal samples (e.g., Richards et al., 1998; Fuller et al., 2006; Bourbou and Richards, 2007; Crowe et al., 2010), the large number of results from the 13 species presented here can be used as an ecological baseline or reference for isotopic site comparisons in the future. This will permit a more detailed understanding of not only the animal diets, but the human diets in Turkey and the classical and Byzantine/medieval world in general.

MATERIALS AND METHODS

Sagalassos and Düzen Tepe, Turkey

The ruins of the ancient city of Sagalassos are located in southwestern Turkey near the village of Ağlasun (Burdur province) and ~110 km north of Antalya (Fig. 1). Sagalassos was constructed at an altitude of between F1
1,450 and 1,600 m above sea level on a south-facing mountainside in the western portion of the Taurus mountain range, in a region known as Pisidia in ancient times. The site was already inhabited in the Bronze Age and may correspond to the mountain settlement of Salawassa, mentioned in Hittite sources from the 14th century BC. Sagalassos was conquered by Alexander the Great in 333 BC and described as "not a small city" (Waelkens, 1993, 1997). At 2-km southwest of Sagalassos, a fortified settlement that was inhabited in Classical-Hellenistic times (5th and 2nd centuries BC) called Düzen Tepe was discovered (Vanhaverbeke et al., 2010).

In 25 BC, the region came under the authority of the Roman Empire and Sagalassos greatly expanded and flourished during the next three centuries. As a result of the strategic location of the town's territory (through which passed the Via Sebaste, connecting Pisidian Antiochia with harbors in Pamphylia), Sagalassos developed into an economic center based on its local ceramic industry ("Sagalassos Red Slip Ware") and the production of cash crops (grains and olives) by a network of dependent rural settlements. In its inscriptions the city proclaimed itself as the "first city in Pisidia" (Waelkens, 1993, 1997). During the first two centuries AD, numerous important buildings were erected, including monumental nymphaea, a library, a macellum, an odeon, Roman baths, and a shrine for the divine Hadrian and Antoninus Pius (Fig. 2). However, Sagalassos started to decline after it F2
suffered two severe earthquakes in the early 6th century AD, which destroyed much of the city and the aqueducts in the region (Sintubin et al., 2003). Although the city was

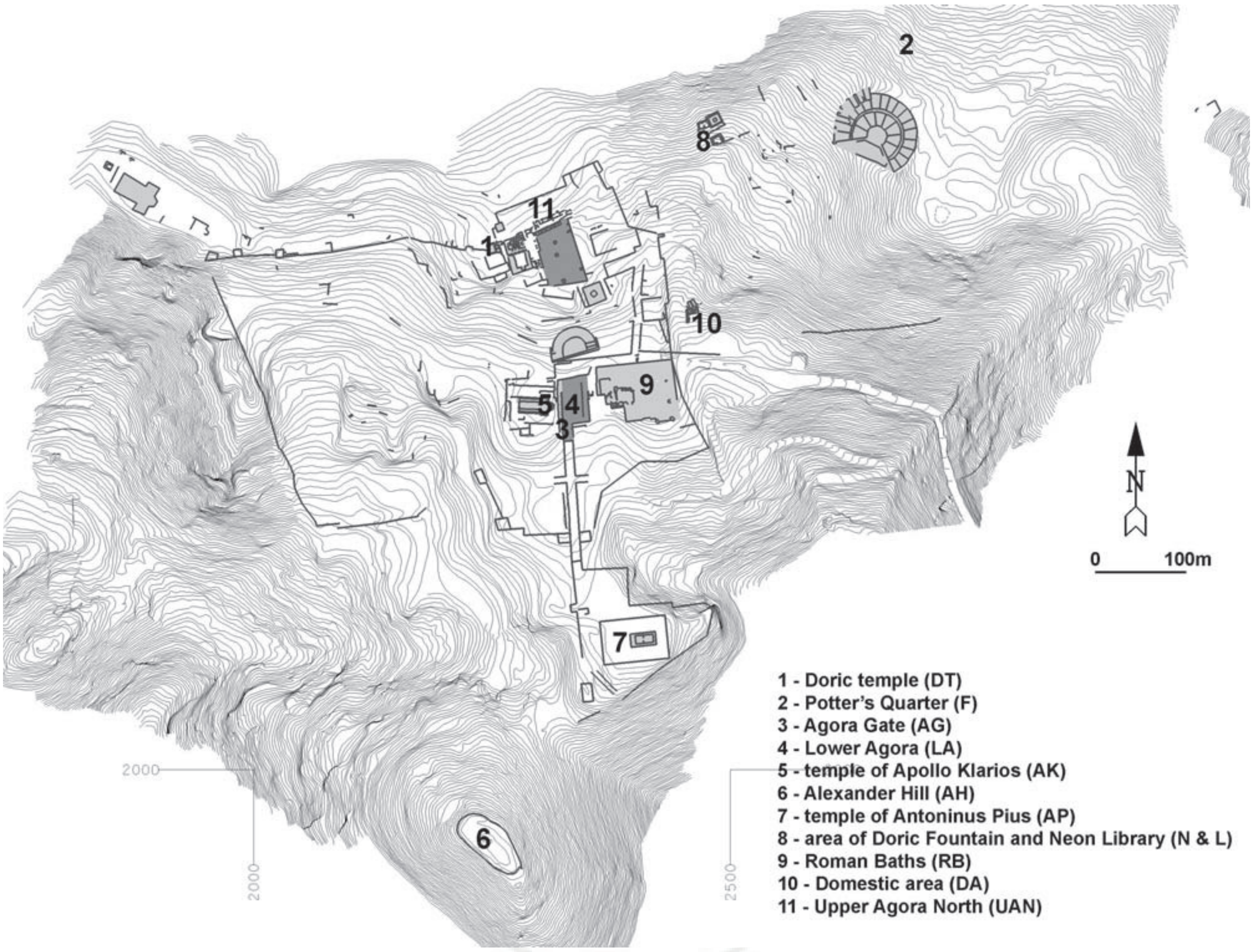

Fig. 2. Topographical map depicting the location of features in the ancient city of Sagalassos, Turkey.

rebuilt, the economic system in Sagalassos began to disintegrate and the plague of AD 541/542, which wiped out half of the population of Asia Minor, was devastating and a large part of the city was abandoned. In the 10th and the 11th century AD, some small settlements still persist within the boundaries of the Imperial city and one on Alexander's Hill, a conical hill located outside of the city walls (Fig. 2). In the 12th century, a mid-Byzantine fortress constructed on that spot was destroyed in the 13th century when the region was conquered by the Seljuks. For a more detailed description of the history of Sagalassos, including the postmedieval period and its rediscovery, see Vionis et al. (2010) and Waelkens (1993, 1997).

A large number of faunal remains have been recovered and analyzed (De Cupere et al., 1993, 2000, 2005, 2009, in press; Van Neer and De Cupere, 1993; Van Neer et al., 1997; De Cupere, 2001; Dufour et al., 2007), and a subset of this material is used for the isotopic analysis presented here. The majority of the faunal remains were identified in the field with the aid of a local reference collection. In general, the faunal remains were collected
F3 in every excavation area of Sagalassos (Fig. 3) by handpicking in the trench, although part of the material was also retrieved by sieving. The age of these faunal remains is based on their stratigraphic position and associated archeological finds, such as ceramics and coins, as well as some AMS ^{14}C dates. A similar methodology was used for the faunal analysis of the Classical-Hellenistic material from Düzen Tepe (Vanhaverbeke et al., 2010; De Cupere et al., in press). Geochemical prospecting in the territory revealed anomalies in the copper (Cu) and lead (Pb) content of the soil that could be related to human artisanal activities, such as metallurgy (Degryse et al., 2003). As a result of these findings, it was possible to examine the heavy metal content of the bones of domestic animals as a means of documenting their provenance through time (Degryse et al., 2004; Vanhaverbeke et al., 2011). Diachronic changes appear in the pollutant levels of the domestic stock that can be related to changes in land use, and these as well as the isotopic results are discussed together.

At Sagalassos, the main necropolis areas located to the western and eastern outskirts of the city have not been the subject of extensive excavations. However, some isolated human remains have been found in trenches from the Classical-Hellenistic period at Düzen Tepe and the Late Imperial period at Sagalassos. The age of these skeletons was established by associated archeological finds and AMS ^{14}C dates. Most of the recovered human material comes from concentrations of Middle Byzantine inhumation graves found near the Christian basilica of Apollo Klarios, at the Lower Agora and the Agora Gate (Fig. 2; Waelkens et al., 2006). Funerary artifacts indicate that they were buried according to Christian tradi-

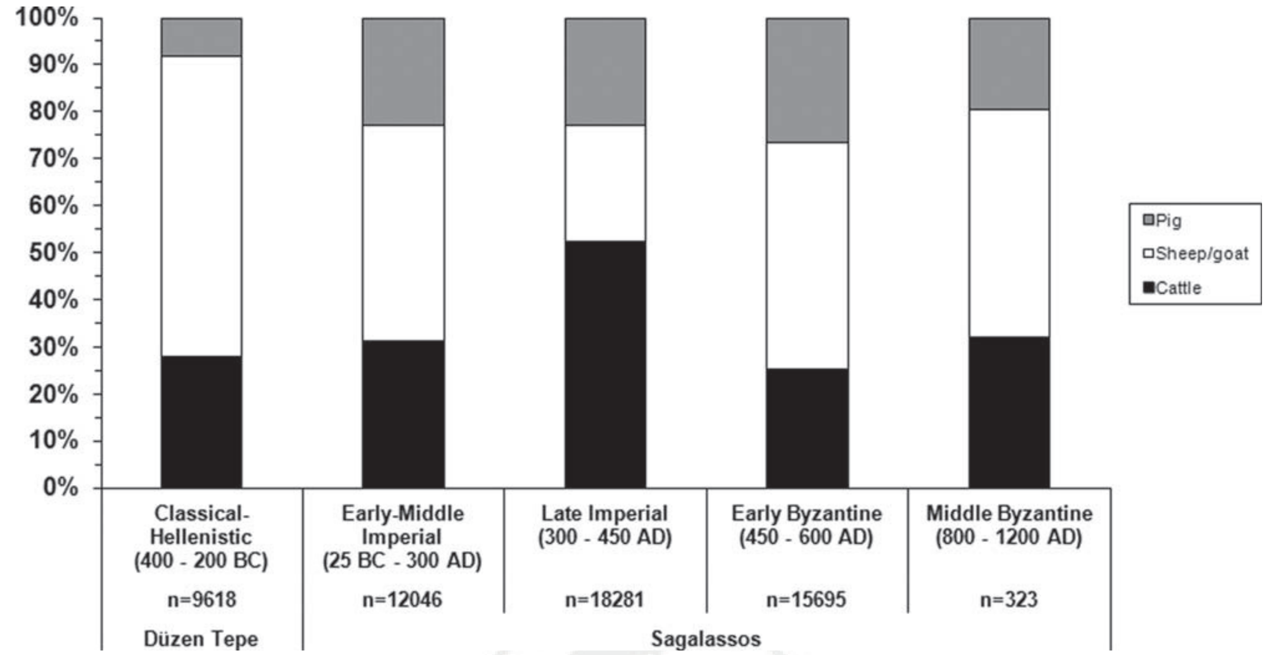

Fig. 3. Temporal changes in the proportions of pig, sheep/goat, and cattle remains recovered during excavations at Sagalassos, Turkey.

tion and the simplicity of the tombs reflects the low social status of the buried individuals (Ricaut and Waelkens, 2008). The incomplete nature and relatively poor preservation of the skeletons did not always allow the sex or precise age of each individual to be determined (Ricaut and Waelkens, 2008).

Collagen was isolated from 454 animals and 49 human bones at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, using the protocol outlined in Richards and Hedges (1999), modified to include a final stage of ultrafiltration prior to lyophilization as described in Brown et al. (1988), and the reader is directed to these articles for more details on the methods. For statistical analysis, ANOVA *ad hoc* Bonferroni tests were used. The data are T1 summarized in Table 1 (mean δ^{13}C and δ^{15}N values and number of samples), and the individual results are presented in Supporting Information Tables S1 and S2.

The archeobotanical information from Sagalassos is based on the analyses of charred plant remains from the different settlement layers in and around the site. The plant remains were extracted by machine flotation, and the average sample volumes varied from 5 to 40 L. Further, the plant material was sorted and identified under magnification and with the help of a reference collection and corresponding identification literature (Davis, 1965–1985; Cappers et al., 2006; Nesbitt, 2006). The results of the archeobotanical analysis in terms of their attribution F4 to certain habitats are summarized in Figure 4 and the F5 main staple crops are plotted in Figure 5 as percentage proportions of the found plant macrofossils.

RESULTS AND DISCUSSION

Individual time periods

Classical-Hellenistic period (400–200 BC). The 38 faunal and 4 human results are summarized in Table 1 and plotted in Figure 6. For the purposes of this study and F6 based on past reviews of stable isotope ratios (Schwarcz and Schoeninger, 1991; Schoeninger, 1995; Katzenberg, 2000; Lee Thorp, 2008), we will be defining and interpreting δ^{13}C values >-19‰ as the threshold, which reflects increasing amounts of C_4 inputs in the diets at Sagalassos. The humans have mean δ^{13}C (-19.4‰ $\pm$ 0.4‰) and δ^{15}N (9.7‰ $\pm$ 0.7‰) values that are typical of a C_3 terrestrial diet based mainly on domestic animal meat and/or secondary products. These human dietary results at Düzen Tepe are in agreement with the findings of Vika (2011) from Classical and Hellenistic populations from Thebes, Greece. The dogs have the highest mean δ^{13}C (-19.1‰ $\pm$ 0.7‰) and δ^{15}N (7.3‰ $\pm$ 1.0‰) values of all the animals, and this illustrates that their diet had a component from the domestic animals, likely meat and bones in the form of food scraps. The diet of the domestic animals is based mainly on C_3 plants and the elevated δ^{15}N values are notable and have also been reported in cattle, sheep, and goats from the Anatolian Neolithic sites of Çatalhöyük and Aşıklı Höyük to the east of Sagalassos (Pearson et al., 2007). It is unknown what caused these high δ^{15}N values, but it could be related to aridity and/or soil salinity (Ambrose, 1991; Schwarcz et al., 1999; Pate and Anson, 2008; Ugan and Coltrain, 2011) or it could suggest that some animals were confined to pens or corrals since their manure would increase the δ^{15}N values of the soil (Commisso and Nelson, 2006, 2007). Indeed, ethnographic studies from central Anatolia have found that the use of sheepfolds was a common practice (Ertuğ-Yaraş, 1997). Whatever the reason, the fact that the mean isotopic values of the livestock are clustered together is evidence that all of the animals were herded and allowed to graze in the same general area or kept in enclosures and fed a nearly identical diet during this period. No significant isotopic differences were found among the species using ANOVA *ad hoc* Bonferroni tests.

TABLE 1. Summary of the stable isotopes ratios of the humans and animals

	Classical-Hellenistic	Early to Middle Imperial	Late Imperial	Early Byzantine	Middle Byzantine	Total
Human (*Homo sapiens*)	−19.4 ± 0.4‰ 9.7 ± 0.7‰ *n* = (4)	–	−19.2 ± 0.2‰ 10.1 ± 0.7‰ *n* = (3)	–	−19.0 ± 0.3‰ 9.1 ± 0.9‰ *n* = (42)	**−19.0 ± 0.3‰** **9.2 ± 0.9‰** ***n* = (49)**
Dog (*Canis lupus* f. familiaris)	−19.1 ± 0.7‰ 7.3 ± 1.0‰ *n* = (5)	−18.5 ± 0.2‰ 8.8 ± 0.4‰ *n* = (5)	−18.6 ± 0.6‰ 9.0 ± 0.6‰ *n* = (10)	−18.3 ± 0.2‰ 9.9 ± 0.4‰ *n* = (7)	–	**18.6 ± 0.5‰** **8.9 ± 1.1‰** ***n* = (27)**
Cattle (*Bos primigenius* f. taurus)	−19.6 ± 1.2‰ 6.1 ± 2.3‰ *n* = (6)	−19.2 ± 0.9‰ 6.9 ± 1.3‰ *n* = (28)	−19.0 ± 1.0‰ 6.5 ± 1.4‰ *n* = (20)	−19.2 ± 0.6‰ 7.4 ± 1.3‰ *n* = (18)	−18.6 ± 1.2‰ 6.3 ± 1.7‰ *n* = (26)	**−19.0 ± 1.0‰** **6.7 ± 1.5‰** ***n* = (98)**
Pig (*Sus scrofa* f. domestica)	−19.7 ± 0.7‰ 5.9 ± 1.7‰ *n* = (5)	−19.8 ± 0.5‰ 7.4 ± 1.3‰ *n* = (27)	−19.9 ± 0.5‰ 7.5 ± 1.0‰ *n* = (20)	−19.9 ± 0.5‰ 7.8 ± 1.6‰ *n* = (19)	−19.8 ± 0.7‰ 7.0 ± 1.3‰ *n* = (19)	**−19.9 ± 0.6‰** **7.3 ± 1.4‰** ***n* = (90)**
Sheep (*Ovis ammon* f. aries)	−19.8 ± 0.7‰ 5.5 ± 1.5‰ *n* = (9)	−19.3 ± 0.7‰ 6.6 ± 1.2‰ *n* = (26)	−19.7 ± 0.8‰ 6.3 ± 1.3‰ *n* = (23)	−19.9 ± 0.7‰ 5.2 ± 1.5‰ *n* = (21)	−19.5 ± 0.7‰ 5.5 ± 1.7‰ *n* = (8)	**−19.6 ± 0.8‰** **6.0 ± 1.5‰** ***n* = (87)**
Goat (*Capra aegagrus* f. hircus)	−19.6 ± 0.3‰ 5.2 ± 1.6‰ *n* = (5)	−19.6 ± 0.5‰ 4.5 ± 1.3‰ *n* = (30)	−19.6 ± 0.5‰ 4.9 ± 1.9‰ *n* = (25)	−19.8 ± 0.5‰ 4.3 ± 0.8‰ *n* = (20)	−19.7 ± 0.1‰ 3.5 ± 1.1‰ *n* = (3)	**−19.7 ± 0.5‰** **4.6 ± 1.3‰** ***n* = (83)**
Fallow deer (*Dama dama*)	−21.2‰ 5.2‰ *n* = (1)	–	–	–	−20.4 ± 0.3‰ 3.9 ± 0.9‰ *n* = (4)	**−20.5 ± 0.4‰** **4.2 ± 0.9‰** ***n* = (5)**
Red deer (*Cervus elaphus*)	−20.8 ± 0.4‰ 4.5 ± 1.2‰ *n* = (7)	–	–	–	–	**−20.8 ± 0.4‰** **4.5 ± 1.2‰** ***n* = (7)**
Brown hare (*Lepus europaeus*)	–	–	–	−21.8 ± 0.5‰ 5.0 ± 1.4‰ *n* = (11)	–	**−21.8 ± 0.5‰** **5.0 ± 1.4‰** ***n* = (11)**
Brown bear (*Ursus arctos*)	–	–	−19.7 ± 0.1‰ 4.6 ± 1.1‰ *n* = (2)	−19.9‰ 6.5‰ *n* = (1)	–	**−19.8 ± 0.1‰** **5.3 ± 1.3‰** ***n* = (3)**
Goose (*Anser anser* f. domestica)	–	–	–	−19.8 ± 0.4‰ 9.5 ± 1.5‰ *n* = (10)	–	**−19.8 ± 0.4‰** **9.5 ± 1.5‰** ***n* = (10)**
Chicken (*Gallus gallus* f. domestica)	–	–	–	−19.7 ± 0.3‰ 8.4 ± 1.2‰ *n* = (10)	–	**−19.7 ± 0.3‰** **8.4 ± 1.2‰** ***n* = (10)**
Chukar (*Alectoris chukar*)	–	–	–	−19.7 ± 0.5‰ 4.8 ± 1.1‰ *n* = (9)	–	**−19.7 ± 0.5‰** **4.8 ± 1.1‰** ***n* = (9)**
Pigeon (juvenile) (*Columba livia*)	–	–	–	−20.0 ± 0.6‰ 4.7 ± 1.4‰ *n* = (8)	–	**−20.0 ± 0.6‰** **4.7 ± 1.4‰** ***n* = (8)**
Pigeon (adult) (*Columba livia*)	–	–	–	−20.3 ± 0.6‰ 4.2 ± 0.6‰ *n* = (6)	–	**−20.3 ± 0.6‰** **4.2 ± 0.6‰** ***n* = (6)**
Total	***n* = 42**	***n* = 116**	***n* = 103**	***n* = 140**	***n* = 102**	***n* = 503**

Presented are the mean $\delta^{13}C$ and $\delta^{15}N$ results and the number of samples analyzed by species and historical period.

Early to Middle Imperial period (25 BC–300 AD). A total of 116 animals were analyzed, and a summary of the data are presented in Table 1 and plotted in Figure
F7 7. The dogs have elevated mean $\delta^{13}C$ (−18.5‰ ± 0.2‰) and $\delta^{15}N$ (8.8‰ ± 0.4‰) values indicating a diet based on the domestic animals. The small C_4 dietary component and the ^{15}N-enriched values of the dogs suggest that the sheep and cattle made up a larger proportion of their diet. The mean values of the cattle ($\delta^{13}C$ = −19.2‰ ± 0.9‰; $\delta^{15}N$ = 6.9‰ ± 1.3‰) and sheep (−19.3‰ ± 0.7‰; $\delta^{15}N$ = 6.6‰ ± 1.2‰) are similar and ^{13}C-enriched compared to the pigs and the goats. These $\delta^{13}C$ values were found to be significantly different between the cattle and pigs (P value = 0.0035) and between the sheep and pigs (P value = 0.0039). This is evidence that the cattle and the sheep were fed or grazed together as many of these animals show evidence of increased C_4 plant consumption. In contrast, the pigs have a more C_3 terrestrial signature (−19.8‰ ± 0.5‰) and higher $\delta^{15}N$ values (7.4‰ ± 1.3‰), meaning that they were kept separate from the other animals and fed a diet that included some refuse from human activity. The goats have the most unique isotopic values ($\delta^{13}C$ = −19.6‰ ± 0.5‰; $\delta^{15}N$ = 4.5‰ ± 1.3‰) and these $\delta^{15}N$ results were found to be highly statistically significant in relation to all of the other animals (P value < 0.0001). These results indicate that the goats were managed very differently compared to the cattle, sheep, and pigs and kept, herded or allowed to graze in different areas around Sagalassos, possibly along the mountainsides (see section on sheep/goats below).

Late Imperial period (300–450 AD). Results from 100 faunal samples and 3 humans are summarized in Table 1 and graphically illustrated in Figure 8. The humans F8
had a terrestrial C_3 diet that was mainly composed of

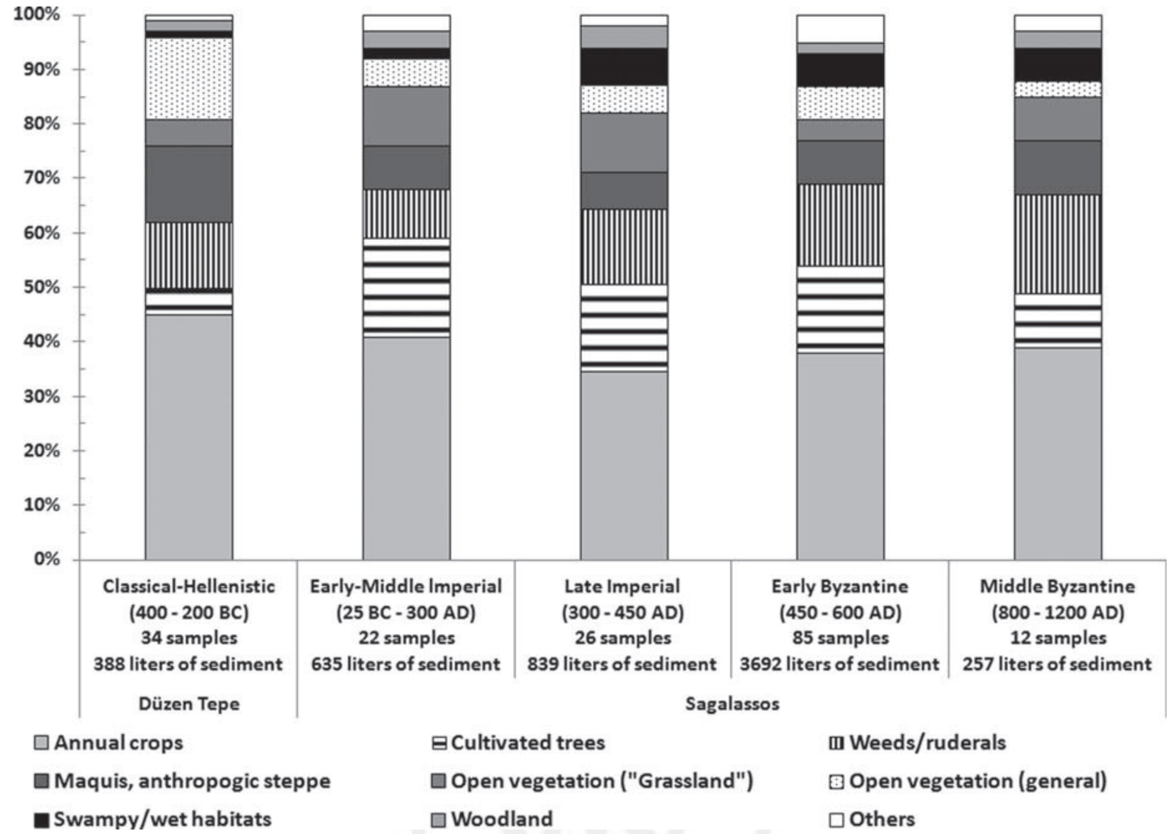

Fig. 4. Diachronic representation of environmental changes at Düzen Tepe and Sagalassos based on the archaeobotanical analysis of charred plant remains recovered (percentage proportions) by machine flotation of sediment.

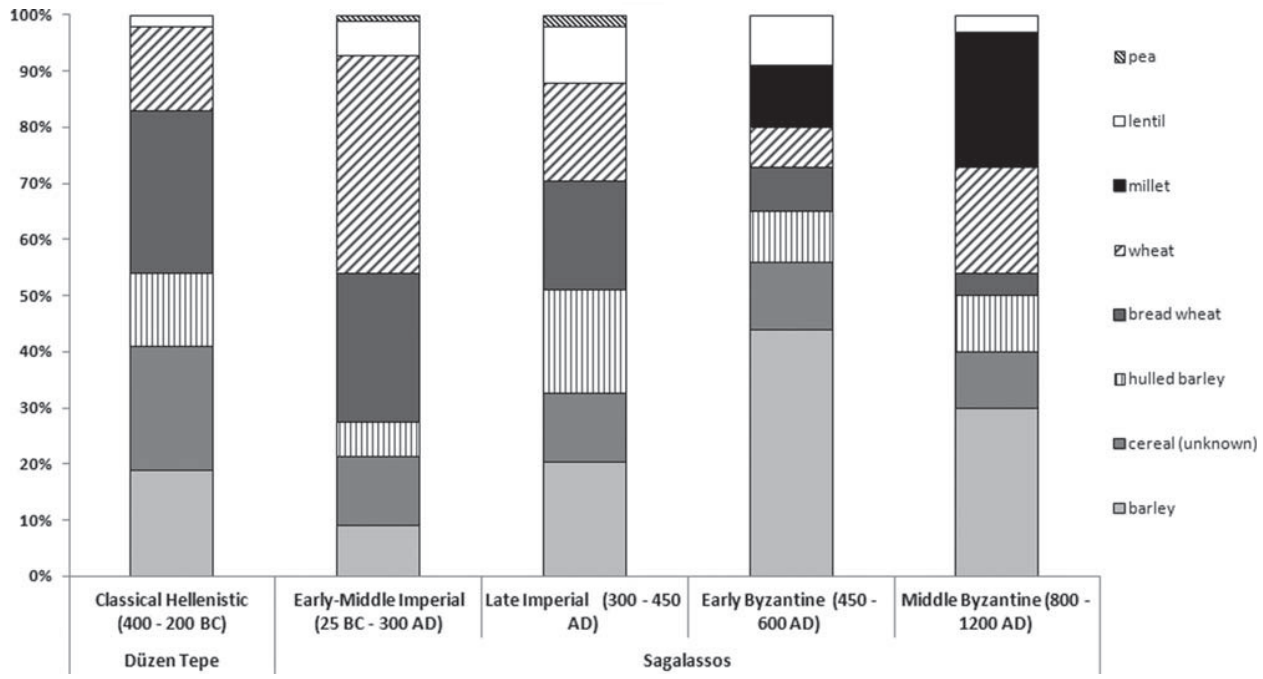

Fig. 5. Diachronic representation of the main stable crops recovered at Düzen Tepe and Sagalassos based on the archaeobotanical analysis of charred plant remains recovered (percentage proportions) by the machine flotation of sediment.

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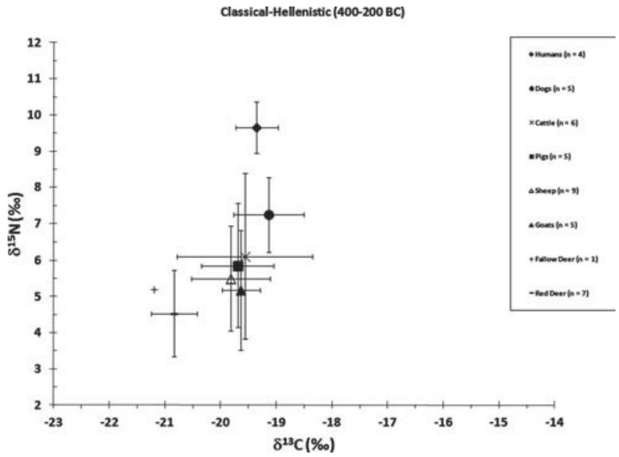

Fig. 6. Human and faunal $\delta^{13}C$ and $\delta^{15}N$ results from the Classical-Hellenistic period at Düzen Tepe, Turkey.

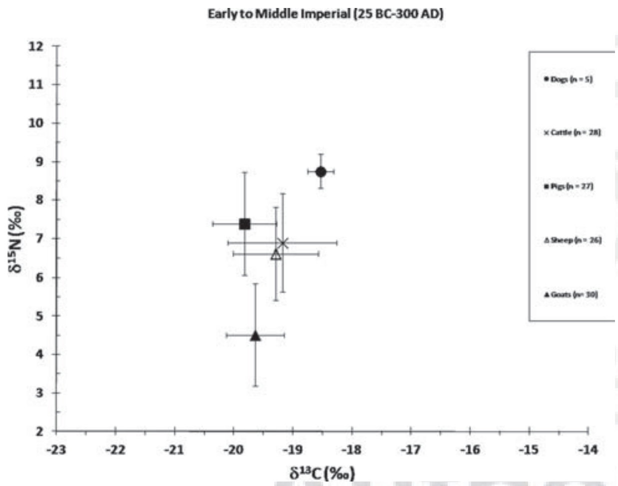

Fig. 7. Faunal $\delta^{13}C$ and $\delta^{15}N$ results from the Early to Middle Imperial period at Sagalassos, Turkey.

the domestic animals and likely heavily influenced by pork consumption based on their high $\delta^{15}N$ values (10.1‰ ± 0.7‰). The dogs have ^{13}C-enriched results (−18.6‰ ± 0.6‰) indicating that they had a C_4 plant signature in their diet likely by way of the consumption of the cattle. The pigs exclusively ate C_3-terrestrial protein resources (−19.9‰ ± 0.5‰) and have high $\delta^{15}N$ values (7.5‰ ± 1.0‰) indicative of some human refuse consumption. The pig $\delta^{13}C$ results are statistically different from the cattle (*P* value = 0.0008), and the $\delta^{15}N$ results are significant in relation to the sheep (*P* value = 0.0016) and goats (*P* value < 0.0001). This is evidence that the pigs were fed, herded, or kept differently from the other livestock during the Late Imperial period. In contrast, the cattle display evidence for grazing on C_4 plants or being fed a C_4 fodder, but there are a number of sheep that also show this C_4 isotopic signal. The mean $\delta^{13}C$ values between the values of the cattle and the sheep were found to be statistically distinct (*P* value = 0.0153). In addition, the cattle $\delta^{15}N$ values were found to be significantly different from the goats (*P* value = 0.0006), which means that these animals were tended, fed, or cared for separately. Compared to the goats ($\delta^{13}C$

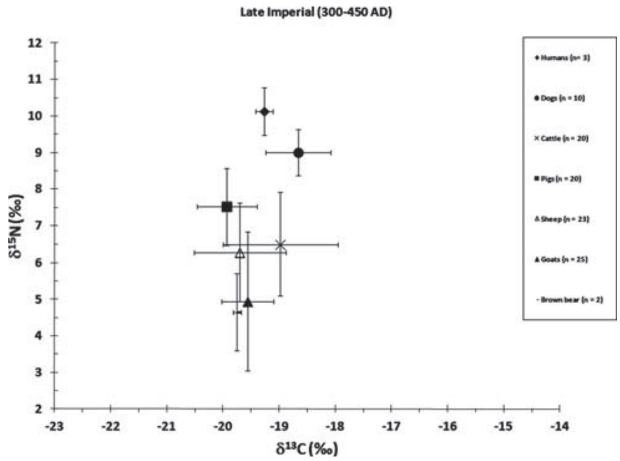

Fig. 8. Human and faunal $\delta^{13}C$ and $\delta^{15}N$ results from the Late Imperial period at Sagalassos, Turkey.

= −19.6‰ ± 0.5‰; $\delta^{15}N$ = 4.9‰ ± 1.9‰), the mean isotopic values of the sheep ($\delta^{13}C$ = −19.7‰ ± 0.8‰; $\delta^{15}N$ = 6.3‰ ± 1.3‰) are ^{15}N-enriched and statistically significant (*P* value = 0.0011). Again, while the $\delta^{15}N$ values are different, the overlap in $\delta^{13}C$ values could suggest that the sheep and goats were sometimes, but not always, herded and kept together at farms in the Sagalassos area. Thus, these isotopic results indicate that the animal husbandry practices appear to have grown more specialized during the Late Imperial period with specific and unique diets (fodders), grazing areas and care practices likely being employed for the pigs, cattle, and goats. The sheep have a mixture of isotopic signals between the cattle and the goats and were possibly fed, grazed, and kept with these groups at different times during the year.

Early Byzantine period (450–600 AD). Results from the 140 faunal samples are summarized in Table 1 and presented in Figure 9a. All of the dogs have an input of F9
C_4 protein (−18.3‰ ± 0.2‰) and the high $\delta^{15}N$ values (9.9‰ ± 0.4‰) suggest that this is likely from the consumption of cattle and other domesticates. The cattle have statistically distinct $\delta^{13}C$ values from the pigs (*P* value = 0.0004), sheep (*P* value = 0.0018), and goats (*P* value = 0.0017) and have different $\delta^{15}N$ values from the sheep (*P* value < 0.0001) and goats (*P* value < 0.0001). These differences highlight the fact that they were fed (foddered) with some C_4 plants in contrast to the other livestock. The pigs have a terrestrial C_3 diet and the highest mean $\delta^{15}N$ values (7.8‰ ± 1.6‰) corresponding to a diet that was supplemented by sheep and goat protein in the form of human refuse. Further, these $\delta^{15}N$ values are highly statistically significant compared to the sheep (*P* value < 0.0001) and goats (*P* value < 0.0001). The isotopic values of the sheep ($\delta^{13}C$ = −19.9‰ ± 0.7‰; $\delta^{15}N$ = 5.2‰ ± 1.5‰) and the goats ($\delta^{13}C$ = −19.8‰ ± 0.5‰; $\delta^{15}N$ = 4.3‰ ± 0.8‰) are not statistically distinct, and this indicates that the sheep and goats were kept, herded, or grazed together.

In addition to the dogs and the typical livestock recovered, a number of other animal species were analyzed from the Early Byzantine period at Sagalassos (Table 1; Fig. 9b). The mean isotopic values of the geese ($\delta^{13}C$ = −19.8‰ ± 0.4‰; $\delta^{15}N$ = 9.5‰ ± 1.5‰) and chickens

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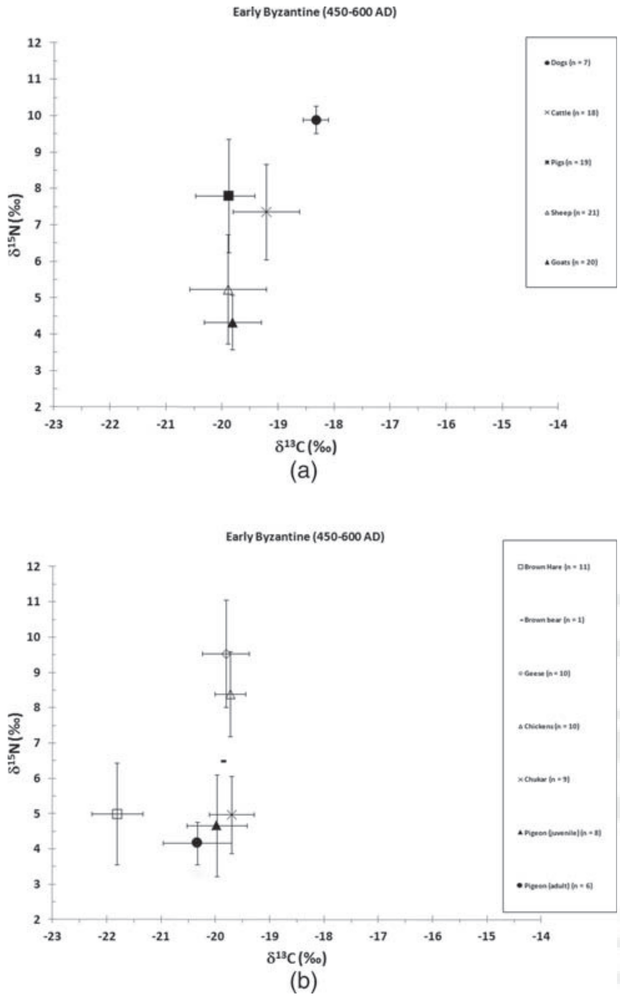

Fig. 9. (**a**) Faunal δ^{13}C and δ^{15}N results from the Early Byzantine period at Sagalassos, Turkey. (**b**) Additional faunal δ^{13}C and δ^{15}N results from the Early Byzantine period at Sagalassos, Turkey.

(δ^{13}C = −19.7‰ ± 0.3‰; δ^{15}N = 8.4‰ ± 1.2‰) are indicative of a C_3 diet and both have extremely elevated δ^{15}N values. These results, which are not statistically significant from each other (P value = 0.0763), indicate that both the geese and chickens were feeding on a diet that included pork, beef, and lamb likely in the form of table scraps and this type of feeding behavior has also been observed in domestic turkeys from the southwest United States (Rawlings and Driver, 2010) and agrees with historical accounts from Roman Italy (Spurr, 1983). Some domestic fowl and geese from the Roman period at York have also been found to have high δ^{15}N values that were interpreted to be the result of the consumption of insects and/or aquatic foods and this could also be a possibility here at Sagalassos (Müldner and Richards, 2007). In contrast, the chukars (*Alectoris chukar*) and pigeons (*Columba livia/oenas*) also have a terrestrial diet, but their low δ^{15}N values suggest that they were eating a diet that was not influenced by human foods in the form of the domestic animals. The hares (*Lepus europaeus*) have the most ^{13}C-depleted values (−21.8‰ ± 0.5‰) and nitrogen results (5.0‰ ± 1.4‰) similar to the sheep and goats.

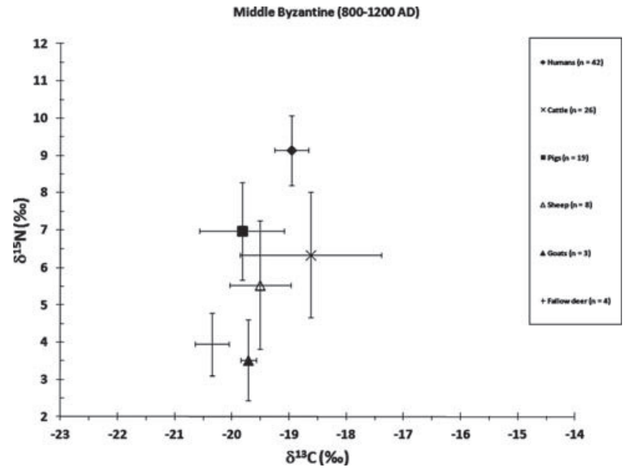

Fig. 10. Human and faunal δ^{13}C and δ^{15}N results from the Middle Byzantine period at Sagalassos, Turkey.

Middle Byzantine period (800–1200 AD). Stable isotope ratio results from 60 faunal and 42 human samples are summarized in Table 1 and depicted in Figure 10. F10
The mean δ^{13}C (−19.0‰ ± 0.3‰) and δ^{15}N values (9.1‰ ± 0.9‰) of the humans show that the diet was C_3 terrestrial and composed of the livestock, mostly the cattle, ovicaprines, and pigs. The cattle have a mixed diet of C_3 and C_4 plants and display the most C_4 plant consumption of all the animals during the Middle Byzantine period (δ^{13}C = −18.6‰ ± 1.2‰). They have δ^{13}C values that are statistically significant compared to the pigs (P value = 0.0004) and δ^{15}N values that are statistically significant to the goats (P value = 0.0091). The pigs were eating a mostly C_3 diet with the addition of a small amount of C_4 foods (cattle) and the high δ^{15}N values, which suggest that the diet was influenced by human refuse, are statistically significant compared to the goats (P value = 0.0003). The number of sheep and goat remains analyzed was small, and the isotopic results were not found to be statistically distinct between the two groups suggesting that there were similarities in feeding and animal management practices during this period. Still, more isotopic data from sheep and goats are needed to confirm this observation.

Diachronic patterns

There have been few studies that use stable isotope ratios to examine diachronic human diet and/or animal husbandry practices at an archeological site (e.g., Müldner and Richards, 2007; Pearson et al., 2007; Eriksson et al., 2008; Fuller et al., 2010; Jørkov et al., 2010; Vika, 2011) and none from the Classical-Hellenistic, Roman, or Byzantine periods in Turkey. Here the isotopic data from the humans and domestic animals (dogs, cattle, pigs, sheep, and goats) are discussed in relation to changes through the different time periods. These isotopic results are then compared to zooarcheological and archeobotanical information where available. In addition, previous work on the analysis of trace elements in the bones of cattle, pigs, and goats from the Early to Middle Imperial, Late Imperial, and Early Byzantine periods found marked changes in Pb and Cu contents (Degryse et al., 2004; Vanhaverbeke et al., 2011). These high heavy metal contents were linked to the intake of foods from the polluted area in the vicinity of Sagalassos, and these results are used with the isotopic results to better understand the proximity with which the animals were raised in relation to the urban center.

Human diet and environment

Although the number of humans analyzed was limited and mainly composed of Middle Byzantine individuals, the isotopic results indicate that the protein portion of the diet was based mainly on C_3 plants and domesticated animals. However, the mean $\delta^{13}C$ values subtly increase (≈0.4‰) through time possibly suggesting that C_4 dietary resources were becoming more prominent in the diet. This trend is similar to the $\delta^{13}C$ results of the cattle (see below) and could indicate increased beef consumption through time, albeit such a trend is not visible in the zooarcheological data (Fig. 3). Unfortunately, as the main necropolis sites of Sagalassos have yet to be excavated this work is preliminary and a future isotopic study on a larger number of skeletons is planned.

In addition to the isotopic results presented here, zooarcheological analysis indicates that the animal portion of the human diet was mainly based on the breeding of domestic animals, i.e., cattle, pigs, and sheep/goats. However, the relative importance of these animals at Sagalassos, changed through time (Fig. 3, see De Cupere, 2001; Vanhaverbeke et al., 2010; De Cupere et al., in press). During the Classical-Hellenistic period, the inhabitants of Düzen Tepe mainly relied on sheep/goats. A similar situation is observed during the Early to Middle Imperial period, although the proportion of the small livestock decreases at Sagalassos, in favor of pig and only to a small extent for cattle. This situation is in sharp contrast with the increased reliance on beef consumption during the Late Imperial period. The Early Byzantine period is again characterized by an emphasis on the herding of sheep and goats, a situation that continues into the Middle Byzantine period. The share of pig remains is more or less constant throughout the Imperial and Byzantine periods at Sagalassos (Fig. 3).

The palynological studies show that the anthropogenetic impact on the vegetation in the area of Sagalassos starts from about 400 BC onwards and is expressed in the form of forest clearance and increasing field cultivation (Vermoere et al., 2002; Kaniewski et al., 2008). In the archeobotanical assemblages habitats with open vegetation and maquis were common during the Classical-Hellenistic period and agriculture relied mainly on bread wheat and less on leguminous crops (Fig. 4). These land use practices were maintained during the Early to Middle Imperial period, when arboriculture also played a significant role in the economy of the study area and had a significant impact on the landscape (Fig. 4 and see Kaniewski, 2008). The wetlands and river surroundings were also increasingly used. In addition, from the Early Byzantine period onwards millet, a C_4 crop, is first identified and starts to play an increasing role in the plant economy of Sagalassos (Fig. 5). During the Middle Byzantine period millet is found in higher quantities in the archeobotanical assemblages, where it was likely used as an animal fodder, and these findings are in agreement with the isotopic results of the humans and domestic animals, especially the cattle, sheep, and dogs (see below).

The domestic animals

Dogs. The mean $\delta^{13}C$ data from the dogs show an increasing trend of about 0.8‰ from the Classical-Hellenistic to the Early Byzantine period, although this trend is not statistically significant (P value = 0.0689) (Fig. 11a). The mean $\delta^{15}N$ results also show an increase of ≈2.6‰ between the Classical-Hellenistic and Early Byzantine period, and this change is highly statistically significant (P value < 0.0001). In addition, the Early to Middle Imperial (P value = 0.0185) and Late Imperial (P value = 0.0014) periods are also statistically distinct from the Classical-Hellenistic period for the dog $\delta^{15}N$ values (Fig. 11b). For all of the time periods the dogs are the most ^{13}C and ^{15}N-enriched, and thus have the highest amount of C_4 plant and animal protein consumption, both likely occurring in the form of meat from the livestock, especially the cattle. F11

Dog remains are regularly found at Sagalassos, albeit not in large numbers. The total lack of butchery traces and the presence of partial and almost complete skeletons, besides isolated bones, indicate that these animals were not consumed. Osteometric analysis of the dog remains showed that small, medium, and large-sized dogs lived in the town of Sagalassos. However, although a large diversity of dog breeds has been indicated for the Roman period (Toynbee, 1983; Clutton-Brock, 1984), it is impossible to establish the type on the basis of the osteological remains. The majority of the dog remains are of adult individuals and the presence of pathological deformations on the vertebrae (*spondylosis deformans*) of several specimens can be related to old age (De Cupere, 2001). These isotopic results pointing toward the consumption of cattle by the dogs seem in agreement with classical texts that mention that the diet of dogs in Italy included among others whey, milk, and bones, but raw meat was dissuaded (Peters, 1998; p 176). In addition, Roman writers recommended that "farm dogs" be fed bread, milk, liver, and bone broth (Merlen, 1971; p 66 cited in MacKinnon, 2010).

Cattle. The cattle have mean $\delta^{13}C$ values that generally increase by ≈1‰ over the five different eras of study (Fig. 11a). While this trend is not statistically significant (P value = 0.1302) among the time periods, it does hint at the increasing importance that C_4 plants played in the diet of some of the cattle. Historical sources mention the use of millet as an animal fodder for quadrupeds (especially esteemed for oxen) in Roman Italy (Spurr, 1983). However, the archeobotanical records from Sagalassos point to the introduction of millet in the territory only from the Early Byzantine period onwards (Fig. 5). Therefore, the cattle with C_4 isotopic results from earlier periods, as well as during the Byzantine, could have also acquired these signatures by grazing on a variety of indigenous C_4 plants that grew within the territory of Sagalassos.

The question that then needs to be explored further is: Besides millet, what species of indigenous C_4 plants could these cattle have been eating in the area around Sagalassos? Unfortunately, no detailed studies on the distribution of C_4 plants within Anatolia have been conducted, but comparison to regions with similar environmental characteristics, such as southeastern Europe, suggest that the prevailing C_4 plants are thermophylous species of the grass family (Poaceae) and sedges (Cyperaceae), which are related to wetlands (Pyankov et al., 2010). These C_4 grasses require a mean temperature of

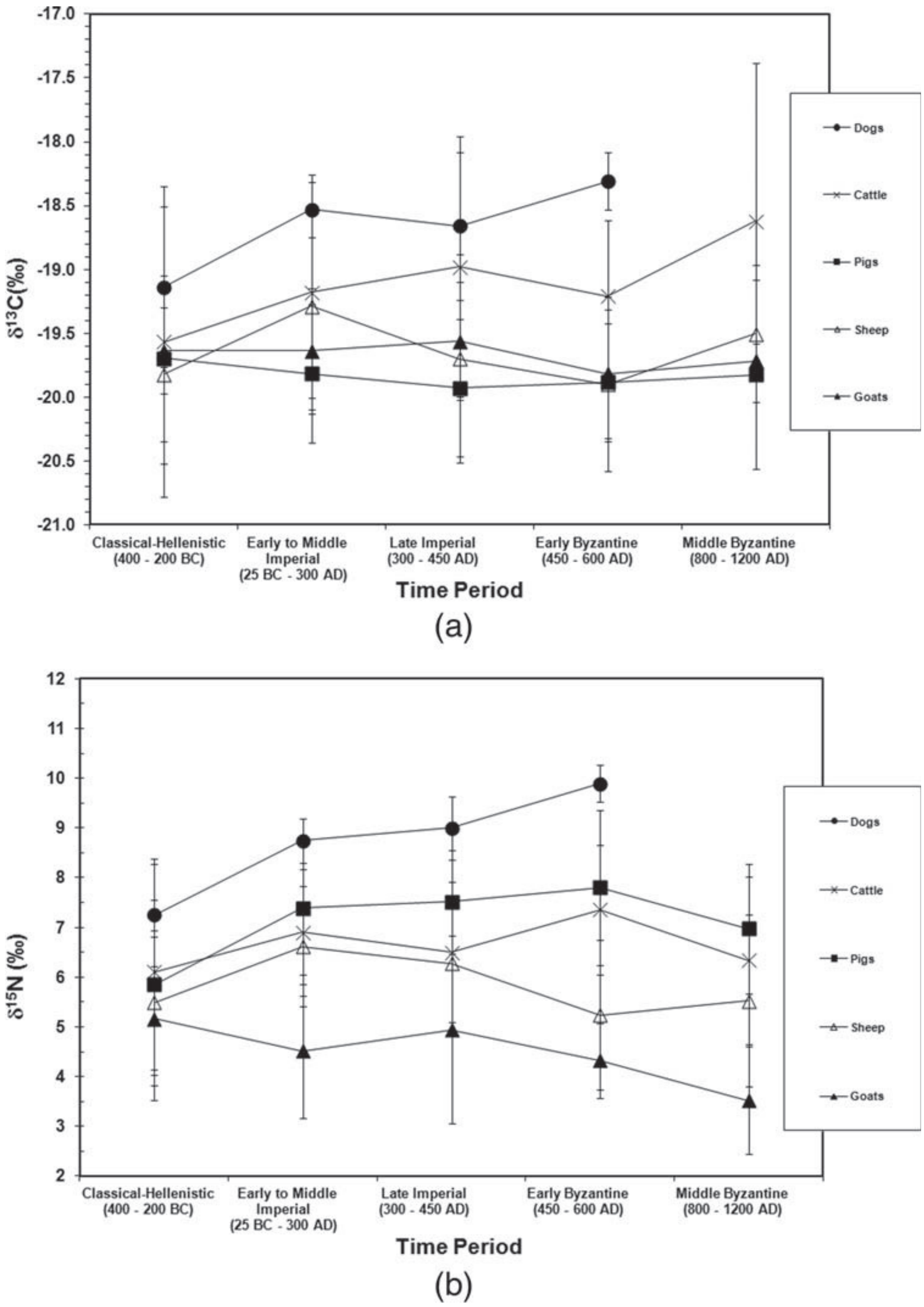

Fig. 11. (**a**) Diachronic $\delta^{13}C$ values for the fauna at Sagalassos, Turkey. (**b**) Diachronic $\delta^{15}N$ values for the fauna at Sagalassos, Turkey.

~22°C during the warmest months and also sufficient precipitation during the warm growing season, and these requirements are fulfilled for the Sagalassos region (Collatz et al., 1998). In addition, increasing humidity and temperatures have been reconstructed for the period from about 800 BC to about 300 AD for the eastern Mediterranean (Bottema et al., 1993, Bar-Matthews et al., 1999, Lamy et al., 2006) and such conditions may have been very favorable for grasses with C_4 type photosynthesis (Ehleringer et al., 1997, Sage et al., 2011).

The archeobotanical assemblages from the periods under consideration (Fig. 4) show an emphasis on the use of open vegetation and an increase in weeds and ruderals during the Classical-Hellenistic and Early to Middle Imperial period. During the Late Imperial and Early to Middle Byzantine periods swampy and wetland habitats are part of the exploited area in and around Sagalassos. These areas could have provided some input of C_4 plants to the diets of the cattle: C_4 plants like *Bolboschoenus maritimus* and *Eleocharis* sp. are rather abundantly found in the archeobotanical record. Both plant taxa occur in about 30–40% of the archeobotanical samples studied from the Late Imperial and Early Byzantine periods. Another wetland C_4 plant is *Fimbristylis* sp., but it is present within just five samples (ca. 6%) from the Early Byzantine period. In addition, C_4 grasses growing in rather fresh/wet open vegetation, such as *Setaria verticillats/viridis* (occurring in ca. 45% of the studied samples) and *Echinochloa* sp. (20% occurrence), are frequently observed for the Early to Middle Imperial and Late Imperial periods. Their abundance in the archeobotanical remains highly suggests their importance as a type of vegetation used by the inhabitants of Sagalassos during these periods. These findings are in agreement with ethnographic studies from central Anatolia where riverbeds and wetlands areas are frequently used as cattle pastures and areas for the collection of cattle fodder (Ertuğ-Yaraş, 1997). Thus, this observed mix of isotopic signatures in the cattle, some with an exclusive C_3 diet and those with significant C_4 plants in their diet could reflect that the cattle were being raised and fed at different farms with varying environmental characteristics (more or less wetland) from across the territory and brought to Sagalassos for sale, slaughter, and consumption by the urban populace.

Finally, the spread of local C_4 plants is also favored by anthropogenic pressure on the vegetation and deforestation (Sage et al., 2011). Studies on the distribution of C_4 plants along a grazing gradient have shown that the proportion of C_4 annual grasses and halophytes increases under grazing pressure (Wang, 2002). So most probably this increasing use of C_4 plants in the diet of the cattle reflects also the general intensification of land use during the Early to Middle Imperial and Late Imperial periods (see Vermoere, 2002; Kaniewski et al., 2008), which could have led to a higher proportion of C_4 plants in the pasture land.

The cattle mean δ^{15}N values do not show a general trend like the δ^{13}C values, but the lowest δ^{15}N values (6.1‰ ± 2.3‰) occur during the Classical-Hellenistic period and the highest values (7.4‰ ± 1.3‰) are found during the Early Byzantine period (Fig. 11b). None of these diachronic changes are statistically significant for the δ^{15}N results (P value = 0.1489), indicating that the protein portion of the diet was relatively unchanged. In addition, the elevated δ^{15}N values of the cattle could be related to how the animals were kept and pastured. Studies in southern Africa and Greenland have shown that δ^{15}N values of soils and plants generally increased in areas used for domestic cattle grazing or cultivation (Commisso and Nelson, 2006, 2007; Aranibar et al., 2008). This pattern agrees with the expected responses of physical and microbial processes to these human activities: enhanced ammonia volatilization, decreased soil crust N_2 fixation, and reduced litter inputs through export of plant material from the system (Aranibar et al., 2008).

The majority of the cattle recovered at Sagalassos were butchered and thus used to feed the human population. The slaughtering pattern indicates that these animals were consumed at an old age indicating they were not only kept for their meat but also for other purposes such as power and possibly milk (De Cupere, 2001; p 143). Pathological deformations observed on their metapodals and phalanges are indicative of hard labor (De Cupere et al., 2000), likely related to the transport of goods and agricultural activities. The economic character of the city of Sagalassos excludes a complete self-supporting meat industry but implies the importation of food from rural production sites. These sites were most probably located near the city of Sagalassos during the Early to Middle Imperial and Early Byzantine periods, as indicated by the elevated heavy metal contents of the bones. During the Late Imperial period, the cattle must have been imported from a larger distance, beyond the polluted area around the city (Vanhaverbeke et al., 2011). Thus, the grazing and foddering practices of the cattle, not only changed in terms of C_3 vs. C_4 content (isotopic results), but by location in relation to the urban center (heavy metal content), and it is likely that these findings are linked through space and time.

Pigs. The mean δ^{13}C values of the pigs show almost no variation through time and indicate that the diet was based almost exclusively on a constant C_3 terrestrial diet (Fig. 11a). The mean δ^{15}N values show an increase (5.9‰ ± 1.7‰) from the Classical-Hellenistic period to the Early to Middle Imperial period (7.4‰ ± 1.3‰) and remain relatively constant until they decrease again during the Middle Byzantine period (7.0‰ ± 1.3‰) (Fig. 11b). These results are only statistically significant between the Classical-Hellenistic and Early Byzantine periods (P value = 0.0437). Still, these elevated δ^{15}N values during Imperial and Byzantine periods reflect that pigs were consuming a large amount of animal protein likely in the form of human refuse.

Analysis of the pig remains at Sagalassos indicates that they were mainly being raised for their meat since generally they were slaughtered young, before 2 years of age. Adult individuals are very rare among the remains found at Sagalassos, and this suggests that the pigs were kept outside the city and brought to town for consumption (De Cupere, 2001; p 143). In general, it is assumed that pigs were herded in the woods. Historical sources indicate that these animals were pastured in oak, beech, and chestnut groves and also fed with beans and grain (White, 1970; p 318), and this would have resulted in somewhat lower δ^{15}N values due to the high consumption of plant proteins. Microwear analysis and the study of linear enamel hypoplasias of the pig teeth from Sagalassos suggested that they were likely free-herded as opposed to enclosed during most of their lives but fattened up, possibly in enclosures, prior to slaughter with a soft non-abrasive diet (Vanpoucke et al., 2009). In addition, the constant high concentrations of heavy metals (Cu and Pb) in the pig bones from all of the periods indicate that herding and/or the collection of fodder for pigs always occurred in or near the polluted urban center of Sagalassos (Vanhaverbeke et al., 2011). These heavy metal results are in agreement with the relatively stable δ^{13}C and δ^{15}N results and indicate that there was little change in the feeding practices (human refuse) and location (near the urban center) of where the pigs were kept through time.

Sheep and goats. During the five time periods, the mean δ^{13}C values of the sheep are relatively stable, between −20‰ and −19‰, reflecting a constant C_3 terrestrial diet for the population as a whole (Fig. 11a). However, like the cattle, there are a number of individual sheep that show consumption of some C_4 plants/fodder in their diet, especially during the Early to Middle Imperial and Late Imperial periods. In fact, the δ^{13}C results between the Early to Middle Imperial and the Early Byzantine periods are close to reaching statistical significance (P value = 0.0509), and this suggests that there were subtle changes in the way in which the sheep were foddered and grazed through time. This finding is in agreement with ethnographic evidence from the region, where sheep were frequently pastured in similar areas as cattle (Ertuğ-Yaraş, 1997). The mean δ^{15}N values of the sheep are higher during the Early to Middle Imperial (6.6‰ ± 1.2‰) and Late Imperial periods (6.3‰ ± 1.2‰) and then decrease during the Early (5.2‰ ± 1.5‰) and Middle Byzantine periods (5.5‰ ± 1.7‰) (Fig. 11b). These results are statistically distinct between the Early to Middle Imperial and Early Byzantine periods (P value = 0.0009), and this decrease in δ^{15}N values could reflect that the sheep were being grazed at different locations around the site of Sagalassos during the Imperial and the Byzantine periods.

Like the sheep, the goats have mean δ^{13}C values that remain nearly constant (−20‰ to −19‰) for all of the time periods, and the diet was based almost exclusively on C_3 plants (Fig. 11a). Again, like the cattle and sheep, a small number of individual goats during the Early to Middle Imperial and Late Imperial periods show a small C_4 plant component to the diet. Thus, the goats had less C_4 fodder compared to the sheep, and this reflects that the goats were herded or allowed to graze more freely on C_3 plants in the area of Sagalassos, possibly on the mountainsides surrounding the site. In contrast to the δ^{13}C values, the goat mean δ^{15}N values are the highest during the Classical-Hellenistic period (5.2‰ ± 1.6‰) and then decrease during the Early to Middle Imperial (4.5‰ ± 1.3‰) and Late Imperial (4.9‰ ± 1.9‰) periods and have the lowest mean values during the Early (4.3‰ ± 0.8‰) and Late Byzantine periods (3.5‰ ± 1.1‰) (Fig. 11b). However, this diachronic trend in δ^{15}N shows no statistical significance between the eras (P value = 0.2632). The decrease in goat δ^{15}N values from the Roman to the Byzantine periods is also observed in the sheep and indicates an overlap in herding and grazing practices between both animals during the different periods.

Sheep and goats are the most common species found at Sagalassos and their slaughtering age indicates that they were bred for more than their meat. It is assumed that, in addition to their manure, goats were important for the production of milk and hair, while the sheep would have produced wool (De Cupere, 2001; p 144). Goat remains are more common at Sagalassos than those of sheep, an observation that is in agreement with the rough environment and terrain of the city in which goats thrive better than sheep. Indeed, the Roman writer Columella also mentions that goats are best herded in rough wooded regions, as they like to feed on bushes and shrubs such as evergreen oak (White, 1970; p 313). The sheep, on the contrary, are more likely to graze on pastures or be integrated into a farm and feed on arable land (White, 1970; p 304–306). These practices are still being applied today as shown by observations made on herding in the territory of Sagalassos (Beuls et al., 2000) or in Central Anatolia (Ertuğ-Yaraş 1997). Shifts in the herding areas of the goats were also indicated by the heavy metal analysis of their bones. During the Early Imperial and Early Byzantine periods, the goats have elevated Pb and Cu levels and thus were kept or herded closer to the urban area. However, the lower heavy metal concentrations observed during the Late Imperial period are indicative of the goats grazing at a distance beyond the polluted area around the settlement (Vanhaverbeke et al., 2011). These results indicate that the Late Imperial period was a time of increased integration of the city of Sagalassos with its territory (Vanhaverbeke et al., 2011).

CONCLUSIONS

This study is the largest and most detailed isotopic investigation of animal species from the Classical-Hellenistic, Roman, and Byzantine/medieval periods, and the first to diachronically examine humans and animals from these periods in Turkey. The combination of stable isotope ratios, zooarcheological, archeobotanical, and trace element evidence creates a better understanding of the herding, grazing, and livestock management strategies employed by the inhabitants of Sagalassos over 1,600 years of occupation.

During the Classical-Hellenistic period, all of the domestic animals had δ^{13}C and δ^{15}N results that clustered together; evidence that the animals from Düzen Tepe were herded in the same general area or kept in enclosures and fed on similar foods. These results reflect that the settlement of Düzen Tepe was inhabited by a self-sustaining community that likely produced its own domestic animals. In contrast, the situation was different at the site of Sagalassos during the Imperial and Byzantine periods where distinct differences among the animal populations were observed. One of the most interesting findings was that cattle and some of the sheep had similar carbon and nitrogen values reflecting a varying C_4 plant diet, suggesting that they were likely grazed or foddered together at certain time periods.

The diachronic analysis of the isotopic trends in the dogs, cattle, pigs, sheep, and goats highlighted subtle variations in these animals. The δ^{13}C values of the dogs and cattle increased (reflecting C_4 plant consumption) during the Imperial and Byzantine periods, but the pigs and the goats displayed little change or a mainly constant C_3 plant-based diet. The sheep had a variable δ^{13}C pattern reflecting periods of greater and lesser consumption of C_4 plants in the diet. In addition, the δ^{15}N results of the dogs, pigs, cattle, and sheep increase substantially from the Classical-Hellenistic to the Imperial periods reflecting increased animal protein consumption in the diet, but the goats registered a decrease. The dogs, pigs, and cattle continue to have elevated δ^{15}N values during the Early Byzantine period, but the sheep and goats decreased. By the Middle Byzantine period the δ^{15}N values of the cattle, pigs, and goats decrease but the sheep show a modest increase. Finally, it is hoped that this research will spur additional isotopic projects in Turkey, as there remains a vast wealth of information to be gleaned from the archeological sites in this country.

ACKNOWLEDGMENTS

This research was made possible thanks to the General Directorate for Antiquities (Turkish Ministry of Culture). Annabell Reiner and Olaf Nehlich are thanked for assistance with collagen preparation and the isotopic analysis.

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