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Reconstructing the Diets of Greek Byzantine Populations (6th–15th Centuries AD) Using Carbon and Nitrogen Stable Isotope Ratios

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ABSTRACT Documentary evidence and artistic representations have traditionally served as the primary sources of information about Byzantine diet. According to these sources, Byzantine diet was based on grain (primarily wheat and barley), oil, and wine, supplemented with legumes, dairy products, meat, and marine resources. Here, we synthesize and compare the results of stable isotope ratio analyses of eight Greek Byzantine populations (6th–15th centuries AD) from throughout Greece. The $\delta^{13}C$ and $\delta^{15}N$ values are tightly clustered, suggesting that all of these populations likely consumed a broadly similar diet. Both inland and coastal Byzantine populations consumed an essentially land-based C_3 diet, significant amounts of animal protein, and possibly some C_4 plants, while no evidence of a general dependence on low-$\delta^{15}N$ legumes was observed. One interesting result observed in the isotopic data is the evidence for the consumption of marine protein at both coastal sites (a reasonable expectation given their location) and for some individuals from inland sites. This pattern contrasts with previous isotopic studies mainly on prehistoric Greek populations, which have suggested that marine species contributed little, or not at all, to the diet. The possibility that fasting practices contributed to marine protein consumption in the period is discussed, as are possible parallels with published isotope data from western European medieval sites. Am J Phys Anthropol 146:569–581, 2011. © 2011 Wiley Periodicals, Inc.

The investigation of diet is an important theme in Byzantine studies (e.g., Mayer and Trzcionka, 2005; Papanikola-Bakirtzi, 2005; Brubaker and Linardou, 2007). Traditionally, this investigation has used documentary sources, which provide rich information on the identity and symbolism of foods but do not always make their relative nutritional importance clear, and zooarchaeological and botanical assemblages, which are still underutilized. Stable isotope ratio analysis of bone collagen, a comparatively recent addition to the study of Byzantine diet (Garvie-Lok, 2001; Bourbou and Richards, 2007; Bourbou et al., 2008; Bourbou, 2010; Bourbou and Garvie-Lok, in press), can compensate for these shortcomings and has already made valuable contributions. Here, we reconstruct broad dietary patterns for one region of the Byzantine empire during the early (4th–9th centuries AD) and middle/late Byzantine (10th–15th centuries AD) periods by integrating the results of a number of prior isotopic studies, comparing values of 142 individuals from eight sites in Greece.

A question of particular interest here is the extent to which marine resources were consumed. Given the extensive coastline of Greece, it might be thought that marine resources would have been important to the diet in all past eras. However, isotopic studies of Greek prehistoric populations have demonstrated that marine resources generally contributed little or not at all to the diet (e.g., Papathanasiou, 2003; Richards and Vika, 2008; Triantaphyllou et al., 2008; Papathanasiou et al., 2009; Petroutsa et al., 2009; Petroutsa and Manolis, 2010). A major exception is the high-status burials in Grave Circles A and B at Mycenae, whose values suggest up to 20–25% marine foods in the diet of some individuals (Richards and Hedges, 1999a, 2008). While

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Additional Supporting Information may be found in the online version of this article.

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later eras are much less thoroughly researched, some sites do show evidence for significant marine resource use, as at Kenchreai (1st–3rd centuries AD) and Isthmia (4th–8th centuries AD; Rife and Garvie-Lok, unpublished results). However, it is unclear whether such marine use was common. This is a particularly interesting question for the Byzantine period in Greece, when Christian fasting regulations may have encouraged increased marine consumption. The importance of marine resources to the diet of contemporaneous Medieval populations (5th–16th centuries AD) further west in Europe has been investigated in a number of isotopic studies (e.g., Müldner and Richards, 2005; Richards et al., 2006; Müldner and Richards, 2007a,b; Salamon et al., 2008). The results, in combination with documentary evidence, suggest that faith played a role in marine resource use in the West. Here, we will compare findings for Greek and Western populations, allowing us to explore potential common factors in marine resource consumption in the two areas.

RECONSTRUCTING DIET BY STABLE ISOTOPE RATIO ANALYSIS

Stable carbon and nitrogen isotope ratio analysis of archaeological bone collagen has been widely used for dietary reconstruction of medieval populations (e.g., Bocherens et al., 1991; Mays, 1997; Richards et al., 1998; Herrscher et al., 2001; Herrscher, 2003; Polet and Katzenberg, 2003; Müldner and Richards, 2005; Richards et al., 2006; Müldner and Richards, 2007a,b; Salamon et al., 2008; Garvie-Lok, 2009; Rutgers et al., 2009). The methodology, covered by numerous review articles (e.g., Katzenberg, 2008; Lee-Thorp, 2008), is based on the principle that the isotopic composition of an individual's tissues reflects that of the foods consumed. Bone is renewed constantly, yet its turnover is slow. Depending on the area sampled, bone collagen stable isotope data represent a long-term average of diet over the last 10 years or more of a person's life (Wild et al., 2000; Hedges and Reynard, 2007). Because collagen is synthesized preferentially from dietary proteins under most conditions, its stable carbon isotope composition primarily reflects that of the consumer's main protein sources rather than an average of all dietary items (Ambrose and Norr, 1993; Tieszen and Fagre, 1993).

Stable carbon isotope ratios (δ^{13}C) can track the consumption of plants of different photosynthetic pathways (C_3 and C_4) through the food web, distinguishing, for example, the consumption of C_3 cultivars such as wheat and rice from the use of C_4 cultivars such as millet and maize (Bender, 1971). Because marine organisms often have elevated δ^{13}C values, δ^{13}C analysis is also useful in distinguishing between dependence on C_3 terrestrial and marine-based foods (Walker and DeNiro, 1986; Schwarcz and Schoeninger, 1991; Richards et al., 2006). Stable nitrogen isotope ratios (δ^{15}N) increase with each trophic level; recent work suggests that this trophic level elevation is in the range of 3–5‰ (Bocherens and Drucker, 2003). Because of this effect δ^{15}N values are used to infer the relative importance of plant and animal products in the diet (Sealy, 2001; Petzke et al., 2005; Katzenberg, 2008). However, they cannot distinguish between meat and dairy products from the same animal (O'Connell and Hedges, 1999). As with δ^{13}C values, δ^{15}N values are generally higher in aquatic ecosystems and can distinguish between terrestrial and marine resource dependence.

DIET IN THE BYZANTINE EMPIRE

The Byzantine Empire (or Byzantium) was the predominantly Greek-speaking continuation of the Roman Empire. The Roman Empire was divided into eastern and western halves in the fourth century A.D. Although the western half collapsed by the fifth century, the eastern half, which included the region known today as Greece, persisted for more than a thousand years in total (ca. 306–1453 AD).

Documentary evidence (e.g., tax records, physicians' comments, travelers' tales, military purchase records, and the dietary regimens at monasteries) and artistic representations (e.g., religious images, illustrations in manuscripts, and the mosaics and wall paintings of churches, palaces, and houses) have traditionally served as the primary sources of information about diet in the Byzantine empire (Koukoules, 1952; Dembinska, 1985; Kaplan, 1992; Mango and Dagron, 1995; Anagnostakis, 1995, 1996; Flandrin and Montanari, 1996; Kislinger, 1996; Braudel, 1998; Bober, 1999; Koder, 2005; Stathakopoulos, 2007; Talbot, 2007; Tsougarakis, 2007; Anagnostakis, 2008). Because Byzantine archaeology has not traditionally emphasized the excavation and publication of middens, the zooarchaeological record offers much less evidence for Byzantine diets (Rautman, 1990; Nobis, 1993). However, published analyses of animal bones from some Byzantine sites do exist, and provide valuable supplementary information (e.g., Kroll, 2010). Together these lines of evidence portray a Byzantine diet that, despite geographical variation, economic, and cultural changes, remained fundamentally similar between parts of the empire and over time, agreeing closely with Braudel's vision (1966, 1998) of the essential Mediterranean diet. A portrait of this diet is sketched here; expected δ^{13}C and δ^{15}N values of key resources and their implications for dietary reconstruction are discussed further below.

The general Byzantine diet was based on grain, oil, and wine. The key grains were wheat and barley; the C_4 grain millet was also cultivated (Teall, 1959). Legumes such as chickpeas and lentils were consumed regularly (Dalby, 1996; Motsias, 1998), as were fruits, vegetables, wild greens, and nuts, whose nutritional importance varied by season and region (Koukoules, 1952; Koder, 1992, 1995, 2005; Motsias, 1998; Littlewood et al., 2002; Dalby, 2003; Anagnostakis and Papamastorakis, 2005; Grünbart, 2007). Although sugarcane, another C_4 cultivar, was grown in the Arab-controlled Mediterranean from the seventh century, the Byzantines ate little of it, considering it a rarity more suited to medicaments (Galloway, 1977; Eideneier, 1991).

Turning to land animals and their products, the documentary sources indicate that sheep, goats, pigs, chickens and cattle were the main domesticated animals, with sheep and goats predominating. Birds and other game were also eaten, especially by the affluent but also

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Abbreviations

BCH	Bulletin de Correspondance Hellénique
Bull Mem Soc Anthropol Paris	Bulletins et Mémoires de la Société d'Anthropologie de Paris
Byz Sym	Byzantina Symmeikta
DOP	Dumbarton Oaks Papers.

TABLE 1. Mean adult human collagen stable isotope values from Byzantine Greece listed by site (mean ± 1 S.D.)

Site	Date (AD)	Location	n	Mean δ^{13}C (‰)	Mean δ^{15}N (‰)
Eleutherna	6th–7th c.	Inland	27	−18.9 ± 0.6	8.2 ± 1.4
Messene	6th–7th c.	Inland	21	−19.2 ± 0.3	8.7 ± 0.6
Sourtara	6th–7th c.	Inland	27	−18.2 ± 0.3	9.5 ± 0.3
Kastella	11th c.	Coastal	19	−18.8 ± 0.3	9.1 ± 1.2
Stylos	11th–12th c.	Inland	10	−18.8 ± 0.7	9.4 ± 1.7
Servia	11th–15th c.	Inland	15	−18.7 ± 0.3	8.7 ± 0.6
Nemea	12th–13th c.	Inland	11	−19.0 ± 0.3	8.7 ± 0.5
Petras	12th–13th c.	Coastal	12	−19.2 ± 0.3	9.5 ± 0.7
		Total	142		

by rural populations where game was plentiful (Kazhdan, 1997; Motsias, 1998; Dalby, 2003; Koder, 2005). Milk came largely from sheep and goats; it was predominantly used for dairy products such as cheese, which were widely consumed (Braudel, 1966; Kazhdan, 1997; Motsias, 1998; Dalby, 2003). The available faunal evidence is consistent with this picture. For example, Mylona (2008a) identified donkey, cow, pig, sheep, goat, wild goat, red deer, chicken, and hare or rabbit in her study of the animal remains from the middle Byzantine (11th–12th centuries AD) house at Pyrgi (Hagia Anna) in Crete. The most common animal was sheep, echoing the documents' evidence for the importance of dairying; the presence of deer, wild goat, and hare or rabbit also confirms that wild game was consumed. Kroll's (2010) synthesis of faunal evidence from sites throughout the Byzantine world tells a similar story: middens contain a diversity of wild and domesticated species, with sheep and goats dominating most assemblages. In general, the age profile of these sheep and goat remains is consistent with a dairying economy (Kroll, 2010: 158).

In addition to the terrestrial foods, marine resources are also frequently discussed, and more than 110 fish and 30 other aquatic organisms are mentioned in Byzantine literature (Braund, 1995; Dagron, 1995; Dalby, 1996; Maniatis, 2000; Kislinger, 2005; Chrone-Vakalopoulos and Vakalopoulos, 2008). Documentary evidence such as the *Geoponika* (Beck, 1895) provides guidelines for fishing methods (see also Koukoules, 1952; Curtis, 1991) and for the organization of the fish industry (Maniatis, 2000). Information on fish as a food comes from medical texts such as the work of Oribasius (Reader, 1928–1933), where most fish and aquatic animals are portrayed as foods of high nutritional value that provide substantial benefits to human health. However, all fish were not equal; they were differentiated as of superior (e.g., red mullet) or inferior (e.g., mackerel) quality, and were sold accordingly for higher or lower prices (Maniatis, 2000). The preparation of fish was also an important factor in its cost. Fish could be salted or dried, and preserved fish eggs and fermented fish sauce (*garum*) were also used (Dalby, 1996; Koder, 2005). Preserved fish, regardless of species, tended to be very inexpensive (Maniatis, 2000). Freshwater fish was also valued (Chrone-Vakalopoulos and Vakalopoulos, 2008), and its consumption could be expected where lakes and rivers existed. Few Byzantine sites preserve abundant fish remains. Where fish bones are preserved they indicate the use of a diversity of species, confirming the documentary sources (Kroll, 2010). An example is the rich assemblage recovered from late Roman/early Byzantine (5th–7th centuries AD) Itanos: in addition to sea turtles, seashells, birds and mammal remains, this site yielded four families of coastal small and large fish: sea breams (Sparidae), parrot-fish (Scaridae), groupers/combers (Serranidae), and picarels (Centracanthidae), (Mylona, 1997, 2008b).

Although they provide abundant evidence as to the foods that were available and how they were valued, the written sources do not always identify the relative importance of these products in the Byzantine diet. For example, although we know the names of some legumes and how they were prepared, their nutritional importance is less clear than for grain (Koder, 2007). Similarly, assessing the frequency of consumption of various marine species and meat is problematic. Meat consumption by the average Byzantine person is uncertain, with some sources suggesting that meat was generally available while others suggest that it was a dietary rarity (Koder, 2005, 2007). When discussing marine resource use, it is particularly important to consider the potential role of fasting in the daily diet. The church often required its faithful to refrain from eating certain foods (Koder, 2005; Nicholas and Louvaris, 2005; Parry, 2005). Its calendar imposed some form of dietary restriction for nearly half the days of the year. On these days meat consumption was prohibited. Prohibitions of other foods varied between specific fasting days. However, fish consumption was usually permitted and even the strictest fasts allowed the consumption of other marine resources such as shellfish. For any person following them faithfully, these rules would have resulted in a diet whose animal protein came to a large degree from marine resources. We cannot assume that all people adhered to the fasting regimen. We also must consider that people could adhere to the fasting requirements by simply eliminating all animal products from their diet. Still, it is reasonable to suggest that fasting regulations made marine resources important to the Byzantine diet—a suggestion that can be tested using stable isotope analysis.

MATERIAL AND METHODS

This study integrates data from the isotopic analyses of 142 adult humans from eight Byzantine era sites in Greece, both inland and coastal (Table 1; Fig. 1). Samples from three of the sites (Servia, Petras, and Nemea) were analyzed by Garvie-Lok (2001). The Servia (n = 15) material is derived from subfloor graves in the episcopal church of Kastron. This series of burials dates to the initial centuries after the church was constructed in the 11th century AD. The site lies at a distance of 50 km from the coast, but because it is separated from it by the northern extension of the Olympos-Pelion-Ossa mountain range, fresh marine resources would not have been easily available in premodern times. The Petras (n = 12) samples are from a rural cemetery dating to the late 12th or early 13th century AD. This site sits directly on the coast and would have enjoyed easy access to fresh marine resources. The Nemea (n = 11) samples are from

Fig. 1. Map of sites from which human and faunal samples have been analyzed.

TABLE 2. Mean faunal collagen stable isotope values from Greece listed by site (mean ± 1 S.D.)

Site and date (AD)	Animal	n	Mean δ^{13}C (‰)	Mean δ^{15}N (‰)
Eleutherna (6th–7th c.)	Sheep	2	−20.4	5.3
Sourtara	Dog	1	−18.7	8.4
(6th–7th c.)	Goat	1	−20.7	2.6
Athens	Cow	4	−20.2 ± 0.6	6.0 ± 0.9
(9th–18th c.)	Pig	6	−20.3 ± 0.9	6.1 ± 1.8
	Sheep/goat	10	−19.6 ± 0.4	6.1 ± 2.9
Kastella	Pig	3	−20.7 ± 0.3	5.7 ± 1.9
(11th c.)	Sheep/goat	6	−20.2 ± 0.8	4.8 ± 0.7
	Red deer	1	−21.0	4.6
Corinth	Cow	1	−20.4	4.2
(12th–13th c.)	Pig	1	−19.6	3.6
	Sheep/goat	4	−19.7 ± 0.4	4.0 ± 1.0
Mytilene	Cow	1	−21.4	3.5
(14th–19th c.)	Pig	2	−20.8	5.9
	Sheep/goat	4	−21.5 ± 0.2	6.5 ± 1.3
	Total	47		

a Byzantine farming community, and date to the 12th–13th century. The site is only about 20 km from the nearest coastline, but like Servia, it is separated from the sea by mountains, and it would have been difficult for the inhabitants to obtain fresh marine resources during the Byzantine era.

The five remaining sites, Eleutherna (n = 27), Messene (n = 21), Sourtara (n = 27), Kastella (n = 19), and Stylos (n = 10), were prepared and analyzed by Bourbou and Richards (2007), Bourbou et al. (2008), and Bourbou (2010). The burials at the rural site of Eleutherna (6th–7th century AD) are from excavations at the basilica. The site is located at the eastern part of a natural hill, and the north coast of Crete was accessible through a valley, a travel distance of around 10 km. Also from the same period date the burials of ancient Messene, a site protected from the NE by the mountain Ithomi and surrounded by a fertile valley, $\sim$25 km from the south coast of the Peloponnese. The rural cemetery of Sourtara also dates to the 6th–7th centuries AD and is located in Northern Greece, around 60 km from the sea and close to the site of Servia (see above). The burials excavated at the church of Ag. Ioannis Theologos at Stylos date to the 11th–12th centuries AD. The site is near the modern village of Stylos, which is well-known for its natural springs. It is $\sim$10 km from the northern coast of Crete, but even the shortest route to the coast is winding and rugged, making access less direct than this distance suggests. The urban cemetery of Kastella dates to the 11th century AD, and has immediate access to the sea, as the north coast of Crete is only a few hundred meters from the site location. These eight cemetery populations represent communities mainly depending on agriculture and husbandry, or involved in other subsidiary activities (i.e., household

TABLE 3. Collagen stable isotope values for modern fish samples (mean ± 1 S.D.; Garvie-Lok, 2001)

Common name	Scientific name	Diet (major dependence; Whitehead et al., 1989)	n	δ^{15}N (‰)	δ^{13}C (‰)
Sardine	*Sardina pilchardus*	Plankton	4	6.7 ± 0.8	−16.4 ± 0.4
Anchovy	*Engraulis encrasicolus*	Zooplankton	4	6.3 ± 0.8	−17.5 ± 0.8
Gilt-head sea bream	*Sparus aurata*	Crustaceans, molluscs, fish	1	9.7	−17.9
White sea bream	*Diplodus sargus*	Invertebrates	1	10.6	−12.1
Blue whiting	*Micromestitius poutassou*	Crustaceans, amphipods	1	17.9	−14.8
Red mullet	*Mullus surmuletus*	Invertebrates, small fish	2	8.5	−15.4
Horse mackerel	*Trachurus mediterraneus*	Crustaceans, fish	1	8.1	−15.5
	Means	All fish		9.7 ± 3.9	−15.7 ± 2.0
		Sardine and anchovy		6.5 ± 0.8	−17.0 ± 0.8
		Other fish		10.9 ± 4.0	−15.1 ± 2.1

manufacture, trade, and fishing). Most settlements were of rural character, with the exception of Messene where a more urban settlement organization existed.

To provide a context for the human stable isotope values, faunal values for each site should be known. However, associated fauna were only available for Eleutherna ($n = 2$), Kastella ($n = 13$), and Sourtara ($n = 2$). To supplement these samples, and give an idea of the wider regional variation in the local ecosystem, faunal results (Garvie-Lok, 2001) from three other sites dating to the Byzantine through early modern periods are also discussed: Corinth ($n = 6$), Athens ($n = 20$), and Mytilene on the island of Lesvos ($n = 7$; Table 2).

Because fish remains were not a part of these faunal collections, stable isotope ratio values for marine resources were estimated from modern Aegean and Adriatic fish ($n = 14$; Garvie-Lok, 2001; see Table 3). These fish were purchased fresh from the Athens central market. Bones were cleaned of soft tissue and defatted, and collagen was extracted using the same method used for the Nemea, Servia and Petras archaeological remains (see below; Garvie-Lok, 2001).

Samples from Nemea, Petras, and Servia represent ribs and long bones. Collagen was isolated by soaking bone chunks in repeated changes of 1% HCl solution (Sealy, 1986), then treated with 0.125M NaOH for 20 hours to remove humic and fulvic acid contaminants (Katzenberg and Weber, 1999). Collagen preservation was assessed from collagen yield, C:N ratios, %C and %N (DeNiro, 1985; Ambrose, 1990; Supporting Information Tables S1 and S2). The collagen was analyzed at the Stable Isotope Laboratory of the University of Calgary (Canada), Department of Physics and Astronomy, using an NA 1500 elemental analyzer coupled to a Finnigan Mat TracerMat mass spectrometer.

Samples from Eleutherna, Kastella, Messene, Sourtara, and Stylos were collected mainly from ribs and long bones. Human bone collagen was extracted from these samples following a modified Longin procedure (Longin, 1971), as outlined in detail elsewhere (Richards and Hedges, 1999b), with the addition of an ultrafiltration step (Brown et al., 1988). Isotopic values for the Kastella samples were measured using a Carlo Erba elemental analyzer coupled to a ThermoFinnigan Delta Plus XL mass spectrometer at the Isotope Laboratory, Department of Archaeological Sciences, University of Bradford. Isotopic values for the samples from Eleutherna, Messene, Sourtara and Stylos were measured using a ThermoFinnigan Flash elemental analyzer coupled to a ThermoFinnigan Delta Plus XL mass spectrometer at the Max Planck Institute for Evolutionary Anthropology, Department of Human Evolution, Leipzig, Germany.

RESULTS

The diagenesis indicators and stable isotope data are presented in Supporting Information Tables S1 and S2. As the analyses were originally undertaken as part of several different studies, diagenesis indicators for individual sites were interpreted separately. In the case of Nemea, Petras and Servia and for the Athens, Corinth and Mytilene fauna, samples with C:N ratios outside the acceptable range of 2.9–3.6 recommended by DeNiro (1985) or %C or %N below the limits (13 and 5%, respectively) set by Ambrose (1990) were rejected, as were samples with collagen yields below 1%. Collagen yields between 1 and 2% were accepted only if no other preservation indicator showed borderline values. Data sets were also examined for linear correlations between indicator values and δ^{13}C and δ^{15}N values. Only the samples that were accepted according to these criteria are presented here. Measurement accuracy during the runs was ±0.1‰ for δ^{13}C and ±0.2‰ for δ^{15}N.

For the sites of Eleutherna, Messene, Sourtara, and Stylos, the collagen was well preserved, and all the samples had yields of over 1% and C:N ratios between 2.9 and 3.6, which is indicative of collagen suitable for isotopic analysis (DeNiro, 1985). Replicate measurement errors on known standards in the runs were less than ±0.2‰ for both δ^{13}C and δ^{15}N.

Summary values for the human, animal, and fish results are presented in Tables 1–3, respectively. The isotopic values of the faunal samples are graphically represented in Figure 2, and those of the human samples are provided in Figure 3 and 4.

The faunal δ^{13}C values are generally indicative of C_3-based diets, ranging from −21.7‰ (for a sheep/goat from Mytilene) to −18.7‰ (seen in a goat from Kastella and a dog from Sourtara). Mean sheep/goat values (likely the best general indicator of the isotopic baseline as sheep/goats would usually have been grazed on the surrounding hills) are: Eleutherna δ^{13}C = −20.4‰, δ^{15}N = 5.3‰; Kastella δ^{13}C = −20.2 ± 0.8‰, δ^{15}N = 4.8 ± 0.7‰; Sourtara δ^{13}C = −20.7‰, δ^{15}N = 2.6‰; Athens δ^{13}C = −19.6 ± 0.4‰, δ^{15}N = 6.1 ± 2.9‰; Corinth δ^{13}C = −19.7 ± 0.4‰, δ^{15}N = 4.0 ± 1.0‰, and Mytilene δ^{13}C = −21.5 ± 0.2‰, δ^{15}N = 6.5 ± 1.3‰. Some intersite variability exists in the sheep/goat δ^{13}C and δ^{15}N values. The Mytilene sheep/goats have significantly lower δ^{13}C values than those from other sites, and significantly higher δ^{15}N values than those from Corinth and Kastella (Mann-Whitney U test, $\alpha = 0.05$, Davis, 1986). As well, the Kastella sheep/goats show significantly lower δ^{13}C values than those at Athens (Mann-Whitney U test, $\alpha = 0.05$, Davis, 1986). The Athens sheep/goat results have a

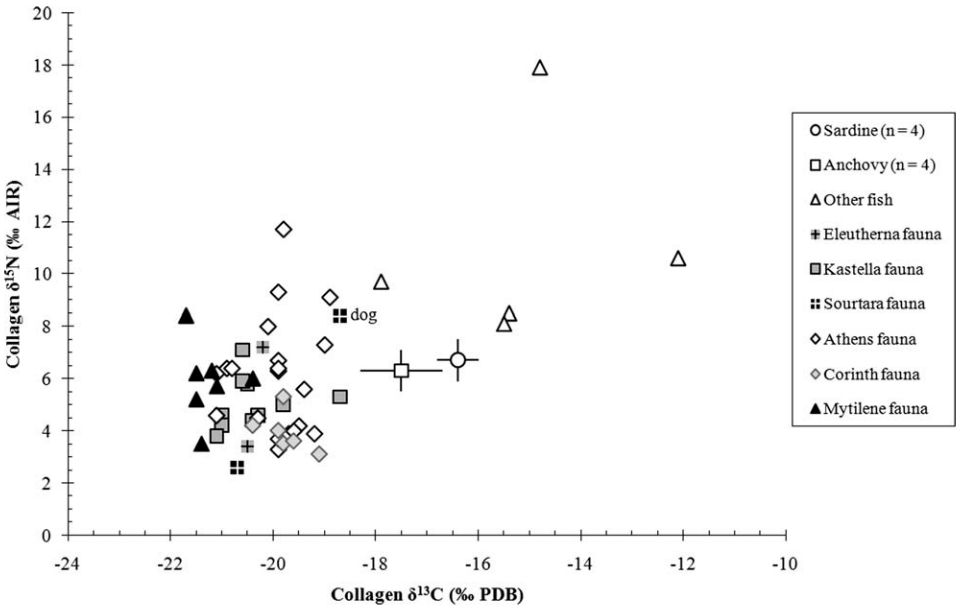

Fig. 2. Values for faunal collagen (archaeological terrestrial fauna and modern fish).

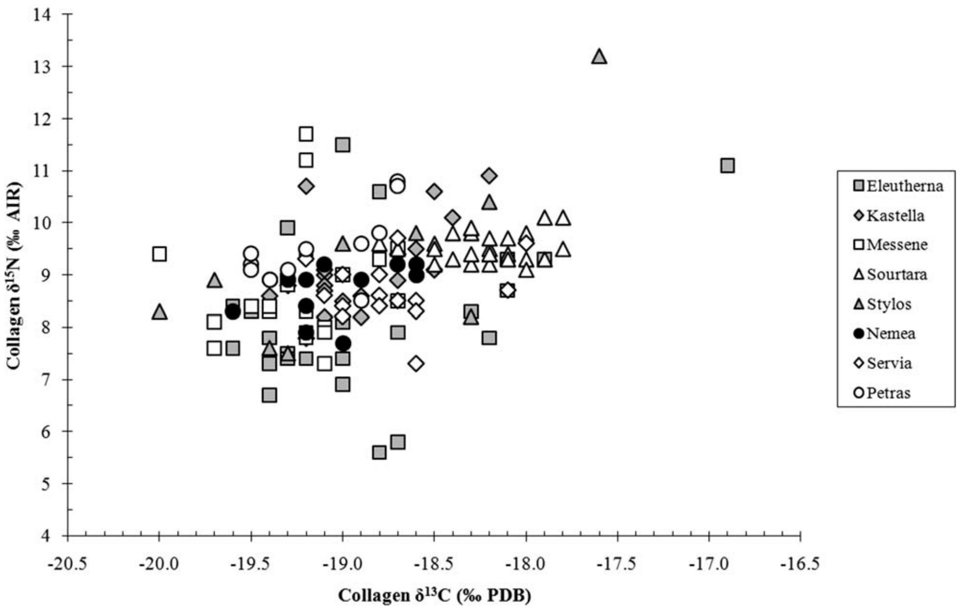

Fig. 3. Collagen stable isotope values for humans, displayed individually.

wide scatter, with δ^{15}N values ranging from 3.3 to 11.7‰. The presence of significant intersite variability in sheep/goat δ^{13}C and δ^{15}N is not surprising given the potential variations in local soil chemistry, plant communities, and animal husbandry practices. As expected, the δ^{13}C and δ^{15}N values of the modern fish are higher than those of the fauna. A difference is seen between the two small plankton-consuming species (sardines and anchovies) and the other species, which have diets of a higher trophic level (see Table 3). The stable isotope values of the sardines (δ^{13}C = −16.4 ± 0.4‰, δ^{15}N = 6.7 ± 0.8‰) and anchovies (δ^{13}C = −17.5 ± 0.8‰, δ^{15}N = 6.3 ± 0.8‰) are modestly elevated above the archaeological fauna. The δ^{13}C and δ^{15}N values of the other fish species are more variable, which is expected given their different feeding habits and places of capture in the Aegean and Adriatic. With δ^{13}C values ranging from −17.9‰ (gilt-head sea bream) to −12.1‰ (white sea bream) and δ^{15}N values ranging from 8.1‰ (horse mackerel) to 17.9‰ (blue whiting), they are generally elevated above the low trophic level fish and the archaeological fauna.

The human stable isotope values are broadly similar, with most individuals showing δ^{13}C values between −18 and −20‰ and δ^{15}N values between 6 and 10‰. Mean δ^{13}C values range from −18.2 ± 0.3‰ at Sourtara to −19.2 ± 0.3‰ at Petras and Messene, and mean δ^{15}N values range from 8.2 ± 1.4‰ at Eleutherna to 9.5 ± 0.7‰ at Petras. When tested using the unequal variance

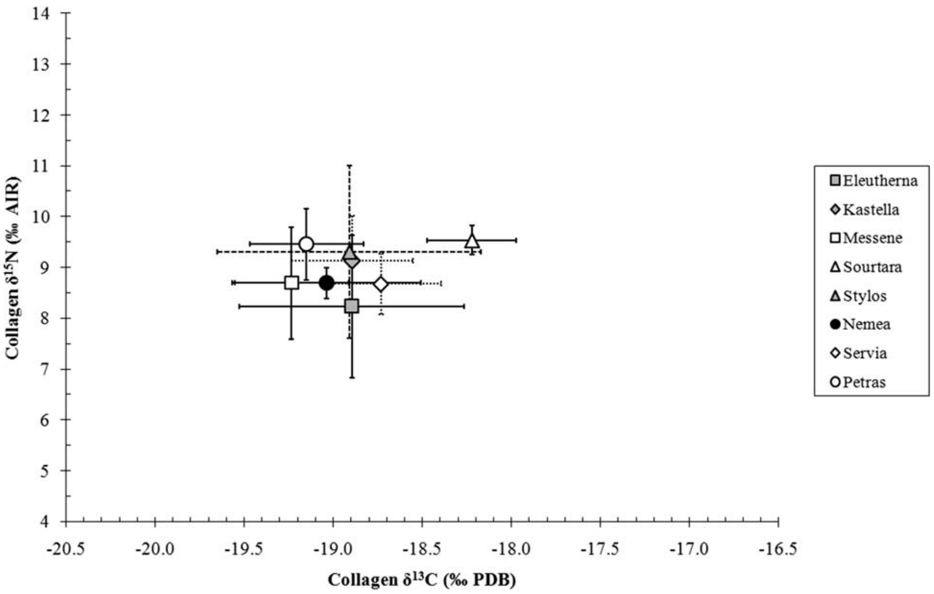

Fig. 4. Human collagen stable isotope values by site (mean ± 1 S.D.).

t-test, a measure appropriate given the small size and uncertain distribution of the samples (Ruxton, 2006), a number of the groups show significantly different δ^{13}C and/or δ^{15}N values at $\alpha = 0.05$. Sourtara, an inland rural group from northern Greece, is the most distinctive. At δ^{13}C = −18.2‰ ± 0.3, δ^{15}N = 9.5 ± 0.3‰, it has significantly higher δ^{13}C values than all of the other groups and significantly higher δ^{15}N results than Eleutherna, Messene, Nemea, and Petras. The results of the other seven sites cluster together. Servia, another inland northern rural site, shows relatively high δ^{13}C (−18.7 ± 0.3‰, significantly higher than Messene, Nemea and Petras), but relatively low δ^{15}N results (8.7 ± 0.6‰). Kastella, Stylos, and Eleutherna share similar δ^{13}C values but differ in δ^{15}N, with Kastella (9.1 ± 1.2‰) and Stylos (9.4 ± 1.7‰) relatively high and Eleutherna (8.2 ± 1.4‰) significantly lower. The lowest δ^{13}C values are seen at Nemea, Messene, and the coastal Petras, which combines low δ^{13}C (−19.2 ± 0.3‰) and high δ^{15}N (9.5 ± 0.7). Despite the statistically significant differences, the mean site values fall into a relatively tight cluster and this is interesting given the diverse foods available to Byzantine era Greek populations and the wide range of likely δ^{13}C and δ^{15}N values estimated for these resources. The sites were also considered by era within the Byzantine period by pooling the early samples from Eleutherna, Messene, and Sourtara (n = 75, δ^{13}C = −18.7 ± 0.6‰, δ^{15}N = 8.8 ± 1.2‰) and comparing them to the later samples from Kastella, Stylos, Servia, Nemea, and Petras (n = 67, δ^{13}C = −18.9 ± 0.4‰, δ^{15}N = 9.0 ± 0.9‰). Although the δ^{13}C difference is statistically significant, the small magnitude of the δ^{13}C and δ^{15}N differences strongly suggests that there were no major dietary shifts between the early and later periods.

DISCUSSION

Estimated δ^{13}C and δ^{15}N values of foodstuffs in the Greek Byzantine diet

Given the documentary evidence, the fauna and fish results and literature δ^{13}C and δ^{15}N values for some general classes of plant foods, it is possible to lay out a rough framework of isotopic values for some available foods to help with the interpretation of the human results (see Fig. 5). As outlined above, the fauna show δ^{13}C values ranging from −21.7 to −18.7‰. This is consistent with a generally C_3-based diet from grazing on wild vegetation, possibly supplemented by some foddering on waste from C_3 crops. Although millet is known to have been available, there is no indication that millet or waste from millet crops contributed significantly to these animals' diets.

The faunal δ^{15}N results vary between and within sites, and mean values for sheep/goat, the most abundant category in the sample series, range from 4.0‰ (Corinth) to 6.5‰ (Mytilene). Because the δ^{15}N values of an animal's meat and milk are broadly similar to that of its bone collagen (Steele and Daniel, 1978; DeNiro and Epstein, 1981; Hare et al., 1991; Kornexl et al., 1997), this suggests a δ^{15}N value in the 4.0–6.5‰ range for the meat and milk. However, this overlooks the issue of intersite and intrasite variability. Mean δ^{15}N values for sheep and goat at Mytilene and Corinth differ by almost a full trophic level, possibly reflecting differences in local vegetation δ^{15}N values, local animal husbandry practices or both. Sheep/goat δ^{15}N values at Athens vary widely, too much to be explained solely by the presence of suckling young in the sample and possibly reflecting the importation of animals from various regions into the community. Given that several of the human samples discussed in this study cannot be associated with faunal assemblages, this evidence for regional variability inserts a degree of uncertainty into the dietary reconstruction for the region. This uncertainty, however, is unavoidable at this time unless all sites without firmly associated faunal remains—in other words a majority of Byzantine-era sites—are to be avoided. Thus, it is most prudent to pool the site data, providing a very broad and general estimated isotopic signature for domesticated animal meat and milk defined by the box outline in Figure 5 labeled "domesticates."

The δ^{13}C and δ^{15}N values of the modern fish suggest that marine resources can be divided into two groups:

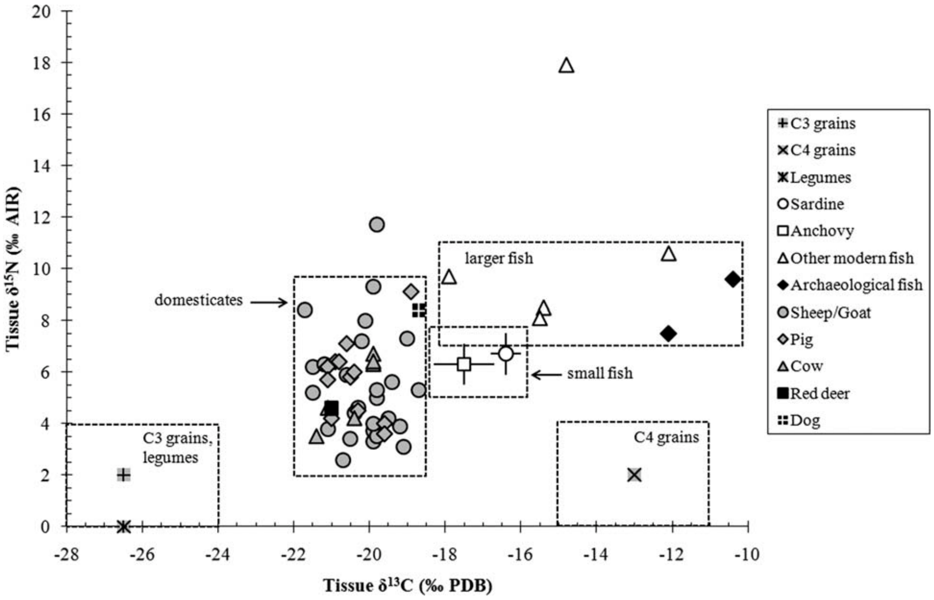

Fig. 5. Reconstructed values (collagen for heterotrophs, seeds for plants) for items in the Byzantine diet. For reasoning and sources used, see text.

sardine and anchovy with δ^{13}C values in the -16.4 to -17.5‰ range and δ^{15}N values in the 6.3–6.7‰ range, and other fish of higher trophic level with generally higher δ^{13}C and δ^{15}N values. This suggests the potential for confusion between the smaller fish and meat or milk from domesticated animals; sardines and anchovies have higher δ^{13}C values, but their δ^{15}N values fall in the upper range of the domesticates. The higher trophic level fish pose less of a problem, with δ^{15}N values higher than those of most domesticates.

As with the faunal values, a degree of uncertainty is present for the fish results. Given the significant impact that pollutants such as sewage can have on the stable isotope values of marine organisms (Rau et al., 1981), it is possible that recent human activity has altered the Aegean food web δ^{13}C and δ^{15}N values, making modern fish an inaccurate model for Byzantine marine resources. Pennycook (2008) found δ^{13}C values of -12.1‰ and -10.4‰ and δ^{15}N values of 7.5 and 9.6‰ for two archaeological fish bones (a sea bream and a tuna) from the Peloponnese. The fact that these are in the general area of those reported here for higher trophic level fish offers some support for the modern fish as a proxy for Byzantine values. It is hoped that further archaeological fish measurements will eventually produce a database of preindustrial values. However, for this study, fish are provisionally assigned the modern values shown by the boxes in Figure 5 (note that this figure also shows the two archaeological fish from Pennycook, 2008). This model assumes that all marine resources would have contributed enriched ^{13}C and ^{15}N signals to Greek Byzantine diets. In the case of the higher trophic level fish, this signal would have stood out clearly against the values of terrestrial animal products. In the case of the small lower trophic level fish, the difference would have been more minor.

Turning to plant products, estimates must come from modern literature δ^{13}C and δ^{15}N values. Most plants mentioned in the documents, including wheat, barley, legumes, olives, fruits, nuts, and vegetables, are C_3 plants, which have tissue δ^{13}C values in the -33 to -22‰ range, with a mean value around -26.5‰ (Bender, 1971; Smith and Epstein, 1971; Deines, 1980). Millet and cane sugar are among the C_4 plants, which have tissue δ^{13}C values in the -20 to -9‰ range, with a mean value around -13‰ (Bender, 1968, 1971; Smith and Epstein, 1971; Deines, 1980). These are the only C_4 plants whose use is documented in the sources. As cane sugar was a relative rarity, this leaves millet as the only significant C_4 plant in a diet dominated by C_3 plant resources.

Modeling the δ^{15}N values of plant proteins is more difficult. Legumes, a potentially important item in the diet, have low δ^{15}N values close to 0‰. The δ^{15}N values of non-leguminous plants fall close to the δ^{15}N values of soil nitrogen, which vary according to local conditions and cannot be arbitrarily predicted (Delwiche et al., 1979; Kohl and Shearer, 1980; Virginia and Delwiche, 1982; Shearer et al., 1983; Schoeninger and DeNiro, 1984). An attempt to estimate local plant δ^{15}N values by subtracting a 4‰ trophic-level enrichment from the collagen values of domesticated fauna suggests low δ^{15}N values in the 0–4‰ range for plants in the animals' diets. Thus, the δ^{15}N values of grains and other nonlegumes consumed by humans would have been in the 0–4‰ range, close to the legumes. This may underestimate the δ^{15}N values of the grain consumed by humans, because cultivation techniques such as manuring soils can elevate grain δ^{15}N values (Bogaard et al., 2007). However, as with the other ranges depicted in Figure 5 it seems a reasonable generalization. Based on this model, reliance on grain and legumes should be easily distinguishable from reliance on the meat or dairy products of domesticated animals, and even more so from reliance on marine resources.

In sum, the reconstructed δ^{13}C and δ^{15}N values of foodstuffs place higher trophic level fish well away from other resources. Lower trophic level fish occupy a space closer to the domesticated fauna, but are still distinctive enough to allow a substantial dependence on them to be

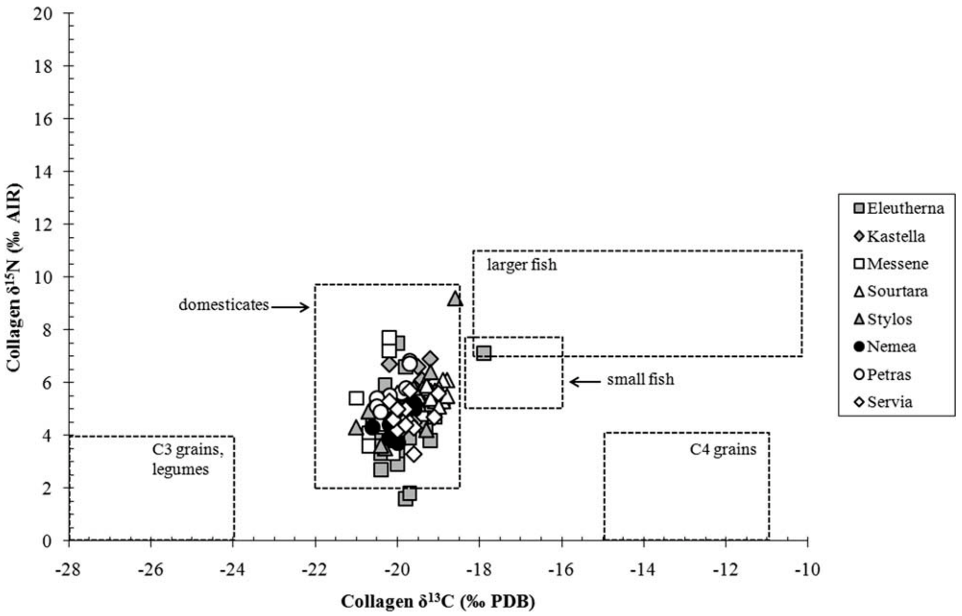

Fig. 6. Human collagen values compared to general values for dietary items portrayed in Figure 5. Human values have been adjusted one trophic level down (-1‰ for δ^{13}C; -4‰ for δ^{15}N).

distinguished from dependence on domesticated animal products. Legumes and millet would also have had distinctive values, and should be easily distinguishable from the other resources commonly used.

Isotopic results and human diet

While one must be cautious that the individuals studied are from eight archaeological sites from across Greece and span a period of ~900 years, the δ^{13}C (mean range = -18.2 to -19.2‰) and δ^{15}N (mean range = 8.2 to 9.5‰) results are broadly similar enough between the communities to indicate the existence of a general "Byzantine diet" (Figures 3 and 4). This agrees with the documentary sources that suggest a reliance on a trio of staples—grain, oil, and wine—that was supplemented, depending on class and other variables, by other foods.

Figure 6 portrays the ranges for dietary items established in the previous section as well as human collagen results shifted down one trophic level (1‰ for δ^{13}C and 4‰ for δ^{15}N). Although this does not capture the subtleties of the human diet, it does allow the groups to be considered relative to the likely values of their foods. With a few exceptions, the human δ^{13}C values fall into the region expected for C_3 resource dependence, indicating that the main diet at all sites was based on staples such as wheat and barley rather than millet. There is some evidence for minor use of millet at some sites. For example, the northern inland sites of Sourtara (δ^{13}C = -18.2‰ ± 0.3) and Servia (δ^{13}C -18.7 ± 0.3‰) show relatively high δ^{13}C values in the absence of easy access to coastal resources. This suggests that both populations consumed some C_4 resources, either directly in the form of millet or indirectly in the form of meat or dairy from millet-fed animals. This finding is consistent with comments made by writers of the Byzantine era (e.g., Simeon Seth, cited in Teall, 1959) that millet was a poor grain, suitable mainly as a fallback food.

The adjusted human δ^{13}C and δ^{15}N values fall into the general area occupied by the domesticated fauna (Fig. 6). This suggests a substantial reliance on meat or dairy products. Hedges and Reynard (2007) have argued that the typical high δ^{15}N values of European agricultural populations often reflect a heavy reliance on dairy foods. Given the uncertainty over meat consumption by the general Byzantine population, it is not possible to exclude meat as an explanation for these values. Still, the documentary and faunal evidence for the importance of dairy foods (Kroll, 2010) makes their use an attractive explanation for the generally high δ^{15}N values seen in Byzantine Greece (Garvie-Lok, 2001; Bourbou and Garvie-Lok, in press).

While the data suggest a primary dependence on dairy products, there are some indications of marine use. As Figure 3 shows, individual values show a rough trend from the region around δ^{13}C = -19.5, δ^{15}N = 8.0 (occupied by the lower end of the Eleutherna, Messene and Stylos values) to the region around δ^{13}C = -18.0, δ^{15}N = 10.0 (occupied by the Sourtara samples and the upper end of the values from Kastella, Servia, and Stylos). This trend is statistically significant (R^2 of δ^{13}C and δ^{15}N = 0.186, $P < 0.05$). This correlation suggests some input from marine resources, since increasing marine resource consumption causes enriched ^{13}C and ^{15}N ratios in humans (Walker and DeNiro, 1986; Richards et al., 2006). Clearly, there is more than one factor at work here; for one thing, the inland location of Sourtara makes a heavy marine component in the diet unlikely. However, for the coastal sites of Kastella and Petras, it is reasonable to conclude that higher δ^{13}C and δ^{15}N values reflect the consumption of marine resources.

A few individuals are notable for values that stand apart from the majority. These include an adult female and an adult male from Eleutherna with very low δ^{15}N values of 5.7 and 5.8‰ and a group of four samples from Messene, Eleutherna, and Kastella with moderate δ^{13}C values around -19‰ and high δ^{15}N values around -11‰. As well, two individuals with values suggesting heavy marine resource dependence are present: one at

Eleutherna ($\delta^{13}C = -16.9‰$, $\delta^{15}N = 11.1‰$), and one at Stylos ($\delta^{13}C = -17.6‰$, $\delta^{15}N = 13.2‰$). As the diets of these individuals differ significantly from those of most of their groups, it is possible that they were buried at the sites under study but spent much of their lives in communities with different diets. The two marine-dependent individuals can thus be taken as possible evidence that there were communities in Byzantine Greece that were heavily dependent on marine resources.

These results agree with some others published for Byzantine remains. Three Byzantine burials from the coastal site of Abdera, Greece analyzed by Agelarakis (1987, 1989; pers. com., 2007) produced average values of $\delta^{13}C = -18.8‰ \pm 0.4$, $\delta^{15}N = 9.5 \pm 1.1‰$, similar to the results reported here and also considered by that researcher to reflect some marine resource use. Also, an analysis of remains from Byzantine (5th–7th century AD) Elaiussa, in modern Turkey, produced average values of $\delta^{13}C = -18.8‰ \pm 0.5$, $\delta^{15}N = 9.0 \pm 1.1‰$; the researchers in that study interpreted the values as indicating a diet combining C_3-based terrestrial resources with fish (Georgi et al., 2005).

Marine foods in Byzantine and Western medieval diets

Medieval Western Europe was a diverse area, showing significant temporal and geographical variation in dietary practices due to differences such as climate, socio-economic conditions, and local customs (Weiss Adamson 2002, 2004). Despite this variation, an important role for marine resources is often seen. A large variety of seafood was consumed, with marine mammals (i.e., whales and porpoises) as well as fish and mollusks included in the diet. While fish were often eaten fresh, a large proportion was salted, dried, and, to a lesser extent, smoked. Notably important were the herring and cod fisheries in the Atlantic and the Baltic Sea, which expanded greatly in the later medieval period (Barrett et al., 2008; Salamon et al., 2008). A considerable motivation for marine food consumption existed as the Roman Catholic Church, like the Eastern Orthodox Church, regularly imposed dietary restrictions on its faithful. Fasting regulations varied over time and by social class, but the basic point was a prohibition on the consumption of meat at many times during the year including Fridays and Lent (Henisch, 1976; Bazell, 1997; Tanner and Watson, 2006).

The importance of fish to the medieval diet in Western Europe is supported by a number of recent isotopic studies. Müldner and Richards (2005) found an important role for aquatic (freshwater and marine) resources at the late medieval sites of St. Giles, Warrington and Towton, possibly reflecting the influence of fasting regulations imposed by the church. This idea was further investigated in a diachronic isotopic analysis of samples from Roman to Post-Medieval York (late 2nd−19th centuries AD; Müldner and Richards, 2007a). The isotopic results suggest that the 11th and 12th centuries were a time of transition where large amounts of marine food began to be included in the diet, possibly due to the increasing impact of fasting rules on fish consumption and the rise of commercial deep-sea fisheries from about 1000 AD. In addition, Richards et al. (2006) presented isotopic data for Newark Bay, Orkney ranging from the Iron Age through the Late Medieval period that show an increase in the frequency of individuals with marine isotopic values, starting in the Viking period and peaking in the 11th–14th centuries AD. Finally, Salamon et al. (2008) analyzed and compared human dentin and bone collagen from sites in Italy. The isotopic data suggest a shift in human diets from a predominantly C_3 base in the early medieval period (500–1000 AD) to the use of substantial marine resources in the later medieval period (1300–1500 AD), possibly associated with innovations in fishing techniques and preservation methods.

Given that both areas had fasting regulations encouraging the consumption of fish, it is appealing to draw an analogy between medieval Western Europe and Byzantine Greece and suggest that the evidence presented here for a marine component in the Byzantine diet reflects, at least to some extent, the influence of fasting customs. It is important to note, although, that factors other than religion would always have been in force. For example, in their study of Imperial Roman Isola Sacra Prowse et al. (2004) found evidence for significant marine resource consumption that is too early to be attributed to Christian practices. They argue that this dietary pattern may reflect economic factors such as relative ease of access to marine resources at this major port or the relative prosperity of the individuals studied. This reminds us that although the influence of fasting practices on Byzantine diet is an attractive hypothesis to test further, it must be seen in a broader social and economic context.

CONCLUSIONS

This study illustrates the significant contributions that isotopic analysis can make to our knowledge of diet in complex historic societies. Despite the large geographical and chronological span of the sites, the isotopic results suggest the existence of a general "Byzantine diet", supporting the documentary evidence. This diet was primarily based on C_3 staples (wheat and barley) and domesticated animals that fed on C_3 plants. A substantial dependence on C_4 grain is not indicated, with the exception of the samples from the northern inland sites of Sourtara and Servia where some millet use was likely. All eight sites have human $\delta^{15}N$ results that are substantially above the values of the local domesticates, suggesting substantial consumption of meat or, more likely, milk. However, the patterning of $\delta^{13}C$ and $\delta^{15}N$ values in several groups and the presence of a few individuals with values unambiguously indicating marine resource use support the idea that some Greek Byzantine populations consumed significant amounts of marine protein.

The evidence for significant consumption of marine species during the Byzantine period contrasts with previous isotopic analyses of prehistoric Greek populations, which generally found marine species contributing little or not at all to the diet. Given the temporal separation of the periods this makes sense, as advanced fishing techniques and a well-organized fish market likely made fish far more available to the majority of the Greek Byzantine population. These results are also very interesting in the context of cultural values surrounding food. We speculate that one factor in the increased consumption of marine resources in the Byzantine era may have been dietary restrictions imposed by the Orthodox Church. A number of isotopic studies of medieval Western populations have demonstrated the increasing importance of fish to the medieval diet over time, implicating the impact of fasting regulations and advances in fishing techniques. The prospect that similar factors were at work in the Byzantine Empire deserves further investigation.

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