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Title

A Tale of Two Villages: Isotopic Insight into Diet, Economy, Cultural Diversity and Agrarian Communities in Medieval (11^{th}-15^{th} century AD) Apulia, Southern Italy.

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Abbreviated title: Isotopic Study of Diet in Medieval Apulia, Italy.

Abstract

This study uses bulk stable isotope analysis of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) of bone collagen to investigate the diets of two deserted medieval villages, Apigliano and Quattro Macine, in Apulia, Southern Italy. The sampled cemeteries represent Latin Catholic and Greek Orthodox religious culture. The aim was to investigate potential inter- and intra-site variation (age, sex, faith, ethnicity, burial location) between these culturally diverse populations and place them in a wider medieval Italian context. Bone collagen was analysed from 103 humans and 33 animals. Sixty-eight humans were sampled from Apigliano (c.13th-15th centuries AD) and 35 individuals from Quattro Macine (c.11th-15th centuries AD). Non-adults, and adults of male, female and unknown sex and contemporaneous animals were sampled from both sites. The isotopic data indicates that both sites subsisted on a terrestrial C_3-based diet with a limited intake of high trophic level protein from meat and fish, as indicated by low $\delta^{15}N$ values. Diet of non-adults matched that of adults from five years of age at Apigliano, but Quattro Macine non-adults exhibit significantly depleted $\delta^{15}N$ values. Variability in diet differed between the two settlements, with Apigliano demonstrating a greater range and higher $\delta^{15}N$ values overall than Quattro Macine. We interpret the differential dietary patterning between sites as a result of socio-cultural and socio-economic factors. Comparison with isotopic data from other Medieval populations indicates trends in subsistence differences across the Italian Peninsula, particularly associated with the rural/urban nature of settlement and the local economy. This research adds new medieval dietary evidence from a geographical area previously unexplored using isotopic techniques.

Keywords: Middle Ages, Collagen, Stable Isotope, Diet, Mediterranean

1. Introduction

Human consumption of food serves a purpose beyond biological necessity and is highly affected by cultural preferences. The choice and procurement of food influences the exploitation of the natural environment and cements societal concepts of identity and culture (Twiss, 2012). During the medieval period in Italy, the peninsula experienced the cohabitation of many different religious and ethnic groups belonging to all echelons of the social hierarchy. Different beliefs and prescriptions pertaining to the foods that could, and could not, be consumed and the manner in which they were to be eaten would have communicated cultural affiliation and served to reaffirm differences, where desired. Throughout the medieval period therefore, there existed multiple dietary patterns that had their basis in traditional Roman foodways that were subsequently added to and altered by various invading peoples and cultural influences. Stable isotope analysis of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) for the purpose of human palaeodietary reconstruction is an approach that has the potential of exploring complex and at times controversial themes such as identity, ethnicity, religion, trade, subsistence economies and animal husbandry (e.g. Alexander et al., 2015, 2019; Makarewicz and Sealy., 2015; Reitsema et al., 2017). Previous isotopic analysis of Italian populations have primarily focussed on Roman communities (i.e. Craig et al., 2009; Craig et al., 2013; Crowe et al., 2010; Killgrove and Tykot., 2013; Prowse et al., 2004; Prowse et al., 2005; Prowse et al., 2007; Prowse et al., 2008; Rutgers et al., 2009), although analyses of medieval communities are growing in number (e.g. Salamon et al., 2008; Reitsema and Vercellotti., 2012; Iacumin et al., 2014; Ciaffi et al., 2015; Baldoni et al., 2016; Buonincontri et al., 2017). Evidence from the south of Italy, however, is scarce, with one study of a Franciscan Friary from Montella, Campania (Torino et al., 2015). To date there is no body of isotopic research conducted on populations from Apulia from any historical period, leaving the unique geographical location of this region, at the very centre of the Mediterranean Sea and its trade routes, uninvestigated.

Targeting this paucity of isotopic data, we applied stable isotope analysis of carbon and nitrogen to the bone collagen of individuals from two deserted medieval villages in southern Apulia, Apigliano and Quattro Macine dating to between the 8^{th} and 15^{th} centuries AD. The inhabitants of these settlements were members of impoverished agricultural communities under complex political and religious influences (Arthur et al., 2012; Loud, 2014). Although contemporary, these settlements were affected by the highly fragmented powers, both domestic and foreign, which claimed supremacy over southern Italy throughout the Middle Ages (Arthur et al., 2012; Goskar, 2011; Loud, 2014). The ever-changing political and cultural landscape left indelible marks on the region, resulting in a variety of religious, ethnic and linguistic cultural traits, though with substantial Byzantine influence (Safran, 2014). The data from these two sites thus offers the opportunity to explore the interaction of ethnicity, diet and nutrition in rural communities that have traditionally received less attention, and that perhaps best reflect the typical practice for foodways in this region. Isotopic analysis of carbon and nitrogen of bone collagen provides a direct measure of the major protein sources in diet to the level of the individual. This technique has the potential to differentiate marine and terrestrial resource exploitation, the consumption of C_3 and C_4 crops and the identification of the trophic level at which an individual is feeding (see Katzenberg, 2000; Sealy, 2001; Schwarcz and Schoeninger, 2011 for detailed reviews). The current study aims to supplement the archaeological and historical record with the use of stable isotope analysis of human and animal bone collagen to explore dietary variation/similarity between and within sites, in relation to burial location, ethnicity, age (adult and non-adult) and sex. We also examine the cultural, ethnic and economic differences between these populations that may have influenced the mode of production and consumption of food (choice), and putting these sites into a wider context of contemporary agrarian communities in Italy.

1.1. The sites

Apigliano lies almost 15 km to the NW of Quattro Macine, and both are located in present day Apulia in south-east Italy (Figure 1). The villages were founded around the 8th century and abandoned by the 16th century, and would have experienced successive governing regimes from Byzantine to Spanish during the course of this time. The individuals sampled for stable isotope analysis pertain to the later medieval period, 11th-15th centuries AD. The populations of these settlements may well reflect the resultant mosaic of Roman, Byzantine Greek and Balkan, Jewish, Norman and later cultural traits that were present in Medieval Apulia (Arthur et al., 2012; Safran, 2014).

[INSERT FIGURE 1 HERE]

Apigliano had a largely Byzantine Greek culture throughout its occupation. Inscriptions and graffiti discovered during excavation were written in Greek, suggesting this was the common language, and the excavated church certainly pertained to the Greek Orthodox faith (Arthur and Bruno, 2009). In total, 186 individuals were identified from Apigliano, 80 adults (18 male, 13 female and 49 indeterminate) and 106 non-adults, excavated from 47 graves in and around the church and 25 small charnel pits in the surrounding cemetery. Of these, 68 individuals were selected for stable isotope analysis (Table 1). The most striking characteristic of the burial population surrounding the church at Apigliano is the funerary tradition of placing a coin in the mouth of the deceased prior to interment (Arthur and Bruno, 2009; Safran, 2014). This tradition was widespread in the Balkans (Arthur and Bruno, 2009; Safran, 2014) and has been discovered at contemporary sites in the region such as Martano, Carpignano Salentino and Maglie, all within a 10km radius of Apigliano, in the district known as Greek Apulia or *Grecià salentina* (Arthur and Bruno, 2009; Gravili, 2009). Whilst certainly not present in all Greek Orthodox burials and generally absent in Italy, it may suggest that the population at Apigliano (but not necessarily the excavated individuals) derives from an, yet undated, migration from the other side of the Adriatic (Arthur, 2005). Perhaps Albania or northern parts of Greece, areas known to have contemporary use of this burial rite amongst some ethnic groups (Arthur and Bruno, 2009).

The settlement of Quattro Macine was contemporary with Apigliano (Arthur et al., 2012; Arthur, 1996). The 10th century saw the construction of a small, perhaps private, Byzantine church, along with possible defensive or boundary works enclosing the settlement (Arthur et al., 2012; Arthur, 1996). Unlike Apigliano, however, Quattro Macine did not remain culturally Greek, with the construction of a Latin Norman church in the 12th century following the Norman conquest of Southern Italy in the preceding century. By 1219 AD the settlement had officially become a fief of the Catholic Archbishop of Otranto, though this may have realistically occurred at an earlier date (Arthur et al., 2012; Arthur, 1996). The establishment of Latin churches has been interpreted as a Norman attempt to counter the persisting Byzantine influence in the region and was a means of reorganising the newly formed Norman duchy (Arthur et al., 2012; Arthur, 1996). However, dating of both churches with corresponding cemeteries at Quattro Macine indicate coexistence up until abandonment of the settlement. A total of 82 skeletons were identified at Quattro Macine, consisting of 35 adults (20 male, 13 female and 2 indeterminate) and 47 non-adults. The individuals were excavated from 58 graves including charnel pits located in and around both the Byzantine and Norman churches. A selection of 35 burials including individuals from both cemeteries were sampled for stable isotope analysis. The ritual deposition of coins in the mouths of the deceased is completely absent from Quattro Macine, thus providing a contrast to the culturally distinct practice at Apigliano. The variety of archaeological finds from Quattro Macine in general, when compared to Apigliano, indicate the former's easier access to an overseas market through the port of Otranto and perhaps a greater consumer capacity for acquiring traded goods.

Although there are no historical records concerning diet at Apigliano or Quattro Macine specifically, botanical analyses from Apigliano yielded evidence of legumes, such as the broadbean in addition to C_3 grains such as wheat and barley, but no evidence of C_4 crops (Grasso and Fiorentino, 2009, 54). Various tree and shrub species were identified including olive, carob and to a lesser extent plum and apple (Grasso and Fiorentino, 2009). The carob tree (*Ceratonia siliqua*) originates in the eastern Mediterranean and its diffusion is closely related to Byzantine domination (Grasso and Fiorentino, 2009). Olive groves were one response to cultivating bad land, which is particularly present at Apigliano. Limited archaeobotanical data is available from Quattro Macine, but the discovery of several rotary querns and grain silos, and the name 'Quattro Macine' (meaning four querns or mills), suggests that grain production and processing was prominent at this settlement, which was also situated in an area of higher rainfall and better soil than Apigliano (Arthur, 1996; Fiorentino, 1999). Faunal remains from both sites show a predominance of ovicaprids throughout settlement occupation, indicating a silvopastoral element to the economy (Arthur, 2009; Arthur, 1996), perhaps more important in later medieval times at Apigliano than at Quattro Macine. The presence of cattle and pigs increases in the 11th and 12th centuries AD at both Apigliano and Quattro Macine, suggesting a change in agricultural strategies following the Norman conquest (Arthur, 2009; Arthur, 1996). However, discovery of butchered small rodents, and perhaps tortoises at Apigliano attests to a population that exploited every possible resource in order to acquire food.

1.2. Diet and economy in medieval Italy

During the later Middle Ages, the gap between upper and lower socio-economic groups grew wider with the rise of the Italian merchant states. Cities such as Venice, Genoa, Florence and Pisa grew exponentially and by the early 14th century AD emerged as the leading centres for long distance trade in the Mediterranean and beyond (Laio-Thomadakis, 1981; Van der Wee, 1993). This exacerbated a north/south divide in Italy, where the north embodied wealth, economic unity, political power and military prowess (Jones, 1966; Laio-Thomadakis, 1981; Van der Wee, 1993). Apulian ports such as Bari, Brindisi, Otranto and Taranto, which had long served as significant Mediterranean trading ports under the Byzantine Empire, could not compete with the merchant fleets of the northern city states and subsequently lost much of their revenue (Laio-Thomadakis, 1981). In terms of food consumption, this led to an overall pattern of cereals, vegetables, and fish (the latter in coastal areas) being consumed in greater quantities in southern Italy and terrestrial meat being more readily available in the north (Adamson, 2004). Zooarchaeological analysis in Apulia has revealed a predominance of sheep, goats, and pigs in the archaeological assemblages; cattle and poultry are also fairly frequent (Mazzorin and Nocera, 2006). Wild game and marine resources are less abundant with only a few fragments of deer and seafood identified. Marine resources are restricted to few species of fish (red snapper, sea bream and sea bass), and some oysters and molluscs, even though soil was sieved during excavation (Mazzorin and Nocera, 2006; Battafarano and Mazzorin, 2006). Indeed, zooarchaeological evidence for marine resources from the medieval period in Apulia indicates that relatively large quantities of fish remains inland are only found in association with castles such as those at Lecce and Muro Leccese, or urban Byzantine centres, indicating the consumption of fish was often linked with high status (Battafarano and Mazzorin, 2006).

In southern Italy, pastoralism was an integral component of the economy, as acidic soils, limited rainfall and shallow bedrock restricted the environmental opportunities for systematic crop cultivation in some parts of the region, such as the surrounding landscape of Apigliano (Arthur, 2004; Montanari, 1999). However, cereals would have featured heavily in day to day life. Crops such as barley, wheat, rye, spelt (all C_3) and C_4 crops such as millet are all attested to in historical documentation. They were significant in the regional diet and grown in those areas where the natural environment permitted (Gonzalez-Turmo, 2012; Arthur, 2004; Tafuri et al., 2009). Grains would have been made into a variety of products including, but not exclusive to bread, soups, porridge, stews, semolina, pearls and sheets, which could be cooked, fermented, fried, baked or dried (Adamson, 2004; Gonzalez-Turmo, 2012). All were modes of food production and preservation that made transportation of cereals possible, and was particularly widespread in southern Italy where shepherding was everyday practice (Gonzalez-Turmo, 2012). Legumes (beans, chickpeas, broad beans and lentils) and nuts (chestnuts and almonds) were also important supplements of protein in low-meat diets, in addition to indispensable nutrition from dairy products (Carpenter, 2008; Vernon, 2008). In the later Middle Ages, food quality and distribution was primarily dictated according to an individual's place within the social hierarchy (Mennell, 1996; van der Veen, 2003). Contemporary Italian texts indicate men were generally afforded a greater ranking in feudal society, and women, like children were considered to be of a lesser status and expected to eat more frugal foods (Safran, 2014). Intra-population patterning in diet along age or gender lines may be explored using isotope analysis.

In a culturally complex and interwoven society as southern Italy, religious food prescriptions and proscriptions would have acted as an agent of cultural unity and division (Albala, 2008). The schism of the 11th century AD separating the Catholic and Orthodox Churches had relatively little impact on dietary habits; fasting and feasts were universal in Christianity and participants from both denominations partook (Matalas et al*.,* 2011, 189). It is therefore difficult to determine the level of, if any, dietary distinctions that were made between Christian denominations or within local communities such as Apigliano and Quattro Macine (Kim et al*.,* nd; Matalas et al*.,* 2011, 189).

2. Materials and methods

[INSERT TABLE 1 HERE]

See Table 1 for summaries of the age and sex profile of human samples and the religious grouping of burials. The individuals analysed in this paper come from three later medieval cemeteries excavated under the direction of Paul Arthur; two at Quattro Macine (Giuggianello municipality) and one at Apigliano (Martano municipality). From Apigliano 68 individuals of

Greek Orthodox burial were sampled for stable isotope analysis, and from Quattro Macine 4 individuals of Greek Orthodox burial, and 31 of Latin Catholic burial were sampled.

Artifactual evidence suggest the Quattro Macine cemeteries date from between the 11th and 15th centuries AD, whilst the excavated cemetery at Apigliano dates to a more limited time frame between the 13th and mid 15th centuries AD. All human material was aged and sexed according to recognised osteological guidelines, first by the late Trevor Anderson, and later by Todd Fenton (Anderson and Niespodziewanski, forthcoming). At Apigliano, the element sampled most frequently was the petrous bone, a small pyramid-shaped bone that is a part of the temporal portion of the skull (White and Folkens, 2005) using bone material left from ancient DNA analysis to avoid unnecessary additional destructive sampling. It should be noted that the otic capsule, a component of the petrous bone which ossifies in utero and during the first two years of life as investigated by Jørkov et al (2009), was not sampled so as to avoid analysing bone collagen that will have pertained to childhood rather than adulthood. Other elements from both sites were selected based on the confidence with which they could be assigned to a particular individual, preferably selecting bones that had already been broken. The cortical and cancellous bone elements plot with similar values at this site. We therefore do not feel that sampling different elements is a significant factor in our results (a complete list of sampled elements is available in Table 6, section 3.3 Human isotopic results).

In order to contextualise the human diet, faunal samples were taken from both Apigliano and Quattro Macine, (Table 2). A total of 33 faunal specimens make up the isotopic baseline, sampled from domestic waste deposits. Domestic and agricultural mammals make up the bulk of taxa in these settlements (Arthur, 1996, 222) and as such, the species selected for this study reflect the taxa most frequently attributed to these sites.

[INSERT TABLE 2 HERE]

Bone collagen was extracted from human and faunal samples (n=136) using a modified Longin (1971) method, (Brown et al., 1988). 300-800 mg of bone was taken from each element and cleaned of visible contaminants with a scalpel. Samples were subsequently demineralised in a 0.6M HCl acid solution at 4°C. The collagen pseudomorph was gelatinised in a pH3 HCl acid at 80°C for 48 hours, ultrafiltered (30 kDa) and freeze dried. Collagen (1 mg) was weighed out in duplicate or quadruplet and analysed by EA/IRMS in a GSL analyser coupled to a 20-22 mass spectrometer (Sercon, Crewe, UK) at the University of York. The analytical error, calculated from repeated measurements of each sample and measurements of a laboratory bovine control from multiple extracts, was <0.2‰ (1σ) for both $\delta^{13}C$ and $\delta^{15}N$. The accuracy of measurements was monitored using international and in house standards with well-known isotopic composition (in-house Fish gelatine: $\delta^{13}C$-15.5±0.1, $\delta^{15}N$ 14.3±0.2; Cane sugar IA-R006: $\delta^{13}C$-11.8±0.1; Caffeine IAEA 600: $\delta^{13}C$-27.8±0.1, $\delta^{15}N$ 0.8±0.1; Ammonium Sulfate IAEA N2: $\delta^{15}N$ 20.4±0.2). All stable isotopic data for carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) are reported in relation to international standards.

Herbivore species (cattle and sheep/goat) and human isotopic data were found to be normally distributed in Shapiro-Wilk normality tests (Apigliano faunal (n=8) $\delta^{13}C$ (W=0.936) P=0.409, and $\delta^{15}N$ (W=0.891) P=0.101; Quattro Macine faunal (n=9) $\delta^{13}C$ (W=0.945) P=0.363, and $\delta^{15}N$

(W=0.978) P=0.935; Apigliano adults (n=34) $\delta^{13}C$ (W=0.983) P=0.778, and $\delta^{15}N$ (W=0.949) P=0.153 and non-adults over the biological age of five (n=13) $\delta^{13}C$ (W=0.954) P=0.668, $\delta^{15}N$ (W=0.900) P=0.132; Quattro Macine adults (n=22) $\delta^{13}C$ (W=0.934) P=0.596, and $\delta^{15}N$ (W=0.949) P=0.140, and non-adults over the biological age of five (n=10) $\delta^{13}C$ (W=0.873) P=0.109, $\delta^{15}N$ (W=0.911) P=0.288), supported by QQ-plots that observed a linear distribution absent of any systematic anomalies or groupings. As such, Welch two-sample t-tests were run when comparing intra-site variation in IBM SPSS statistical software. A 95% confidence level was chosen for all statistical tests.

3. Results

3.1. Collagen quality

Ten human samples failed to produce any collagen for analysis (Table 6). Burials from Apigliano have previously been found to suffer from poor organic preservation (Smith et al., 2002) and this is reflected here in terms of generally low collagen yields from both sites that have a combined average yield of 3.2 ± 2.2 % (1σ). These yields, however, represent the high molecular weight fraction of collagen (>30 kDa) separated out through ultrafiltration rather than the total collagen extract (ultrafiltration can decrease collagen yield by up to 85%, Jørvov et al., 2007), although all yields were above 0.5%. The C:N ratios of all but one sample (AP99SK42, removed from the dataset) were within the accepted range of 3.1-3.5 (Van Klinken 1999) indicating good quality of the collagen overall. The vast majority of the carbon (%C) and nitrogen (%N) weight concentrations were within the range that tend to be reported for intact collagen for Western Europe (34.8 ± 8.8 %C, 1σ, and 11-15 %N, van Klinken 1999), however, even allowing for variation around these suggested values (Van Klinken 1999), there are seven human samples that possess particularly low %C (<20%) and %N (<8%) despite retaining acceptable C:N ratios and possessing $\delta^{13}C$ and $\delta^{15}N$ values that are not atypical of the rest of the population (AP98SK13, AP98SK34, AP99SK106, QM95SK62, QM94SK35, QM95SK42, QM94SK20, Table 6). When considering potential correlations between weight concentrations and isotopic values, we found no correlation between values for %C and $\delta^{13}C$ and %N and $\delta^{15}N$ (pearson's r: $R^2 = 0.03$, $p = 0.098$, and $R^2 = 0.01$, $p = 0.356$, respectively), which indicates that alteration of the isotopic signatures has not necessarily occurred despite low %C and %N. To investigate this further, two samples (QM94SK35 and QM95SK42) with low %C and %N were subject to amino acid (AA) profiling. Their profiles matched a typical collagen AA profile, characterised by a high glycine content, and showed slight racemisation, indicative of archaeological samples (see Supplementary Information). We have therefore retained the aforementioned seven human samples with low %C and %N and a total of 11 samples were rejected from our dataset (identified in Table 6).

3.2.Faunal isotopic results

Summary statistics of faunal $\delta^{13}C$ and $\delta^{15}N$ values from Apigliano and Quattro Macine are presented in Table 3, raw data in Table 4 and the data is plotted with human individuals in Figure 2.

[INSERT TABLE 3 HERE]

[INSERT TABLE 4 HERE]

In general, the isotopic faunal values are consistent with a terrestrial C_3 based diet. There is however a greater range of isotopic values amongst Apigliano taxa, and a more narrow range at Quattro Macine overall (see standard deviations in Table 3). The main domestic herbivores (cattle and ovicaprid) possess means of -20.6‰ ±0.8 and -21‰ ±0.5 in $\delta^{13}C$, and 5.7‰ ±0.8 and 5.3‰ ±0.8 in $\delta^{15}N$ from Apigliano and Quattro Macine, respectively. Cattle and ovicaprids exhibit a slightly wider variation in $\delta^{13}C$ and higher $\delta^{15}N$ values (0.4‰ difference between the means) at Apigliano compared to Quattro Macine. These differences are not, however, statistically significant ($\delta^{13}C$ (T (22)=2.173) P=0.174, $\delta^{15}N$ (T (25)=1.587) P=0.336).

The two horse samples (*Equus f.*) from Quattro Macine possess carbon and nitrogen isotopic values that are similar to cattle and ovicaprids from the same site. However, as we have no horse data from Apigliano, and a lack of clear evidence of butchery on these samples, only the sheep/goat and cattle data are used to construct the herbivore baseline for comparison between sites.

The only carnivores present in this study are one dog from each site, these are enriched 3.4‰ and 2.6‰ above their respective herbivore means, corresponding with an increase in $\delta^{15}N$ following the trophic level offset.

[INSERT FIGURE 2 HERE]

3.3.Human isotopic results

Summary isotopic data according to site, age and sex are presented in Table 5 and plotted with animal data in Figure 2. A complete list of human isotopic data is presented in Table 6.

[INSERT TABLE 5 HERE]

[INSERT TABLE 6 HERE]

3.4.Non-adult results

The Apigliano population includes 25 non-adults from the ages of neonate to 11 years of age and the Quattro Macine population includes 11 non-adults from four to 16 years of age. The 12 individuals below the age of five from Apigliano possess similar $\delta^{13}C$ values to that of the adults, but higher $\delta^{15}N$ values in comparison to both the adult mean (0.8‰), and the remaining 13 Apigliano non-adults over the age of five (0.9‰). This elevation was found to be highly statistically significant ((T (23)=3.558) P=0.002). Non-adult nitrogen data is plotted in relation to age in Figure 3, where a gradual descent of non-adult $\delta^{15}N$ values is visible between the ages of zero and five years. After the age of five, non-adult values are consistent with those of the adults ($\delta^{13}C$ ((T (45)=-1.035) P=0.306); $\delta^{15}N$ ((T (45)=-0.129) P=0.898. In contrast, non-adults over the age of five from Quattro Macine exhibited a lower $\delta^{15}N$ values compared with the adult population mean (by 0.3‰), which was statistically significant ((T (30)=-2.086) P=0.045). Non-adults from both Apigliano and Quattro Macine are therefore grouped according to biological age, those below and above five years, in Table 5 and Figure 2.

[INSERT FIGURE 3 HERE]

3.5.Adult results

Both the Apigliano and Quattro Macine populations yielded isotopic signatures consistent with a predominantly terrestrial, C_3 based diet with a limited intake of higher trophic-level protein. At Apigliano, the enrichment of the human mean above the mean for main domestic herbivores (cattle and ovicaprids) was 1.8‰ for $\delta^{13}C$ and 2.4‰ for $\delta^{15}N$. The Quattro Macine human-herbivore offset was 2.1‰ for $\delta^{13}C$ and 2.3‰ for $\delta^{15}N$. These values are consistent with a stepwise enrichment following consumption of animal proteins. However, a 2.3‰ elevation in $\delta^{15}N$ values is below the expected margins of the trophic level affect where an elevation of at least 3-5‰ is typical (Bocherens and Drucker, 2003). In particular, the majority of each population do not appear to be eating an appreciable amount of protein from those animals with higher $\delta^{15}N$ values such as pigs, chickens and some cattle and sheep/goats, instead it is likely that cereals/plants made up the majority of the diet at both sites.

Comparing the adult populations (34 from Apigliano and 22 from Quattro Macine, Table 5), their $\delta^{13}C$ values are similar with no statistical difference ((T (54)=1.246) P=0.218), but their ^{15}N values differ significantly ((T (54)=2.478) P=0.016), where the median and interquartile range for $\delta^{15}N$ values for Apigliano are higher than those at Quattro Macine (Figure 4). Apigliano demonstrates a slightly higher $\delta^{15}N$ mean (by 0.5‰) and a greater range in $\delta^{15}N$ overall. This was examined in an F-test of equality of variance with a 95% confidence level, where a P-value of (F (1)=7.009) P=0.010 demonstrates the variance of nitrogen is not equal amongst adult individuals between the two populations.

Neither population demonstrate statistically significant differentiation between males and females (AP $\delta^{15}N$ (T (18)=0.446) P=0.661, $\delta^{13}C$ (T (18)=-1.169) P=0.258; QM $\delta^{15}N$ (T (20)=-0.106) P=0.917, $\delta^{13}C$ (T (20)=0.188) P=0.853), this is despite the fact that males possess the highest values for nitrogen, most notably at Apigliano (female max 8.6‰, male max, 9.3‰ Table 5). It should be noted, however, that the Apigliano population contains many adults of indeterminate sex (n=14 of 34 adults aged >18 years), some of which have high nitrogen values (max, 9.4‰), which challenges any further assessment of sex-based dietary differentiation.

[INSERT FIGURE 4 HERE]

The dataset from Quattro Macine and Apigliano includes individuals buried both inside and outside each church (Table 6). From Apigliano, we analysed six individuals over the age of five interred within the religious structure, and 46 interred outside. Statistical comparison of these groups (AP $\delta^{15}N$ (T (45)=0.397) P=0.693, $\delta^{13}C$ (T (45)=0.485) P=0.630) indicate there is no significant difference in isotope values relating to inside/outside place of burial, although the small number of individuals interred within the church may influence this result. At Quattro Macine, only one individual buried in front of the altar of the Byzantine church was available for analysis. This individual, SK42, an adult male, aged 30-35 years (^{14}C dated 1290-1410 cal AD, 95.4% prob.) is a notable outlier, whose $\delta^{15}N$ value of 8.4‰ is two standard deviations above the population mean (7.6‰).

4. Discussion

4.1. Faunal diets and husbandry practices

Omnivore species such as pig and chicken, whose feeding practices are often varied, are useful to explore economic and husbandry practices between the two sites. Pigs from both sites possess isotopic values that group with the herbivores. Pigs were managed by a range of husbandry practices in the Medieval period that would have included free range foraging and/or deliberate feeding with household waste (Hamilton and Thomas., 2012; Halley and Rosvold., 2014). The low $\delta^{15}N$ values for pigs at both sites suggests that enclosed husbandry, where pigs may have been fed on waste from human food scraps, was not generally practiced at either site and instead free range foraging was predominant (Hamilton and Thomas., 2012). Chickens at Quattro Macine possess isotopic values that are in keeping with similarly herbivorous, free range diets, whereas the single chicken from Apigliano has higher $\delta^{13}C$ and $\delta^{15}N$ values approaching that of the humans at the site. Bearing in mind that there is just one individual from Apigliano, this may hint at different management strategies at Apigliano where chickens were kept in a more closely managed, potentially household environment, and fed food scraps. This also seems to be the case regarding the two dogs analysed in this study. Their similarity to the human values indicate that they would have access to similar foods (Figure 2) as has been seen at many historic period sites (Guiry, 2012).

4.2.Non-adult diet

The relatively high $\delta^{15}N$ values for infants under five years at Apigliano that have a gentle descending trend towards the adult mean may be interpreted as reflecting feeding at a higher trophic level due to nursing, supplemented by solid foods (Millard, 2000; Jay et al., 2008). This data hints at prolonged breastfeeding past two years which would be compatible with the Byzantine tradition in the eastern Mediterranean (Fulminante, 2015), although completion of weaning at five years is extremely late and therefore unlikely. Given the small sample size, we are unable to make a clear interpretation of the onset of weaning and cessation of breastfeeding in this population. Other factors such as physiological and/or nutritional stress can also raise infant $\delta^{15}N$ values, which is an important consideration where we are examining the non-surviving infants in the population who do not necessarily represent the dietary norm (Beaumont et al., 2015; Britton et al., 2018). The diets of adults and non-adults over the age of five were similar, suggesting that the solid foods being introduced did not isotopically differ from those being consumed by the adult population.

Only one individual below the age of five is present in the Quattro Macine population and therefore a comparison of potential weaning practices cannot be made between sites. However, non-adults above the age of five at Quattro Macine were statistically significantly depleted in $\delta^{15}N$ compared to the adult mean, indicating a systematic bias of protein-rich foods featuring more frequently amongst the adult population. A similar patterning of lower nitrogen values for non-adults has been reported relatively frequently in isotopic studies, interpreted by either dietary or physiological factors (Tsutaya, 2017). It is puzzling as to why the Apigliano non-adult population does not exhibit lower nitrogen values if there is purely a physiological basis for $\delta^{15}N$ depletion, and in which case, dietary differences appear the most likely explanation, as hypothesised elsewhere (Reitsema et al., 2016; Tsutaya, 2017; Olsen et al., 2018).

The two populations therefore manifest juxtaposing treatment of their non-adults. Apigliano demonstrates a uniform diet amongst all adults and non-adults above the age of five and so if any difference existed it would have been subtle, perhaps distributed according to food quality but not in terms of the specific commodities being consumed. At Quattro Macine however, particular foodstuffs may have been provided to children based on their perceived lower status or reduced requirement for sustenance (Safran, 2014). Incremental isotopic analysis of individual tooth dentine collagen profiles may better serve to differentiate dietary patterns that may have been associated with breastfeeding, physiological stress factors and age related dietary dimorphism (Beaumont et al., 2015; Beaumont et al., 2018; King et al., 2018).

4.3. Adult diet and economic practices

The isotopic data support an interpretation of a predominantly terrestrial based diet at Apigliano and Quattro Macine with $\delta^{13}C$ and $\delta^{15}N$ ranges within the expected margins of the terrestrial C_3 food web (Ambrose, 1991; Chisholm et al., 1982). Estimating the relative contribution of plant or animal protein from bulk bone collagen $\delta^{15}N$ for humans is complicated by a range of environmental and metabolic factors (Hedges and Reynard, 2007). Measuring $\delta^{15}N$ of single amino acids of plants (cereals and legumes), animals and humans from the same site would allow for a more refined interpretation of the animal/plant composition of the human diet (Styring et al., 2015). Isotopic bulk values altogether indicate a diet high in plant foods with modest amounts of animal protein. The greater variability in $\delta^{15}N$ values for humans at Apigliano indicates that the diet was less uniform at this site in comparison to Quattro Macine. This is despite the fact that the individuals found at Apigliano pertain to a tighter chronology of three centuries (13th-15th centuries) compared to five centuries at Quattro Macine (11th-15th centuries).

In the case of Quattro Macine, this may point to a preservation of economic practice from the Norman conquest onwards, suggesting the changes in political regimes had limited impact on local diet despite the increase in cattle and pig witnessed in the faunal assemblages from Norman times. Indeed, the extent to which changes in faunal assemblages reflect changes in diet, rather than modifications in agrarian practice, may be questioned. If not consumed locally, it is possible that these animals were used to meet the demands of the urban market as an economic supplement, or reared on behalf of the feudal lord. The lack of dietary diversity observed within a period of five centuries attests to a stable relationship between population, landscape and economy throughout settlement occupation in the later Middle Ages. However, there were no individuals pertaining to the Byzantine period available for sampling, and therefore a direct isotopic comparison between the two regimes cannot be considered in this study.

Some of the higher $\delta^{15}N$ values at Apigliano reflect a source of higher trophic level protein in the diet, perhaps from fish, although fish remains were generally absent at the site, despite selective sieving. It is possible the individuals with higher trophic level protein had moved inland from the coast. However, given the range in terrestrial faunal $\delta^{15}N$ values at both sites (3-7‰) and the fact that the maximum human $\delta^{15}N$ value is 10‰ which is within the expected trophic level shift of 3-5‰ between herbivores and their consumers (Bocherens and Drucker, 2003), it is difficult to identify any potential marine component to the diet. This scenario is not impossible however. Mediterranean fish tend to possess relatively low $\delta^{15}N$ values of 6-12‰ (Bourbou et al., 2011; Craig et al., 2013; Alexander et al., 2015). The $\delta^{13}C$ values of marine taxa are more enriched than terrestrial C_3 herbivores which in the absence of C_4 plants would usually permit the identification of the consumption of marine foods where $\delta^{15}N$ may not. However, in diets where the majority of the nutrition derives from cereals, and where there is a tight range in $\delta^{13}C$ but a wide range in $\delta^{15}N$ values, as is hypothesised here, a degree of macronutrient scrambling may occur which would lead to $\delta^{13}C$ values preferentially deriving from dominant C_3 carbohydrate sources while $\delta^{15}N$ reflected protein (Craig et al., 2009). This would lead to depleted terrestrial $\delta^{13}C$ values coupled with higher $\delta^{15}N$ values. This dietary scenario has been interpreted for Roman human data from Italy, however many of their $\delta^{15}N$ values tend to be higher than those exhibited at Apigliano (up to ~14‰, Craig et al., 2013). Altogether, if marine protein was consumed at these medieval sites, it would have been low trophic level and only constituted a minor proportion of the diet of few individuals.

The slightly higher $\delta^{15}N$ values at Apigliano may instead reflect the economic basis for the site which may have had to rely more heavily on pastoral agriculture (i.e. occasional meat/dairy from herbivores or chickens/eggs) than Quattro Macine due to poorer local environmental conditions for growing cereals. The area in which Quattro Macine is situated tends to have better soil conditions and higher rainfall which would have consequently yielded better crops and potentially provided a slightly higher standard of living for its inhabitants than Apigliano, where the lack of water and the natural bedrock, often breaking the surface, hampered cultivation (Arthur et al., 2012; Arthur, 1996). The herbivore baselines for both sites were similar, however, herbivores only offer a proxy for plant data averaged over a long period of time and may not necessarily reflect the values of cereals consumed directly by humans.

4.4. Ethnic, social and cultural influences on diet

As mentioned previously, the archaeological evidence and distinct burial practice of depositing a coin in the mouth of the deceased, suggests Apigliano saw the arrival of migrants from the Balkans, potentially Greece (Arthur and Bruno, 2009). It is therefore a possibility that first, second or third generation immigrants are present in the analysis, and may account for some of the scattered isotopic values observed in this population, despite a relatively short chronology. Published isotopic data for Byzantine human populations from Greece (mainly in the south), for example, indicate a tendency towards slightly higher $\delta^{15}N$ values, with the majority of sites exhibiting $\delta^{15}N$ means of over 8.5‰ but with $\delta^{13}C$ values similar to those seen in Apulia (Bourbou et al., 2011). Minor marine fish intake is hypothesised for some of these Byzantine sites, particularly those on the coast (Bourbou et al., 2011). The potential presence of first-generation migrants could be explored though analysis of $^{87/86}Sr$ (Bentley, 2006), $\delta^{16}O$ (Killgrove and Montgomery, 2016) or possibly $\delta^{34}S$ (Nehlich, 2015) for individuals from Apigliano. However, with the current body of evidence, this remains speculative.

The composition of social status among the inhabitants of these villages may also be considered using burial location within or outside a church as a proxy for wealth. There were no isotopic differences detected between burials located within the churches versus outside at Apigliano, which indicates that place of interment as a potential socio-economic indicator does not correlate with isotopic dietary data in this population, unlike observations in isotopic studies of other European Medieval populations (e.g. Müldner and Richards, 2007; Reitsema and Vercellotti, 2012; Colleter et al., 2017). The one exception to this is the single outlier from Quattro Macine, SK42, identified as a male individual who was buried in a tomb in front of the altar of the Greek church. His $\delta^{15}N$ value of 8.4‰ was the highest at this site and indicated a greater proportion of higher trophic level protein in the diet compared to the rest of the population. His prestigious burial location, together with a dietary signature which indicates that he had access to high trophic level foods over his life suggest he may have been a member of the clergy or a powerful family within the village. The consumption of high trophic level protein (meat and to some extent fish) was affiliated with a high status identity in Medieval society (Montanari, 1988). The individuals buried within the churches should be considered somewhat privileged, however, they may well have been little more than honoured members of the peasant community, buried in the churches because of their perceived social status. Unlike wealth, status would not necessarily be associated with a different diet when the financial resources required to procure such foods are absent, subsequently restricting dietary manifestations of status. It is clear from the exalted location of burial that status existed as a concept of differentiating individuals socially, but that the low socio-economic standing of the inhabitants of the medieval villages in this study led to a more restricted distribution of foodstuffs than seen in larger and more prosperous settlements.

All 68 individuals from Apigliano were presumably Greek Orthodox, whereas 31 out of 35 individuals sampled from Quattro Macine were Latin Catholic, the remaining four Greek Orthodox. It is unlikely that any religious differences between the populations would have played a major role in the observed dietary variation between the two sites. The four individuals buried at the Greek Orthodox Church in Quattro Macine are isotopically indistinguishable from those buried at the Latin Catholic church (Table 6). Therefore, if religious food restriction was strictly adhered to at Apigliano and Quattro Macine along religious or ethnic lines it may be too subtle to be detected using isotopic analysis which lacks the resolution to distinguish minor differences such as different cuts of meat. In particular, the difficulty of identifying low levels of fish intake, particularly in the Mediterranean, as discussed above, confounds any investigation of fish consumption and faith in this case.

4.5.Comparison with contemporary agrarian communities in Italy

Apigliano and Quattro Macine are compared to other published Medieval Italian populations dating between the 8th-16th centuries AD in Figure 5. Apigliano and Quattro Macine have similar isotopic values to the sites of Colonna and Monte di Croce (Baldoni et al*.,* 2016; Buonincontri et al., 2017) with some overlap with Albano (Ciaffi et al., 2015), although this latter site represents a shift away from the earlier dietary signature of Colonna in the region around Rome. The tight range (and low standard deviations) in isotopic values at Quattro Macine in particular is notable in comparison to other published sites and reflects a rather restricted dietary 'menu'.

[INSERT FIGURE 5 HERE]

Colonna and Monte di Croce, located in Lazio and Tuscany respectively, reflect diets associated with agrarian economies akin to Apigliano and Quattro Macine in Apulia, and have comparable herbivore baselines (Colonna $\delta^{13}C$ -21‰ ± 0.4, $\delta^{15}N$ 5.8‰ ± 1.7‰; Monte di Croce $\delta^{13}C$ -20.3‰ ± 2.8, $\delta^{15}N$ 4.5‰ ± 2.2‰), (Baldoni et al., 2016; Buonincontri et al., 2017). The grouping of these sites indicates dietary similarities amongst conventional farming communities, where the agricultural customs traditional to the Italian environment produces a basal diet fundamental to the peninsula. These settlements indicate a heavy reliance on C_3 cereal grains such as wheat, barley, rye and vegetables such as legumes, pulses, olives and fruits and nuts, with only occasional C_4 plant consumption (Baldoni et al., 2016; Buonincontri et al., 2017). The consistently low human means for $\delta^{15}N$ among these settlements (Colonna 7.9‰ ± 0.6‰; Monte di Croce 7.6‰ ± 0.6‰), suggest low quantities of animal or marine protein was typical for diets of agricultural communities.

Isotopic data published from the northernmost areas of Italy demonstrate distinct enrichment in $\delta^{13}C$. C_4 plants appear to have formed a more significant proportion of human diet regionally, for example at Friuli and Mainizza (Iacumin et al., 2014), and Trino Vercellese (Reitsema and Vercellotti, 2012). Other settlements practiced more specialised economic strategies, such as at Pava and Trino Vercellese, where pig husbandry and livestock breeding has been hypothesised. These sites demonstrate corresponding higher human $\delta^{15}N$ means (9.6‰ ± 0.6‰ and 9.2‰ ± 0.8‰, respectively), (Buonincontri et al., 2017; Reitsema and Vercellotti, 2012).

Overall, dietary trends evident in the isotopic values of Medieval populations from Italy mirror the primary mode of food procurement and productive economy in each settlement, suggesting self-sufficiency was prevalent in low socio-economic rural communities, with little input of foods acquired outside the area. Although it is probable that a proportion of agrarian produce was kept by feudal lords or sold at market, it is reasonable to argue that low levels of imported goods and aquatic foods were regularly brought in to these communities. The isotopic data put forward no compelling evidence of human dietary variation outside the local isotopic ranges profiled by site specific faunal data within this economic group. Sites where this has been detected, such as metropolitan 15th century Rome, $\delta^{13}C$ and $\delta^{15}N$ population means (-19‰ ± 0.2‰, 10.8‰ ± 1.8‰, respectively) are within the isotopic ranges associated with regular intake of high-trophic level marine protein from the Atlantic Ocean, rather than the Mediterranean Sea

(Salamon et al., 2008). A similar comparison is not evident in isotopic data from other medieval Italian populations, and therefore does not express a scenario of such foods being widely available to the general public, but limited to those with the financial means with which to obtain them, such as the urban populations of Rome. However, natural variation in isotopic faunal baselines makes any direct comparison of dietary components challenging.

5. Conclusion

The results of this research draws attention to dietary variation between two rural sites in Southern Italy that have broadly similar dietary patterns to contemporary rural sites, yet display subtly different isotopic and cultural traits. It is clear that the predominantly terrestrial diet with little animal protein seen at Apigliano and Quattro Macine fits into a wider pattern of rural subsistence in medieval Italy, where cereals, vegetables and fruits were the main dietary components in the Mediterranean diet. The depleted nitrogen values at both sites are believed to have been chiefly influenced by a low socio-economic position limiting access to high trophic foods. However, the variability and generally higher $\delta^{15}N$ values at Apigliano in comparison to Quattro Macine may be the result of constraints imposed on food production by the environment at this latter site, with a more significant pastoral element to the economy. This village was also more mixed in terms of culture, with a potential Balkan component to the population and the variation of values amongst its inhabitants has the potential to be linked, at least in part, with mobility. Quattro Macine, in contrast, embodies a traditional agricultural village relying almost exclusively and continually, on C_3 grain production. The primary components determining diet at these settlements therefore relate to local variability in agrarian strategies, culture and low economic capacity restricting an element of individual choice, to a much greater extent than large-scale events such as the Norman conquest. Evidently, social hierarchies permeated rural (feudal) Italy and did have an effect on dietary choices when financially permissible, but the complex nuances of day-to-day life and differential nutritional treatment of non-adults is equally evident in this study, and improves our understanding of individual agency and subsistence in Medieval farming communities.

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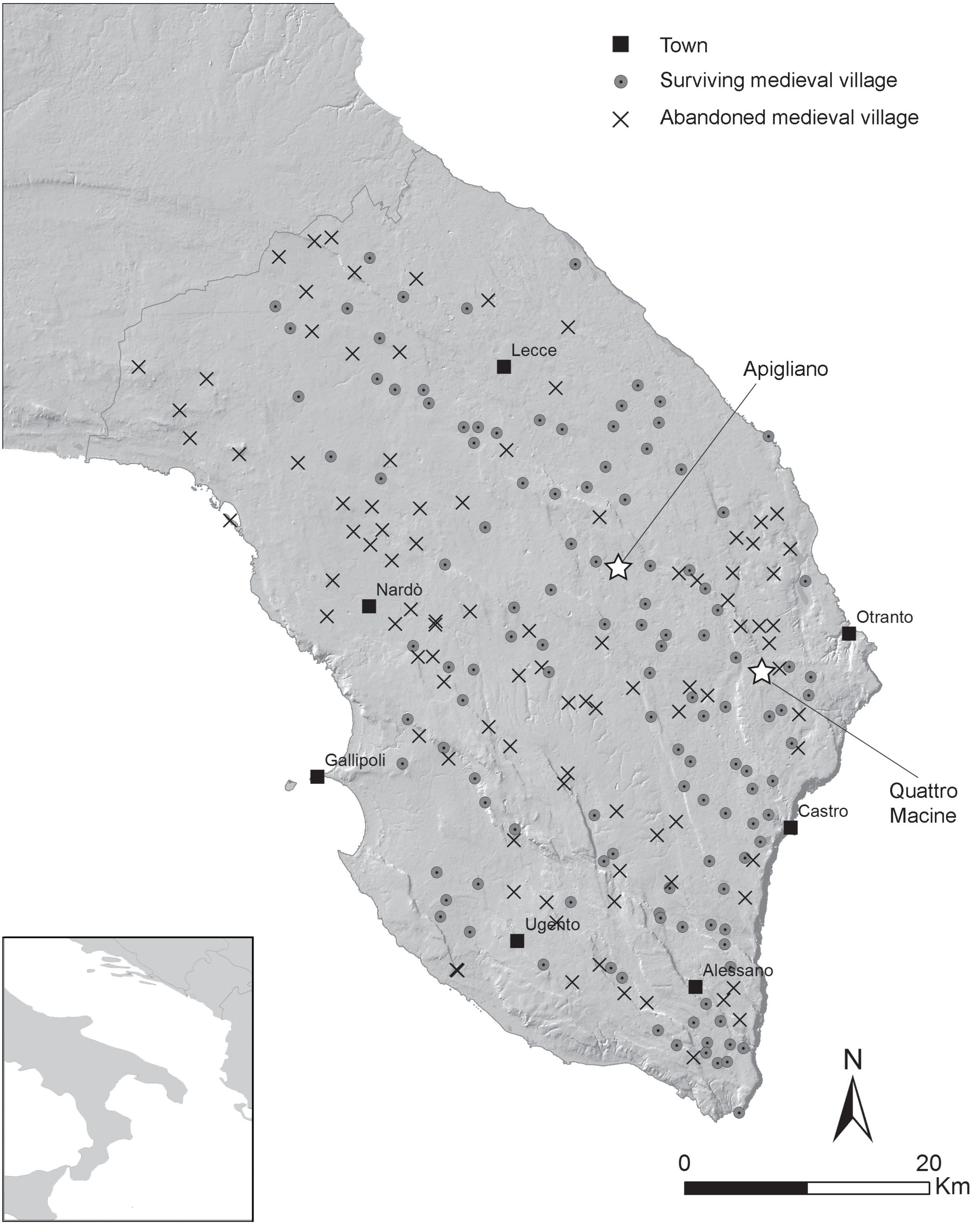

Town
Surviving medieval village
Abandoned medieval village
Lecce
Apigliano
Nardò
Otranto
Quattro
Macine
Gallipoli
Castro
Ugento
Alessano
N
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20
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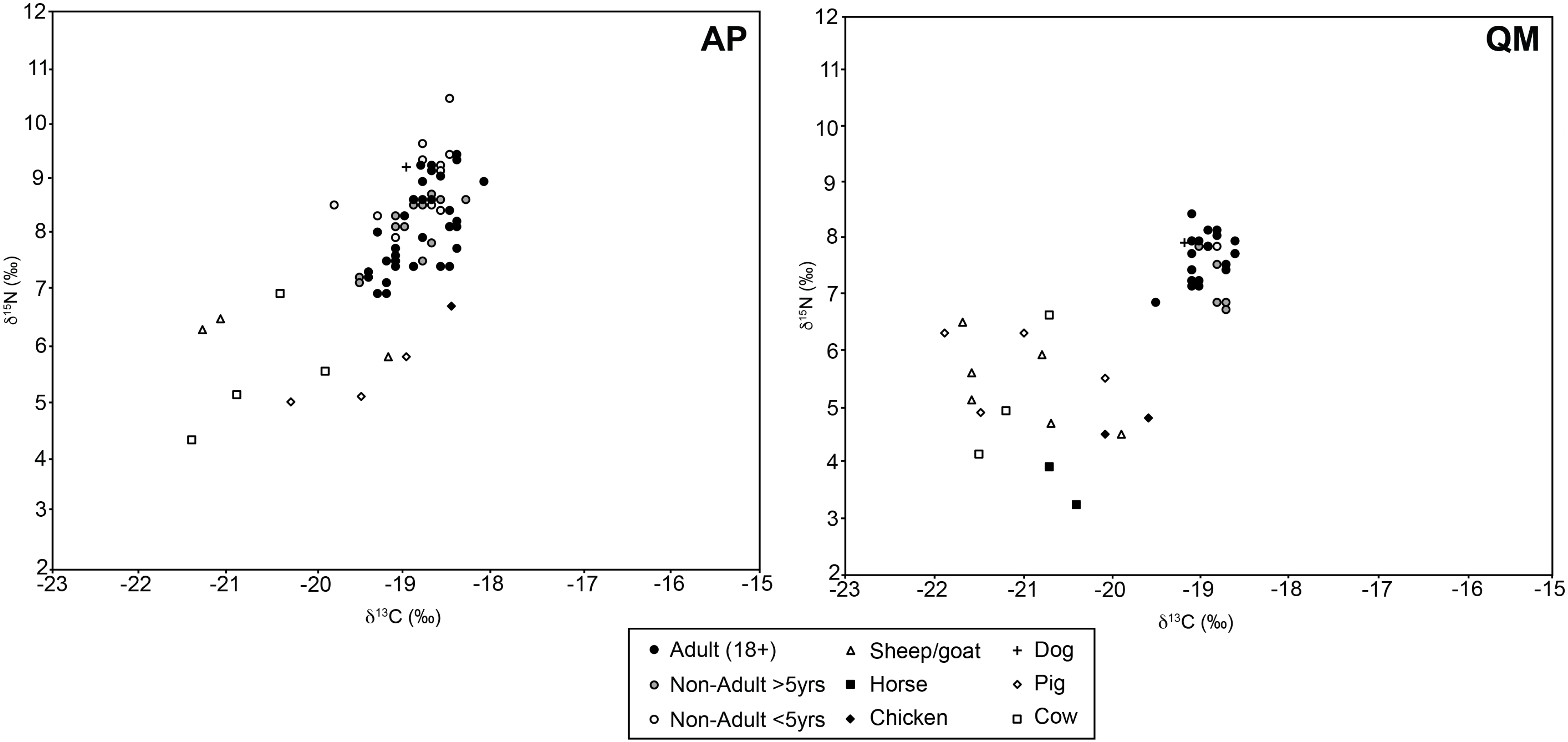
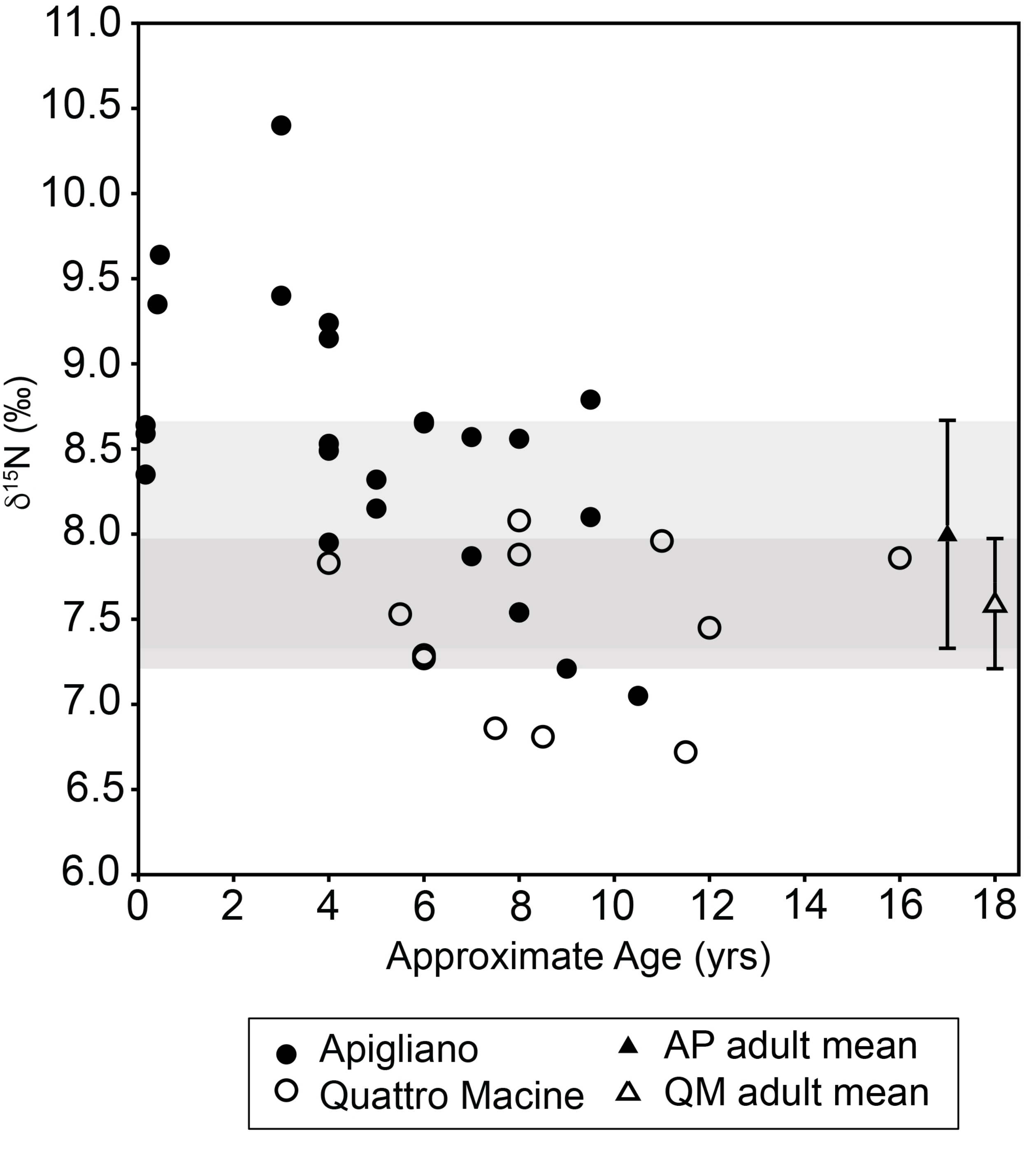

AP
QM
δ15N (‰)
δ13C (‰)
Adult (18+)
Non-Adult >5yrs
Non-Adult <5yrs
Sheep/goat
Horse
Chicken
Dog
Pig
Cow



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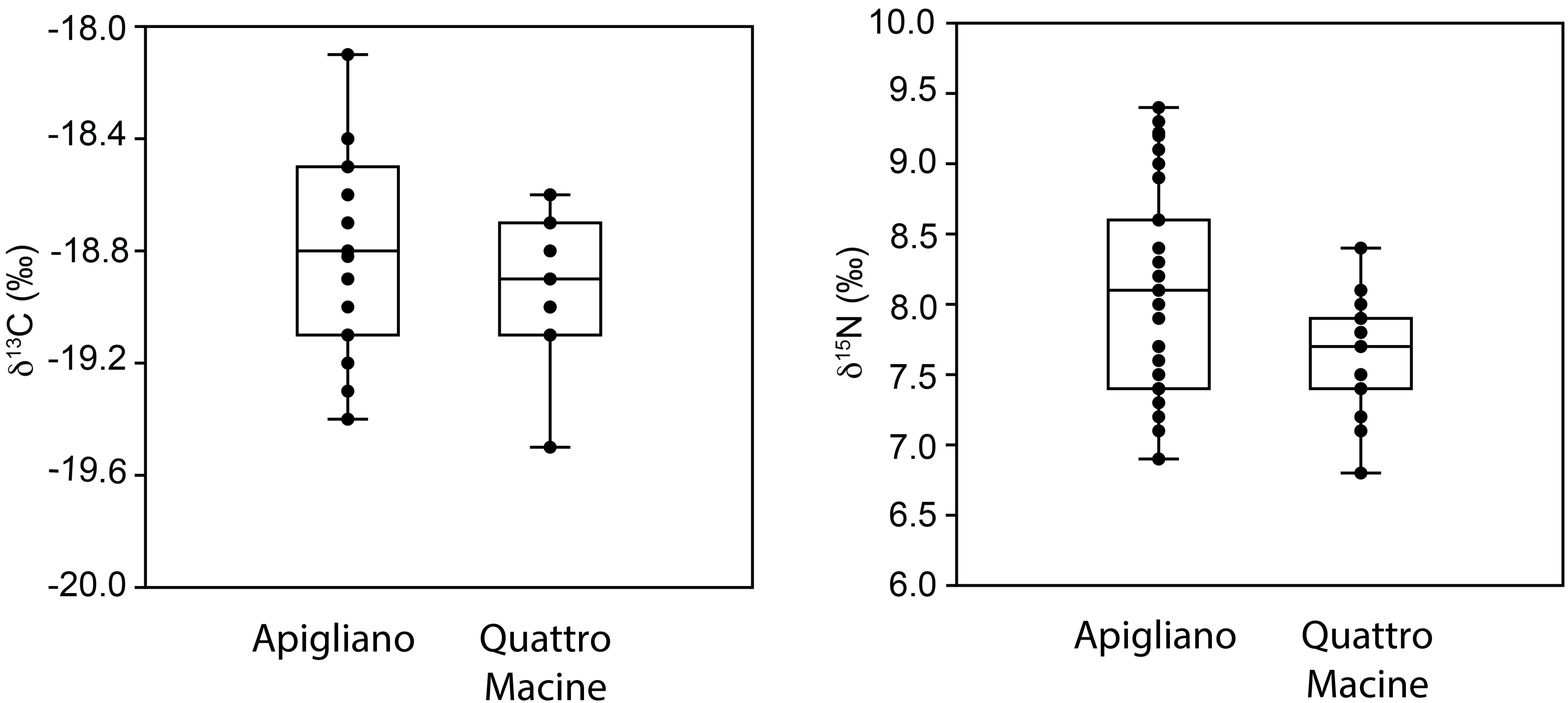
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
δ15N (‰)
0
2
4
6
8
10
12
14
16
18
Approximate Age (yrs)
Apigliano
Quattro Macine
AP adult mean
QM adult mean



-18.0
-18.4
-18.8
-19.2
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δ13C (‰)
Apigliano
Quattro Macine
10.0
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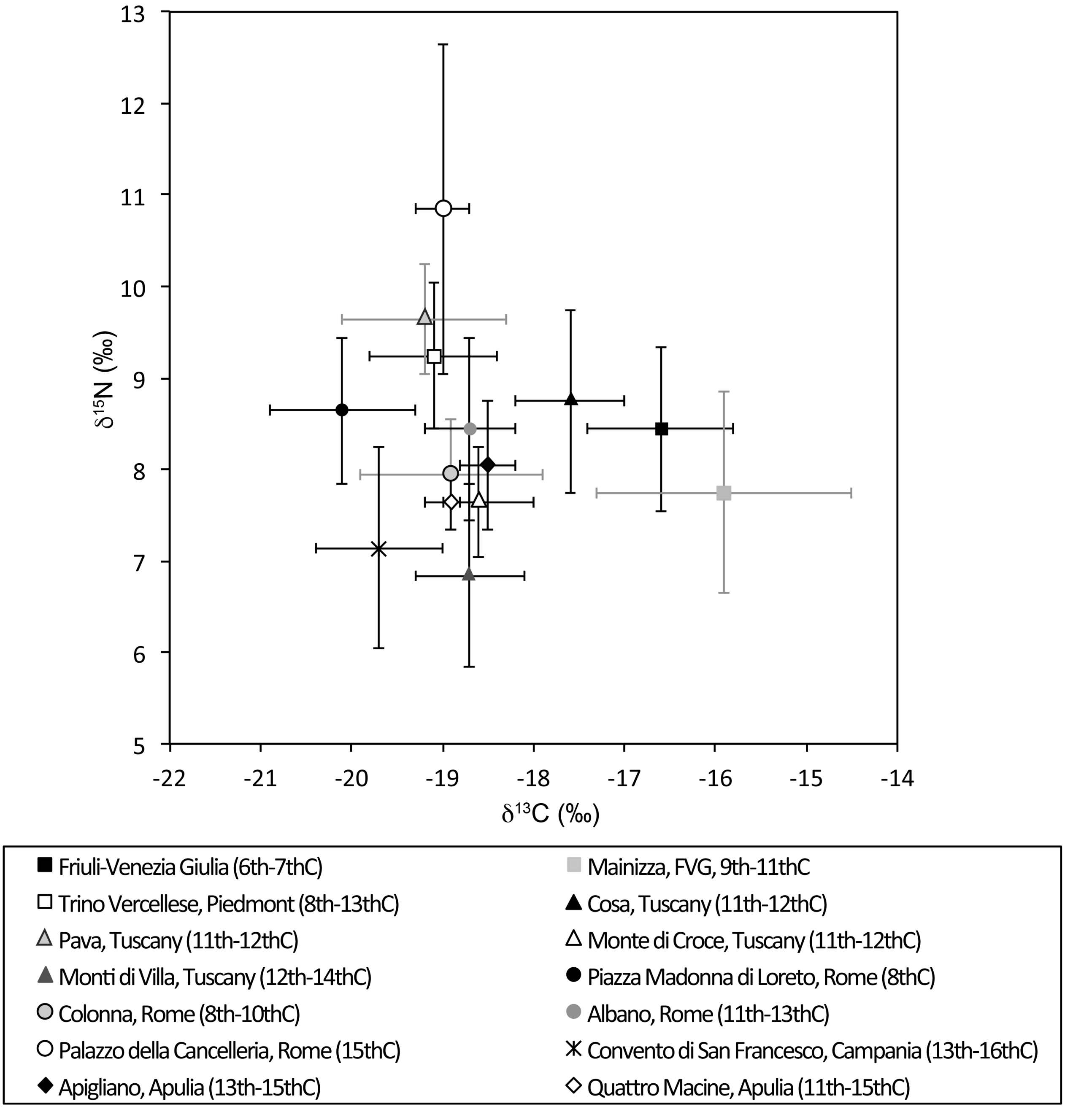
δ15N (‰)
Apigliano
Quattro Macine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-18
-17
-16
-15
-14
δ15N (‰)
δ13C (‰)
Friuli-Venezia Giulia (6th-7thC)
Mainizza, FVG, 9th-11thC
Trino Vercellese, Piedmont (8th-13thC)
Cosa, Tuscany (11th-12thC)
Pava, Tuscany (11th-12thC)
Monte di Croce, Tuscany (11th-12thC)
Monti di Villa, Tuscany (12th-14thC)
Piazza Madonna di Loreto, Rome (8thC)
Colonna, Rome (8th-10thC)
Albano, Rome (11th-13thC)
Palazzo della Cancelleria, Rome (15thC)
Convento di San Francesco, Campania (13th-16thC)
Apigliano, Apulia (13th-15thC)
Quattro Macine, Apulia (11th-15thC)

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Table 1. *Age and sex profile of human samples from Apigliano and Quattro Macine (Non-Adult <18 Years; Adult >18 Years).*

Site and Period	**Age and Sex**	**No. of Individuals**
Apigliano 13th-14th C. AD	Adult Male	14
	Adult Female	10
	Adult Indeterminate	16
	Non-Adult	28
	Total No.	**68**
	Greek Orthodox Burial Rite	*68*
	Latin Catholic Burial Rite	*0*
Quattro Macine 11th-15th C. AD	Adult Male	12
	Adult Female	12
	Non-Adult	11
	Total No.	**35**
	Greek Orthodox Burial Rite	*4*
	Latin Catholic Burial Rite	*31*

Table 2. *Species distribution of faunal samples according to site.*

Species	**Apigliano (No.)**	**Quattro Macine (No.)**
Bos t.	4	4
Sus s.	3	4
Ovis/Capra	4	6
Gallus g.	2	2
Canis l. f.	1	1
Equus f.	0	2

Table 3. *Summary statistics of Apigliano (AP) and Quattro Macine (QM) Faunal isotopic data.*

Site	**Taxon**	**No.**	**$\delta^{13}C$ (‰)**			**$\delta^{15}N$ (‰)**		
			Min	**Max**	**Mean ± 1σ**	**Min**	**Max**	**Mean ± 1σ**
AP	*Ovicaprids*	4	-21.4	-21.3	-20.6 ± 0.5	5.7	6.5	6.1 ± 0.4
	Bos t.	4	-21.4	-19.8	-20.6 ± 0.5	4.3	6.9	5.4 ± 1
	Herbivores	**8**	**-21.4**	**-19.8**	**-20.6 ± 0.8**	**4.3**	**6.9**	**5.7 ± 0.8**
	Sus s.	3	-20.3	-19	-19.6 ± 0.6	5	5.8	5.3 ± 0.4
	Canis l. F.	1	-	-	-18.9	-	-	9.1
	Gallus g.	1	-	-	-18.5	-	-	6.7
QM	*Ovicaprids*	6	-21.5	-20.7	-21.1 ± 0.7	4.5	6.5	5.4 ± 0.7
	Bos t.	3	-21.5	-20.7	-21.1 ± 0.4	4.1	6.6	5.2 ± 1.3
	Herbivores	**9**	**-21.6**	**-19.9**	**-21 ± 0.5**	**4.1**	**6.6**	**5.3 ± 0.8**
	Sus s.	4	-21.8	-20.1	-21.1 ± 0.8	4.9	6.3	5.7 ± 0.6
	Canis l. f.	1	-	-	-19.2	-	-	7.9
	Gallus g.	2	-20.1	-19.6	-19.9 ± 0.3	4.5	4.8	4.6 ± 0.2
	Equus f.	2	-20.7	-20.4	-20.6 ± 0.2	3.2	3.9	3.6 ± 0.5

Table 4. *Faunal stable isotope raw data from Apigliano and Quattro Macine.*

Site	Period (C. AD)	Sample ID	Taxon	Element Sampled	δ13C (‰ PDB)	δ15N (‰ AIR)	Coll. Yield (%)	C%	N%	C/N
Apigliano	12th	AP06SM26	*Bos t.*	Humerus	-20.9	5.11	2.8	41	15.3	3.2
Apigliano	13th-14th	AP09SM32	*Bos t.*	Metatarsus	-19.9	5.5	1.3	21.7	7.7	3.3
Apigliano	9th-10th	AP06SM21	*Bos t.*	Tibia	-21.4	4.3	1.2	29.2	10.7	3.2
Apigliano	9th-10th	AP06SM25	*Bos t.*	Metatarsus	-20.4	6.9	4.7	42.6	15.7	3.2
Apigliano	10th-11th	AP03SM27	*Canis l. f.*	Ulna	-19	9.2	3.3	39.5	14.5	3.1
Apigliano	10th-11th	AP03SM28	*Capra*	Skull Fragment	-20.6	5.6	7.2	42.2	15.6	3.1
Apigliano	9th-10th	AP03SM23	*Gallus g.*	Coracoid	-18.5	6.7	5.4	43	15.7	3.2
Apigliano	12th	AP06SM29	*Ovis/Capra*	Radius	-19.2	5.8	2.3	34.8	12.7	3.2
Apigliano	13th-14th	AP97SM31	*Ovis/Capra*	Scapula	-21.1	6.5	2.3	44.9	16.1	3.2
Apigliano	9th-10th	AP06SM22	*Ovis/Capra*	Ulna	-21.3	6.3	3.3	42.9	15.7	3.3
Apigliano	13th	AP06SM30	*Sus s.*	Mandible	-19	5.8	2.8	36.3	13.2	3.2
Apigliano	14th	AP06SM20	*Sus s.*	Skull Fragment	-20.3	5	1.6	30	11	3.2
Apigliano	9th-10th	AP06SM24	*Sus s.*	Skull Fragment	-19.5	5.1	4.1	44.3	16	3.2
Quattro Macine	13th	QM96SM14	*Bos t.*	Metapodius	-21.2	4.9	1.2	38.6	14.2	3.2
Quattro Macine	14th	QM96SM16	*Bos t.*	Metapodius	-21.5	4.1	1.6	25.1	8.9	3.3
Quattro Macine	9th-10th	QM96SM6	*Bos t.*	Mandible	-20.7	6.6	1.6	43.9	15.9	3.2
Quattro Macine	10th	QM96SM8	*Canis l. f.*	Metacarpal	-19.2	7.9	4.3	44.8	16.5	3.2
Quattro Macine	13th	QM96SM19	*Equus f.*	Tibia	-20.7	3.9	2.7	39.3	14.3	3.2
Quattro Macine	9th-10th	QM96SM4	*Equus f.*	Astragalus	-20.4	3.2	4.6	43.1	15.6	3.2
Quattro Macine	10th	QM96SM1	*Gallus g.*	Femur	-20.1	4.5	4.1	44.3	16	3.2
Quattro Macine	13th	QM95SM13	*Gallus g.*	Femur	-19.6	4.8	7.5	42.3	15.1	3.2
Quattro Macine	10th-11th	QM96SM7	*Ovis/Capra*	Coxal	-19.9	4.5	5	43.7	15.9	3.2
Quattro Macine	11th-12th	QM91SM11	*Ovis/Capra*	Coxal	-21.6	5.6	1.6	40.6	14.8	3.2
Quattro Macine	12th	QM93SM10	*Ovis/Capra*	Radius	-21.6	5.1	4.3	41.1	15.2	3.1
Quattro Macine	13th	QM96SM15	*Ovis/Capra*	Coxal	-20.7	4.7	0.9	34.3	12.4	3.2
Quattro Macine	14th	QM96SM18	*Ovis/Capra*	Scapula	-20.8	5.9	3.5	43.1	15.8	3.1
Quattro Macine	9th-10th	QM96SM2	*Ovis/Capra*	Tibia	-21.7	6.5	2.3	42.2	15.4	3.2
Quattro Macine	13th	QM95SM12	*Sus s.*	Humerus	-21.5	4.9	2.4	42.2	15.4	3.2
Quattro Macine	14th	QM96SM17	*Sus s.*	Humerus	-21.9	6.3	3.2	40	14.8	3.1

Quattro Macine	9th-10th	QM96SM3	*Sus s.*	Radius	-21	6.3	0.9	32.2	11.8	3.2
Quattro Macine	9th-10th	QM96SM5	*Sus s.*	Skull Fragment	-20.1	5.5	3.5	43.7	15.9	3.2

Table 5. *Summary isotopic data for humans from Apigliano (AP) and Quattro Macine (QM) (Non-Adult <18 Years; Adult >18 Years).*

Site, Age and Sex Group	**No.**	**δ¹³C (‰)**			**δ¹⁵N (‰)**		
		Min	**Max**	**Mean ± 1σ**	**Min**	**Max**	**Mean ± 1σ**
AP Adults (M, F, U)	**34**	**-19.4**	**-18.1**	**-18.8 ± 0.3**	**6.9**	**9.4**	**8.1 ± 0.8**
AP Female	8	-19.4	-18.5	-19.1 ± 0.3	6.9	8.6	7.6 ± 0.6
AP Male	12	-19.4	-18.4	-18.9 ± 0.3	7.1	9.3	7.7 ± 0.6
AP Adult Unidentified	14	-18.9	-18.1	-18.6 ± 0.2	7.9	9.4	8.7 ± 0.5
AP Non-Adult	**25**	**-19.6**	**-18.4**	**-18.8 ± 0.3**	**7.1**	**10.4**	**8.5 ± 0.7**
AP Non-Adult <5yrs	12	-19.4	-18.8	-19 ± 0.2	7.9	10.4	8.9 ± 0.7
AP Non-Adult >5yrs	13	-19.6	-18.4	-18.9 ± 0.4	7.1	8.7	8 ± 0.5
QM Adults (M, F)	**22**	**-19.5**	**-18.6**	**-18.9 ± 0.2**	**6.8**	**8.4**	**7.6 ± 0.4**
QM Female	11	-19.1	-18.6	-18.9 ± 0.2	7.1	8.1	7.6 ± 0.4
QM Male	11	-19.5	-18.6	-18.9 ± 0.3	6.8	8.4	7.6 ± 0.4
QM Non-Adult	**11**	**-19.1**	**-18.7**	**-18.9 ± 0.1**	**6.7**	**7.9**	**7.3 ± 0.4**
QM Non-Adult <5yrs	1	-	-	-18.8	-	-	7.8
QM Non-Adult >5yrs	10	-19.1	-18.7	-18.9 ± 0.1	6.7	7.9	7.3 ± 0.4

Table 6. *Human stable isotope raw data from Apigliano and Quattro Macine (Neonate <1 year; Adult >18 years). Samples that failed quality assurance appear in grey italics, and are not included in interpretations.*

Site	Period (C. AD)	Sample ID	Sex	Age (yrs.)	Religious Grouping	Burial location in or outside the church	Sampled Element	$\delta^{13}C$ (‰ PDB)	$\delta^{15}N$ (‰ AIR)	Coll. Yield (%)	C%	N%	C/N
Apigliano	13^{th}-14^{th}	AP99SK68	-	Neonate	Greek Orthodox	Outside	Petrous	-19.3	8.3	1.5	35.1	12.6	3.2
Apigliano	13^{th}-14^{th}	AP00SK76	-	Neonate	Greek Orthodox	Outside	Petrous	-18.8	9.6	1.4	37.4	13.7	3.1
Apigliano	13^{th}-14^{th}	AP99SK104	-	Neonate	Greek Orthodox	Outside	Petrous	-18.9	8.6	1	37.5	13.5	3.2
Apigliano	13^{th}-14^{th}	AP00SK113	-	Neonate	Greek Orthodox	Outside	Petrous	-18.8	9.3	2.2	37.8	13.8	3.2
Apigliano	13^{th}-14^{th}	AP98SK15	-	Neonate	Greek Orthodox	Outside	Petrous	-18.7	8.5	2.3	42.9	15.4	3.2
Apigliano	13^{th}-14^{th}	AP99SK64	-	2-4	Greek Orthodox	Inside	Phalanx	-18.5	10.4	9.1	44.6	16.2	3.2
Apigliano	13^{th}-14^{th}	AP98SK34	-	2-4	Greek Orthodox	Inside	Petrous	-18.5	9.4	1	15.3	5.5	3.2
Apigliano	13^{th}-14^{th}	AP98SK19	-	3-5	Greek Orthodox	Outside	Petrous	-19.1	7.9	1.1	28.7	10.3	3.2
Apigliano	13^{th}-14^{th}	AP98SK11	-	3-5	Greek Orthodox	Outside	Petrous	-18.6	9.2	3.9	40.8	14.9	3.1
Apigliano	13^{th}-14^{th}	AP99SK73	-	3-5	Greek Orthodox	Outside	Petrous	-19.8	8.5	1.2	41.4	14.3	3.3
Apigliano	13^{th}-14^{th}	AP98SK101	-	3-5	Greek Orthodox	Outside	Petrous	-18.6	9.1	2	44.1	15.8	3.2
Apigliano	13^{th}-14^{th}	AP98SK10	-	2-6	Greek Orthodox	Inside	Petrous	-18.6	8.4	2.2	37.4	13.7	3.1
Apigliano	13^{th}-14^{th}	AP99SK63	-	4-6	Greek Orthodox	Outside	Petrous	-19.1	8.3	1.4	41.5	14.5	3.3
Apigliano	13^{th}-14^{th}	AP99SK67	-	4-6	Greek Orthodox	Outside	Petrous	-19.1	8.1	1.5	41.6	15.1	3.2
Apigliano	13^{th}-14^{th}	AP99SK69	-	5-6	Greek Orthodox	Outside	Petrous	-18.6	8.6	1.2	28.5	10.5	3.1
Apigliano	13^{th}-14^{th}	AP98SK102	-	5-6	Greek Orthodox	Outside	Petrous	-18.3	8.6	1.7	43.1	15.7	3.2
Apigliano	13^{th}-14^{th}	AP97SK39	-	6-8	Greek Orthodox	Inside	Ulna	-18.8	8.5	1.1	37.4	13.6	3.2
Apigliano	13^{th}-14^{th}	AP00SK78	-	6-8	Greek Orthodox	Outside	Femur	-18.7	7.8	3.2	43.5	15.9	3.1
Apigliano	13^{th}-14^{th}	AP00SK81	-	7-9	Greek Orthodox	Outside	Petrous	-18.8	7.5	0.7	25.4	8.8	3.3
Apigliano	13^{th}-14^{th}	AP98SK32	-	7-9	Greek Orthodox	Inside	Petrous	-18.9	8.5	1.3	36.3	12.8	3.2
Apigliano	13^{th}-14^{th}	AP00SK79	-	7-9	Greek Orthodox	Outside	Femur	-19.1	7.5	1.2	42.5	15.5	3.1

Apigliano	13th-14th	AP98SK16	-	8-10	Greek Orthodox	Outside	Petrous	-19.5	7.2	1	34.7	12.5	3.1
Apigliano	13th-14th	AP98SK43	-	9-10	Greek Orthodox	Outside	Femur	-19	8.1	7.4	43.3	15.8	3.1
Apigliano	13th-14th	AP98SK48	-	8-11	Greek Orthodox	Outside	Petrous	-18.7	8.7	4.9	41.7	15.3	3.1
Apigliano	13th-14th	AP98SK13	-	10-11	Greek Orthodox	Outside	Petrous	-19.5	7.1	1.1	13.7	4.8	3.5
Apigliano	13th-14th	AP99SK66	?	Adult	Greek Orthodox	Outside	Petrous	-18.7	8.6	1.7	23	8.3	3.1
Apigliano	13th-14th	AP98SK18	?	Adult	Greek Orthodox	Outside	Petrous	-18.7	9.2	0.6	37.6	13.6	3.1
Apigliano	13th-14th	AP97SK56	?	Adult	Greek Orthodox	Outside	Petrous	-18.8	9.2	3.5	45.1	16.3	3.3
Apigliano	13th-14th	AP98SK107	?	Adult	Greek Orthodox	Outside	Petrous	-18.5	8.1	1.8	28.7	10.5	3.1
Apigliano	13th-14th	AP97SK55	?	Adult	Greek Orthodox	Outside	Petrous	-18.5	8.1	1.7	32.2	11.7	3.2
Apigliano	13th-14th	AP97SK40	?	Adult	Greek Orthodox	Inside	Clavicle	-18.8	8.9	1	34.1	12.5	3.1
Apigliano	13th-14th	AP00SK81B	?	Adult	Greek Orthodox	Outside	Petrous	-18.6	9	1.9	34.7	12.8	3.1
Apigliano	13th-14th	AP97SK39B	?	Adult	Greek Orthodox	Inside	Fibula	-18.4	8.2	3.5	40.2	14.8	3.1
Apigliano	13th-14th	AP98SK27	?	Adult	Greek Orthodox	Outside	Petrous	-18.9	8.6	2.7	43.3	15.4	3.2
Apigliano	13th-14th	AP97SK52	?	Adult	Greek Orthodox	Outside	Petrous	-18.4	8.1	4.3	43.4	15.5	3.2
Apigliano	13th-14th	AP00SK75	?	Adult	Greek Orthodox	Outside	Tibia	-18.8	7.9	4.1	43.5	15.9	3.1
Apigliano	13th-14th	AP98SK28	?	Adult	Greek Orthodox	Outside	Petrous	-18.1	8.9	7.2	43.6	15.8	3.2
Apigliano	13th-14th	AP97SK53	?	Adult	Greek Orthodox	Outside	Petrous	-18.7	9.1	6.2	43.7	15.7	3.2
Apigliano	13th-14th	AP97SK54	?	Adult	Greek Orthodox	Outside	Petrous	-18.4	9.4	4.2	42.6	15.3	3.2
Apigliano	13th-14th	AP98SK17	F	Adult	Greek Orthodox	Outside	Petrous	-18.8	8.6	1.3	37.5	13.5	3.2
Apigliano	13th-14th	AP98SK30	F	Adult	Greek Orthodox	Outside	Petrous	-19.2	7.5	1.2	38.9	13.9	3.2
Apigliano	13th-14th	AP97SK7	F	Adult	Greek Orthodox	Inside	Tibia	-19.4	7.2	1.5	40.3	14.2	3.3
Apigliano	13th-14th	AP98SK5	F	Adult	Greek Orthodox	Outside	Carpal	-19.3	6.9	2.8	42.1	15.5	3.1
Apigliano	13th-14th	AP98SK46	F	Adult	Greek Orthodox	Outside	Petrous	-18.5	8.4	2.4	42.8	15.5	3.2

Apigliano	13th-14th	AP99SK106	F	Adult	Greek Orthodox	Outside	Humerus	-19.2	6.9	1.3	19.2	6.6	3.3
Apigliano	13th-14th	AP98SK14	F	Adult	Greek Orthodox	Outside	Petrous	-19.1	7.6	3.1	43.9	15.9	3.2
Apigliano	13th-14th	AP00SK111	F?	Adult	Greek Orthodox	Outside	Tibia	-19.1	7.5	2.8	40.7	15.1	3.1
Apigliano	13th-14th	AP00SK80	M	Adult	Greek Orthodox	Outside	Femur	-18.9	7.4	3.4	24.5	9.1	3.1
Apigliano	13th-14th	AP97SK9	M	Adult	Greek Orthodox	Inside	Tibia	-18.4	7.7	1.4	27.9	10.2	3.1
Apigliano	13th-14th	AP99SK70	M	Adult	Greek Orthodox	Outside	Petrous	-19.1	7.4	2.1	29.3	10.8	3.1
Apigliano	13th-14th	AP99SK71	M	Adult	Greek Orthodox	Outside	Petrous	-19.2	7.1	1.2	32.2	11.9	3.1
Apigliano	13th-14th	AP98SK31	M	Adult	Greek Orthodox	Outside	Femur	-19.3	8	1	37.4	12.7	3.3
Apigliano	13th-14th	AP98SK21	M	Adult	Greek Orthodox	Outside	Petrous	-19.1	7.7	1.4	40.6	14.4	3.2
Apigliano	13th-14th	AP98SK29	M	Adult	Greek Orthodox	Outside	Petrous	-18.4	9.3	3	42.9	15.6	3.1
Apigliano	13th-14th	AP98SK24	M	Adult	Greek Orthodox	Outside	Petrous	-19	8.3	4.1	43.5	15.6	3.2
Apigliano	13th-14th	AP00SK1	M	Adult	Greek Orthodox	Outside	Tibia	-18.9	7.4	2.7	43.5	15.9	3.1
Apigliano	13th-14th	AP00SK110	M	Adult	Greek Orthodox	Outside	Femur	-18.6	7.4	4.7	43.5	16	3.1
Apigliano	13th-14th	AP97SK4	M	Adult	Greek Orthodox	Outside	Fibula	-18.5	7.4	4	43.9	16.1	3.1
Apigliano	13th-14th	AP97SK47	M?	Adult	Greek Orthodox	Outside	Petrous	-19.4	7.3	1.2	41.5	15	3.2
Apigliano	*13th-14th*	*AP99SK42*	*-*	*Neonate*	*Greek Orthodox*	*Outside*	*Petrous*	*-19.3*	*8.9*	*0.2*	*18.7*	*6.3*	*3.7*
Apigliano	*13th-14th*	*AP98SK12*	*?*	*Adult*	*Greek Orthodox*	*Outside*	*Skull*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP98SK45*	*F*	*Adult*	*Greek Orthodox*	*Outside*	*Frontal*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP98SK33*	*-*	*9-11*	*Greek Orthodox*	*Outside*	*Petrous*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP98SK44*	*-*	*Neonate*	*Greek Orthodox*	*Outside*	*Petrous*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP97SK6*	*M*	*Adult*	*Greek Orthodox*	*Outside*	*Petrous*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP98SK60*	*?*	*Adult*	*Greek Orthodox*	*Outside*	*Skull*	*-*	*-*	*0*	*-*	*-*	*-*
Apigliano	*13th-14th*	*AP98SK41*	*M*	*Adult*	*Greek Orthodox*	*Outside*	*Femur*	*-*	*-*	*0*	*-*	*-*	*-*

Apigliano	*13^{th}-14^{th}*	*AP00SK82*	*F*	*Adult*	*Greek Orthodox*	*Outside*	*Petrous*	*-*	*-*	*0*	*-*	*-*	*-*
Quattro Macine	11^{th}-15^{th}	QM95SK60	-	3-5	Latin Catholic	Outside	Rib	-18.8	7.8	9.5	44.9	16.5	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK59	-	10-13	Latin Catholic	Outside	Fibula	-18.7	6.7	2.3	39.3	14.5	3.1
Quattro Macine	11^{th}-15^{th}	QM91SK15	-	11-13	Greek Orthodox	Outside	Rib	-19.1	7.4	4.2	39.5	14.6	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK76	-	5-6	Latin Catholic	Outside	Rib	-18.8	7.5	5.7	43.8	16	3.1
Quattro Macine	11^{th}-15^{th}	QM91SK16	-	5-7	Greek Orthodox	Outside	Clavicle	-19.1	7.2	7.1	42.4	15.7	3.1
Quattro Macine	11^{th}-15^{th}	QM92SK1	-	5-7	Greek Orthodox	Outside	Rib	-19	7.2	4.9	44.3	16.2	3.1
Quattro Macine	11^{th}-15^{th}	QM95SK54	-	7-8	Latin Catholic	Outside	Rib	-18.8	6.8	1.6	37.1	13.5	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK33	-	7-9	Latin Catholic	Outside	Rib	-18.9	7.8	1.1	33.4	12.3	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK58	-	8-9	Latin Catholic	Outside	Radius	-18.7	6.8	4	44.1	16.3	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK37	-	10-12	Latin Catholic	Outside	Rib	-19.1	7.9	6.2	43.1	15.9	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK46	-	15-17	Latin Catholic	Outside	Rib	-19	7.8	3.7	41.1	15.1	3.1
Quattro Macine	11^{th}-15^{th}	QM93SK30	F	20-25	Latin Catholic	Outside	Rib	-19.1	7.2	4.4	42.8	15.7	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK27	F	20-25	Latin Catholic	Outside	Rib	-19	7.2	2.3	42.8	15.8	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK34	F	20-30	Latin Catholic	Outside	Clavicle	-18.9	8.1	8.1	44.4	16.5	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK29	F	25-30	Latin Catholic	Outside	Clavicle	-18.7	7.5	2.1	35.8	13.2	3.1
Quattro Macine	11^{th}-15^{th}	QM95SK81	F	25-30	Latin Catholic	Outside	Rib	-18.8	8	7.5	44.1	16.2	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK47	F	25-30	Latin Catholic	Outside	Rib	-19.1	7.9	6.4	44.4	16.2	3.1
Quattro Macine	11^{th}-15^{th}	QM93SK48	F	30-35	Latin Catholic	Outside	Rib	-18.6	7.9	4.9	40.8	15.1	3.1
Quattro Macine	11^{th}-15^{th}	QM93SK23	F	30-35	Latin Catholic	Outside	Rib	-19	7.1	5.1	43.2	16	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK31	F	40-45	Latin Catholic	Outside	Rib	-18.8	8.1	8.6	43.9	16.1	3.1
Quattro Macine	11^{th}-15^{th}	QM93SK25	F	Adult	Latin Catholic	Outside	Rib	-18.9	7.8	6	43.4	16.1	3.1
Quattro Macine	11^{th}-15^{th}	QM94SK35	F?	35-40	Latin Catholic	Outside	Tibia	-19.1	7.1	1.3	14.6	5.1	3.3

Quattro Macine	11th-15th	QM94SK36	M	20-25	Latin Catholic	Outside	Radius	-19.1	7.4	4.4	34.7	12.9	3.1
Quattro Macine	11th-15th	QM94SK28	M	22-28	Latin Catholic	Outside	Rib	-18.6	7.7	0.9	41.7	15.4	3.2
Quattro Macine	11th-15th	QM94SK65	M	30-35	Latin Catholic	Outside	Fibula	-19.1	7.7	4.8	43.4	15.9	3.1
Quattro Macine	11th-15th	QM95SK63	M	40-50	Latin Catholic	Outside	Rib	-18.9	7.8	1.4	44.3	16.2	3.1
Quattro Macine	11th-15th	QM94SK61	M	40-50	Latin Catholic	Outside	Rib	-19	7.9	6.9	44.9	16.4	3.1
Quattro Macine	11th-15th	QM94SK32	M	40-50	Latin Catholic	Outside	Rib	-18.7	7.5	5.6	45.3	16.8	3.1
Quattro Macine	11th-15th	QM94SK40	M?	30-40	Latin Catholic	Outside	Rib	-18.7	7.4	3.9	40.7	15.1	3.1
Quattro Macine	11th-15th	QM95SK43	M?	50+	Latin Catholic	Outside	Rib	-18.9	7.8	0.6	44.1	16.4	3.1
Quattro Macine	11th-15th	QM95SK42	M	30-35	Greek Orthodox	Inside	Clavicle	-19.1	8.4	1.5	15.9	5.6	3.4
Quattro Macine	11th-15th	QM95SK62	M	45-55	Latin Catholic	Outside	Long Bone	-19.5	6.8	1.4	7.9	6.4	3.5
Quattro Macine	11th-15th	QM94SK20	M	60+	Latin Catholic	Outside	Rib	-18.6	7.7	1.8	18.2	6.4	3.3
Quattro Macine	*11th-15th*	*QM95SK64*	*M*	*30-35*	*Latin Catholic*	*Outside*	*Rib*	-	-	*0*	-	-	-
Quattro Macine	*11th-15th*	*QM95SK72*	*F*	*40-50*	*Latin Catholic*	*Outside*	*Clavicle*	-	-	*0*	-	-	-

Supplementary Information

Collagen amino acid profiling

Samples were prepared using a slightly modified version of the protocol by Penkman et al. (2008). A small sub-sample of extracted collagen (~1 mg) was hydrolysed in 7M HCL (100 µl per mg) under N_2 for 18 hours at 110°C. After hydrolysis, the samples were dried down overnight before being re-hydrated in 0.01mM L-homo-arginine as an internal standard. The samples were analysed using reversed phase high pressure liquid chromatography (RP-HPLC) following a slightly modified version of the protocol by Kaufman and Manley (1998). During the hydrolysis step, both asparagine and glutamine undergo irreversible deamidation to aspartic acid and glutamic acid respectively (Hill 1965). Therefore it is not possible to distinguish between asparagine and aspartic acid and glutamine and glutamic acid, so they are reported as Asx and Glx respectively. The results were assessed using their racemisation values (Table S1) and by comparing the amino acid composition of the samples to a modern reference (Figure S1).

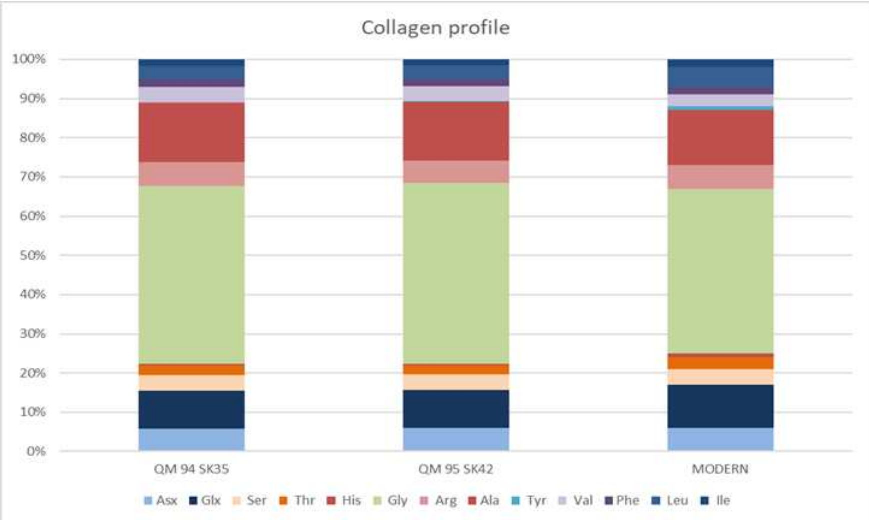

Figure S1. The amino acid composition profiles of the two archaeological samples and the modern reference sample.

Sample	Asx D/L	Glx D/L	Ser D/L	Arg D/L	Ala D/L	Val D/L	Phe D/L	Leu D/L	Ile D/L	Tyr D/L
QM 94 SK35	0.183	0.040	0.024	0.007	0.021	0.018	0.023	0.030	0.000	0.000
QM 95 SK42	0.167	0.038	0.028	0.036	0.021	0.016	0.023	0.061	0.009	0.000
MODERN	0.059	0.000	0.030	0.021	0.014	0.023	0.000	0.000	0.031	0.000

Table S1. The racemisation values of the two archaeological samples and the modern reference.

References

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