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The Medieval Population of Leopoli-Cencelle (Viterbo, Latium): Dietary Reconstruction through Stable Isotope Analysis from Bone Proteins

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Abstract

The Medieval period in Europe was a time of unprecedented social complexity and significant social and political change that had an impact on human diets. The present study aims to use stable isotope analysis from bone proteins to explore the diets of humans (n = 76) and fauna (n = 5) from the Medieval town of Leopoli-Cencelle (VT, Italy). The town was occupied between the 9th-15th centuries CE, however, the analysed remains date to the Late Medieval period (12th-15th centuries CE). Historical sources provide some information about the inhabitants of this community: the majority of the population was represented by craftsmen and traders, but farmers and shepherds were also present. To date, no biomolecular data regarding this community have been published.

The results indicated an increase of 3-5‰ in $\delta^{15}N$ values of humans compared to animals, reflecting a high trophic-level. The $\delta^{13}C$ results indicated that animal and human diet was mainly based on C_3 terrestrial resources, although three humans possessed an isotopic signature indicative of C_4 plant consumption. No statistically significant differences between sexes or age groups (adults *vs* juveniles) were detected. The isotopic results were further placed in their regional and chronological context, adding valuable data to our understanding of diet and food distribution during the Medieval period in Italy.

1. Introduction

The study of dietary patterns in past human populations represents an important issue in the reconstruction of the dynamics of past populations. Food consumption has a significant influence on human behaviour and has been associated with major changes in human history and ecological conditions (Parker Pearson, 2003). Human diet is the culmination of environmental factors, technology, trading, organization of social structure, and culture. Diet underwent significant modifications during the Medieval period. People experienced access to new production technologies alongside the emergence of new nutritional disparities in an increasingly hierarchical society (Nada Patrone, 1981; Montanari, 1988; Adamson, 2004). The majority of the information available from written sources about this significant historic period, for both Italy and Europe, focuses on the dietary habits of high status individuals, with little evidence for the lower social orders. This disparity in information can, however, be addressed with archaeological data (Polet and Katzenberg, 2003; Müldner and Richards, 2005).

The Medieval period, in particular, was characterized by a cultural transformation related to the merging of the classical and barbarian societies that had an influence on diet (Duby, 1975). The classical civilization formed in the Mediterranean area, had a production system based on cereal, vine and olive-tree exploitation, alongside low sheep-farming. In contrast, the production model developed by barbarian peoples in the continental area of Europe promoted a forest-pastoral type economy, heavily based on the exploitation of uncultivated and wooded spaces through the hunting, fishing, harvesting of wild fruits and livestock breeding (especially pigs) (Duby, 1975). The contact and collision of these two cultures led to a progressive expansion of cereal agriculture in Northern Europe alongside increasing exploitation of uncultivated and wooded areas in Central and Southern Europe, the latter having been previously viewed as an obstacle for economic production in these areas. The combined result was the formation of a mixed production system (Montanari, 1979; Duby, 1975). In the Early Medieval period, the diet was highly varied with a consumption of animal proteins (above all meat and fish) combined with plants (Montanari, 1981; 2012). By the Late

Medieval period, however, historical evidence suggests that animal protein intake generally became a privilege of those of higher social status (Montanari, 1988). With regard to grain, wheat was progressively substituted by barley, sorghum, millet, and rye; which were easily tillable and ensured a higher yield (Montanari, 1979).

There are an increasing number of isotopic studies focussing on Medieval Italy (Reitsema and Vercellotti, 2012; Ricci et al., 2012; Pescucci et al., 2013; Iacumin et al., 2014; Scorrano et al., 2014; Ciaffi et al., 2015; Torino et al., 2015; Baldoni et al., 2016), but this study, for the first time, focuses on Leopoli-Cencelle, one of the few Italian Centres of Papal Foundation that has been extensively investigated from both an archaeological and an anthropological point of view. Individuals buried at the cemetery of Leopoli-Cencelle offer an opportunity to explore the diets of a large Medieval community through stable isotope analysis of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in human and animal bone proteins.

The analysis of stable isotopes from bone proteins is an established technique for assessing the diet of archaeological populations (Katzenberg, 2000). This allows for the reconstruction of the main protein sources in the diet in the last decades before death (Hedges et al., 2007). Carbon isotopes allow to discriminate between marine and terrestrial, and C_3 and C_4 sources of protein, whereas nitrogen isotopes indicate the trophic position an individual is feeding at (Ambrose, 1993; Katzenberg, 2000; Schoeninger, 2011). Because stable isotope analysis is performed on individuals, data can be correlated with biological indicators to reveal sex- and age-based differences in diet (Ambrose et al., 1997; Herrschera et al., 2001; Katzenberg, 1993), as well as social stratification (Polet and Katzenberg, 2003; Richards et al., 1998) within an analysed population. Moreover, stable isotope data gives information about the biological status of the individuals; in particular, the enrichment of ^{15}N could be correlated with nutritional stress or metabolic disease, for example (Katzenberg and Lovell 1999; Mekota et al. 2006; Scorrano et al., 2014; Baldoni et al., 2018; Scorrano, 2018; Scorrano et al., 2018).

The archaeological site of Leopoli-Cencelle is located in the Northern Lazio between Tarquinia

(VT) and Allumiere (RM), 80 km northwest of Rome and 12 km northwest of Civitavecchia (Figure 1a). Sapienza University of Rome has been conducting an archaeological survey in the area since 1994, with annual digging campaigns that have provided a framework of this Medieval city from its consecration in 854CE until the 17th century. The city, one of the few Italian Centres of Papal Foundation, is located on the top of a hill 160 meters above sea level between the rivers Mignone and Melledra (Figure 1b). As stated in the *Liber Pontificalis* of the Roman Catholic Church, the foundation of Leopoli-Cencelle was attributed to Pope Leo IV. The Pope founded Leopoli-Cencelle as a new *civitas,* aiming to provide hospitality and safety to the inhabitants of *Centumcellae* (the modern Civitavecchia) after having been attacked by the Saracens (Medieval Islamic raiders) (Ermini Pani, 2014).

The location of the new city afforded access to natural resources, such as water and building materials (i.e. stones and sand) (Ermini Pani, 2014). Archaeological investigation in the South-eastern area, close to St. Peter's Church, revealed a graveyard consisting of burials within sarcophagi made of stone slabs and in earthen graves from which the skeletal remains analysed here were recovered during the 2013 digging campaign. The intense use of the area, as well as its reduction in size in the Late Middle Ages, caused frequent overlapping of the burials that cut across each other (Del Ferro, 2014) (Figure 2). Both archaeological and historical data suggest Cencelle was a dynamic city. The archaeological investigation of the South-eastern area also recovered settlement areas associated with specific activities (i.e. blacksmith, ceramic workshop, bell production, cereal grinding) (Stasolla, 2012).

2. Materials and Methods

A total of 76 human and 5 faunal samples from the 2013 excavation campaign in the Late Medieval Leopoli-Cencelle graveyard (12th-15th centuries CE) were sampled. For each individual, a preliminary anthropological analysis was performed following established methods for sex and age at death estimation. Age at death estimation for adult individuals (from ca. 18 years old) followed methods based on morphological changes in the auricular surface of the ilium (Lovejoy et al., 1985), in pubic symphysis (Todd, 1920a, 1920b; Brooks and Suchey, 1990), and in the sternal end of the fourth ribs (İşcan et al., 1984, 1985). Moreover, dental wear (Brothwell, 1981; Lovejoy, 1985) and the obliteration of the cranial sutures (Meindl and Lovejoy, 1985) were recorded. For non-adult skeletal remains (up to ca. 18 years old), tooth eruption (Ubelaker, 1989), diaphyseal length of bones (Fazecas and Kósa, 1978; Stloukal and Hanáková, 1978; Scheuer and Black, 2000), and secondary ossification centers (cf. Minozzi and Canci, 2015) were taken into account. Sex diagnosis was performed only on the adult sample following the methods proposed by Acsádi and Nemeskéri (1970) and revised by Ferembach et al. (1979), and Phenice's (1969) method. No assumption of sex was made for infant and juvenile individuals who showed incomplete sex maturation.

Protein extraction was performed on ribs and, when unavailable, on long bone fragments following a modified Longin method (1971). In order to remove potential contaminants, the outer surface of the bone was detached with a sterile surgical blade and approximately 500 mg of bone was subsequently pulverized using a mortar and pestle. Eight mL of 0.6 M HCl at 4°C was added to the powder and the sample was left at 4°C on a horizontal mixer for two days, changing the acid after 24 hours to demineralize the bone. Samples were then rinsed three times with ddH_2O, until the pH level became neutral. The gelatinisation of the pellet occurred after heating it in an oven at 75°C for 24–48 h with HCl pH 3.0 (0.001 M). The solute was frozen at -80°C for four hours and then freeze-dried for two days. A simultaneous extraction on modern bovine bone was performed and used as a reference control. Approximately 0.8–1.2 mg of protein was weighed in tin capsules and analysed in duplicate by EA-IRMS on a Sercon GSL analyser coupled with a Sercon 20-22 Mass Spectrometer BioArCh (University of York). Isotope data are reported as delta (δ) values relative to V-PDB (Vienna Pee-Dee Belemnite) for carbon and AIR (Atmospheric air) for nitrogen using International Atomic Energy Agency (IAEA) standards (N-2, and IAEA-600 for nitrogen and IAEA-600 and Iso-Analytical R006 for carbon). Carbon content (%C, > 30%), nitrogen content (%N, ≥ 11%), protein yield (≥ 1%), and C/N ratios (2.9-3.6) were checked for protein quality

(DeNiro1985; van Klinken1999). In order to compare the isotopic data to other Medieval sites, comparisons were performed with coeval sites from literature for which the isotope value data were available for each single individual. Statistical tests (Mann-Whitney) were performed by PAST v. 3.08 (Hammer et al., 2001).

3. Results

Isotope data and protein quality indicators are reported in Table 1. All the analysed samples had satisfactory quality indicators according to the criteria proposed by DeNiro (1985) and van Klinken (1999). Figure 3 shows the plot of $\delta^{13}C$ *versus* $\delta^{15}N$ values for both faunal and human samples. The $\delta^{13}C$ values of the three herbivore samples (cattle and sheep) ranged from -21.9‰ to -19.8‰ (mean -20.6 ± 1.2‰), while $\delta^{15}N$ values ranged between 4.1‰ and 5.3‰ (mean 4.7 ± 0.6‰). The omnivore samples (swine and unspecified omnivore) showed mean values of -19.7‰ and 7.1‰ for $\delta^{13}C$ and $\delta^{15}N$ respectively. Isotope data for the faunal samples were in a range typically associated with C_3 environments (Craig et al., 2009).

Human samples exhibited $\delta^{13}C$ values ranging from -20.5‰ to -17.6‰ (mean -19.2 ± 0.4) and $\delta^{15}N$ values from 6.4‰ to 12.5‰ (mean 8.9 ± 1.0). Both carbon and nitrogen isotope values show high variability within the analysed sample. One individual in particular (SU 11024) possesses an elevated $\delta^{15}N$ value of 12.5‰ and three others (SU 8874, 8899, and 11058) show low $\delta^{15}N$ values of 6.6‰, 6.4‰ and 6.6‰ respectively. These outliers aside, the majority of the human population demonstrates a ^{15}N enrichment of about 3-5‰, compared to the animals, indicative of a typical trophic level shift attributable to the intake of animal protein (Bocherens and Drucker 2003). The $\delta^{13}C$ values are compatible to a diet mainly based on the consumption of C_3 resources, however, the higher $\delta^{13}C$ values of the SU 8855, 8880 and 8939 samples (-17.6‰, -17.9‰ and -18.0‰ respectively) could suggest some C_4 plant consumption. Despite the high variability of isotope values for nitrogen for the population as a whole, no statistically significant differences were identified between sexes (males *vs* females $\delta^{13}C$ Mann Whitney p= 0.2435; $\delta^{15}N$ Mann-Whitney p= 0.2717), nor between adults and juveniles (adults *vs* juveniles $\delta^{13}C$ Mann Whitney p= 0.2189; $\delta^{15}N$

Mann-Whitney p= 0.0932) (Figure 3).

4. Discussion

All five terrestrial animals exhibit $\delta^{13}C$ and $\delta^{15}N$ values within the range of exclusive C_3 feeders; the lack of ^{13}C enrichment led to the preliminary conclusions that they were not foddered with C_4 plants. They were probably raised and fed with the resources available in the local environment. The sample size is small and ideally a wider faunal sample would be preferable for interpretation of the human isotope results.

The human $\delta^{13}C$ and $\delta^{15}N$ values at Leopoli-Cencelle suggest an omnivorous diet mainly based on terrestrial food sources that include both plants and animal protein. The $\delta^{15}N$ values do not suggest any contribution of freshwater fish for the population, despite the location of the site near riverine resources, however their consumption cannot be totally excluded. Based on the small sample of animals analysed here, terrestrial animal proteins were probably mainly derived from pork. Historical sources indicate that in the 14th century pork represented over 30% of animal protein consumption, whereas cattle were primarily employed for working purposes and only secondarily, when too old, for human nutrition (Minniti, 2009; 2012). The use of cattle for milk and dairy products, however, cannot be excluded. Moreover, historical records indicate that during the Middle Ages, C_4 plants often served as a substitute for wheat because of their higher yield, and these grains were frequently used to prepare soups (Montanari, 1979; 2012).

There were four outliers identified by their $\delta^{15}N$ values. The first, SU 11024, exhibited the highest $\delta^{15}N$ value within the analysed sample. This is an infant individual that was aged under 3 years at the time of death and therefore its ^{15}N enrichment is likely to be related to breastfeeding (Fogel et al. 1989). The others (SU 8874, 8899, and 11058) exhibited extremely low nitrogen values compatible with a minor role of animal protein in the diet. These individuals probably subsisted more on plants, with pulses (that tend to possess low $\delta^{15}N$ values, Szpak et al. 2014) being a possibility. The use of pulses at the site is confirmed by archaeobotanical finds from a silo in the South-eastern quarter (Stasolla, 2018). The absence of statistically significant differences between sexes and age groups (adults *vs* juveniles) indicate a similar access to nutritional resources between different social groups. It may be that the moderate-high social status of the Leopoli-Cencelle Medieval population attested by material culture (Stasolla, 2014) led a higher availability of food protein even in the Late Medieval period, when historical sources suggest that economic changes led to a reduction in animal protein sources available to those of low social status (Montanari, 1988). Analysis of further individuals from the cemetery including those of the earlier period of occupation would allow for further investigation of this finding. The similarity of diets between males and females was not expected given the differing views on men and women in medieval society (Pearson, 1997; Baldoni et al., 2016). In Medieval religious communities, women usually received smaller rations of food because of their smaller size (Pearson, 1997), and among the laity and in religious communities, they were encouraged to fast aiming to reduce sexual urges (Bynum, 1987). Moreover, Pearson (1997), argued that, the nutritional needs of early medieval women, particularly given the strains of pregnancy, childbirth, and lactation, were probably not adequately met for many of them.

Archaeological and archaeozoological evidence support the isotopic results, particularly in the South-eastern district of the Medieval city where housing clusters were recovered (Martorelli, 2012; Bougard and Cirelli, 2012). Craft workshops, taverns, henhouses and warehouses were identified (Stasolla, 2018), as well as, fireplaces aimed to both cooking and working purposes (Martorelli, 2012). Thousands of pottery fragments attributable to earthenware pots of different diameters were recovered (Pesez, 1984; Giovannini, 1998), indicating a wide range of dishes that were consumed. Many of them were potentially long-cooked stews with pulses and meat from older animals (Minniti, 2009; 2012; Savelli and Larocca, 2012) that were probably not cooked directly on the fire (Stasolla, 2018). The high numbers of these pottery containers seem to be in line with other archaeological sites from Latium that are characterized by a huge number of earthenware pots that were used for specific dishes in order to avoid the excessive mixture of scents (Faure-Boucharlat, 1990), and also reflect the habit of cooking different dishes at the same fireplace simultaneously (Montanari, 2012; Stasolla, 2018).

In order to evaluate the isotope data from Leopoli-Cencelle within the context of contemporary Italian and European sites, the results of the present research have been compared with published data from other coeval populations (Table 2). The plots of median values for the Italian (Figure 4), Mediterranean (Figure 5) and Northern European (Figure 6) coeval populations are reported. However, statistical comparisons were performed for Italian and Mediterranean sites only because differences with Northern European populations may be the result of differing animal baselines rather than different diets. Tables 2 and 3 report, respectively, median values in the 25th and 75th percentiles and the results of the statistical tests performed. The plots (Figs. 4-6) show median values for each archaeological site since the statistically significant differences did not allow to pool together isotope values by country (data not shown). As shown in Figure 4 and reported in Table 3, statistically significant differences (Mann-Whitney tests $p<0.05$) were found between $\delta^{13}C$ values, mostly within North-eastern Italian sites (Cividale Gallo, Cividale S. Stefano, Mainizza, Romans d'Isonzo; Iacumin et al., 2014), Cosa from central Italy (Scorrano et al., 2014) and Montella from Southern Italy (Torino et al., 2015). For North-eastern and Central Italian sites, the consumption of C_4 (usually millet) or marine resources were interpreted to be responsible for the enriched $\delta^{13}C$ values at these sites (Iacumin et al. 2014; Scorrano et al., 2014). In the North-eastern Italian regions, a progressive decrease in bread consumption occurred in favour of an increase in soup consumption through the Middle Ages (Iacumin et al., 2014). The population from Montella, in the South, (Torino et al. 2015) was associated with a Franciscan friary; so, it may be that they followed a different dietary regime. Statistically significant differences (Mann-Whitney tests $p<0.05$) were found between $\delta^{15}N$ with the North-eastern sites (Iacumin et al., 2014) and Montella (Torino et al., 2015), along with sites from Latium (Scorrano et al., 2014; Ciaffi et al., 2015; Baldoni et al., 2016). The North-eastern sites were characterized by a low animal protein intake even if, for some of them, the consumption of freshwater fish was not excluded due to the proximity to rivers (Iacumin et al., 2014). The complete lack of isotope values compatible with fish consumption was observed in Montella (Torino et al., 2015) even though, as mentioned above, the sample was associated with a Christian order of monks. The $\delta^{15}N$ values observed in Leopoli-Cencelle could be also related to the potential consumption of chicken as source of animal protein, that could have contributed to the ^{15}N enrichment, as witnessed by the presence of henhouses attested by archaeological data (Stasolla, 2018). The observed differences with Colonna, Albano and Cosa are not surprising, even though the sites are relatively close to each other. The Medieval period was characterized by important changes that affected lifestyle and diet, due to access to non-local foods and new production technologies and an increasingly hierarchical society (Nada Patrone, 1981; Montanari, 1988; Adamson, 2004). The analysed specimens from Albano (11th-13th centuries; Ciaffi et al., 2015) and Cosa (11th-13th centuries; Scorrano et al., 2014) are coeval with those from Leopoli-Cencelle, whereas the human remains from Colonna date back to the Early Medieval period (8th-10th centuries; Baldoni et al., 2016) so chronology should also be considered as a causing factor of the observed differences. It is known in fact that small variations in the local environment as well as low temporal shifts could also be responsible for the observed differences (van Klinken et al., 2000).

Comparisons with Mediterranean and Northern Italian sites (Figure 5 and 6) underline that the inhabitants of Leopoli-Cencelle had dietary patterns more similar to Greece (Garvie-Lok, 2001; Bourbou et al., 2011) within the Mediterranean area and with Poland (Reitsema et al., 2010) and Germany (Schutkowsky and Herrmann, 1999) as regards to Northern Europe. Greek diet during the Medieval period was mainly based on terrestrial food sources from both animals and plants (primarily C_3 plants, however, for Nemea, Mitilini and Corinth a small intake of C_4 plants was hypothesized). The authors stated that variations among Greek sites are probably attributable to local environmental sources as well as to a possible distortion of the isotope values due to olive oil consumption (Garvie-Lok, 2001; Bourbou et al., 2011). Isotope values from the Weingarten site in Germany (Schutkowski and Herrmann, 1999) suggest a more vegetarian-based diet with a small protein intake from animal sources whereas, an omnivorous diet with low or almost absent fish consumption was observed in Poland (Reitsema et al., 2010). With regards to $\delta^{15}N$, the observed differences are probably attributable to the different environmental resources available. The high nitrogen values in Croatia are related to high animal protein intake, mostly pork), with low or absent fish consumption (Lightfoot et al., 2012).

Sites in the North usually exhibit ^{15}N enrichment in comparison to Leopoli-Cencelle; this is probably due to consumption of high trophic level proteins and/or marine resources at some sites (i.e. Koksijde, Belgium, Polet and Katzenberg, 2003; Flakstad, Norway, Naumann et al., 2014) but also differing environmental baselines. This is interesting, as Leopoli-Cencelle seems to have relatively high animal protein consumption compared to sites in Italy, but compared to sites in Northern Europe, the $\delta^{15}N$ values are lower, which would potentially suggest less animal (and fish) protein consumption at published Medieval Italian sites compared to contemporary sites in Northern Europe.

5. Conclusions

The present research reconstructed the dietary plans in a Late Medieval sample from Leopoli-Cencelle (VT, Italy). Diet was omnivorous and mainly based on C_3-terrestrial food sources, both plants and animals and indicated a high amount of animal protein in comparison to other published Medieval Italian sites. Although the isotope data suggested that fish consumption did not have a significant role in the diet, the utilization of freshwater resources cannot be excluded. Probable consumption of C_4 plants was hypothesised for three individuals. The absence of statistically significant differences between sexes and age groups indicated that similar diets were consumed across different social groups.

Author contributions

O.R., and C.M.L designed the research; F.R.S. directed the archaeological excavation at Leopoli-Cencelle site; M.B., took part at the excavation as anthropologist supervisor; M.B., and G.S., performed the analysis provided in the study; M.A. performed the isotope analysis by mass spectrometry; L.T.M. gave support in carrying out the research; O.R. provided the financial support for the research; M.B., and C.M.L. wrote the paper, all the authors edited the manuscript for intellectual content, revised and provided critical comments on the manuscript.

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Conflict of interests

The authors declare no conflict of interest

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Figure captions

Figure 1. a) Geographical location of the Medieval archaeological site of Leopoli-Cencelle; and blow up with the localization of Mignone river (www.google.com/maps mod.); b) aerial view of the medieval city (www.google.com/maps mod.).

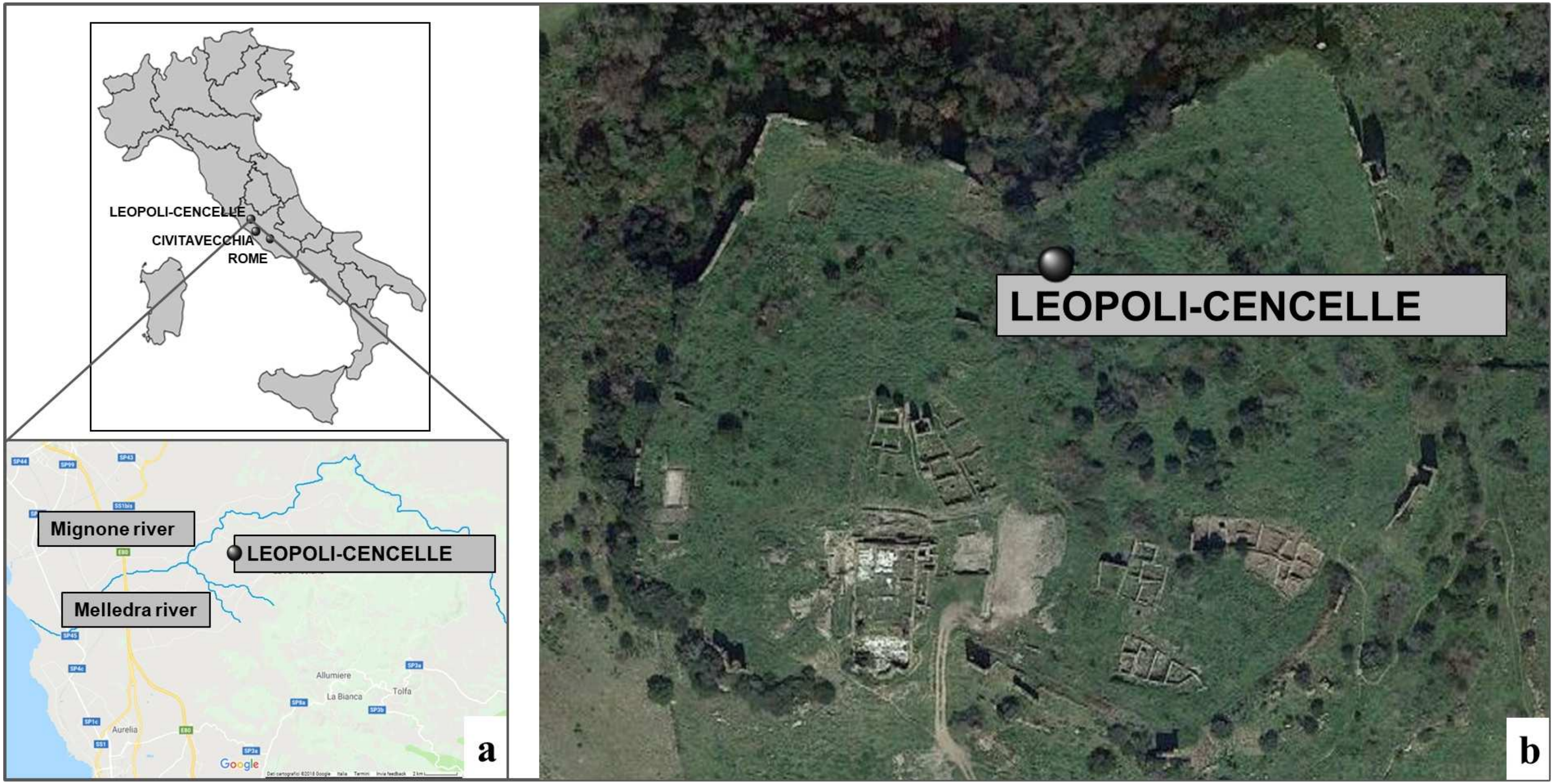
Figure 2. Earthen graves recovered during 2013 excavation campaign in the cemetery area of Leopoli-Cencelle.

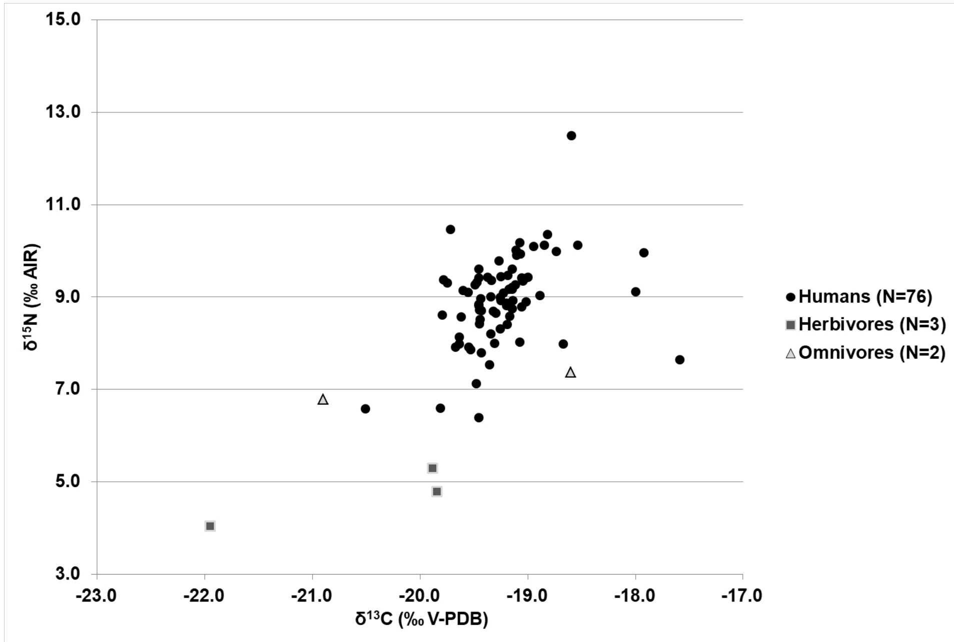
Figure 3. a) Plot of carbon *vs* nitrogen isotope values for human and faunal skeletal samples from Leopoli-Cencelle. Specimens are plotted individually b) Plot of carbon vs nitrogen isotope values for human samples. Specimens are plotted individually and divided by sex and age at death (adults and juveniles).

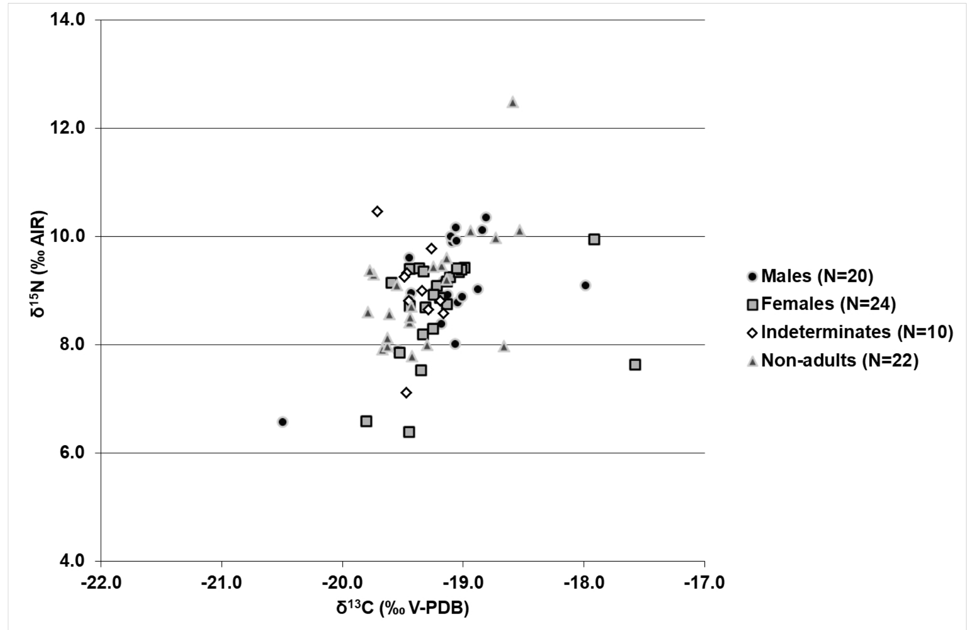
Figure 4. Plots of carbon and nitrogen isotopic values for human samples from Leopoli-Cencelle and Italian Medieval sites: symbols (triangle: Central Italian sites; square: Northern Italian sites; diamond: Southern Italian sites) describe median values of the sites, horizontal and vertical lines end at the 25^{th} and 75^{th} percentile of the site sample.

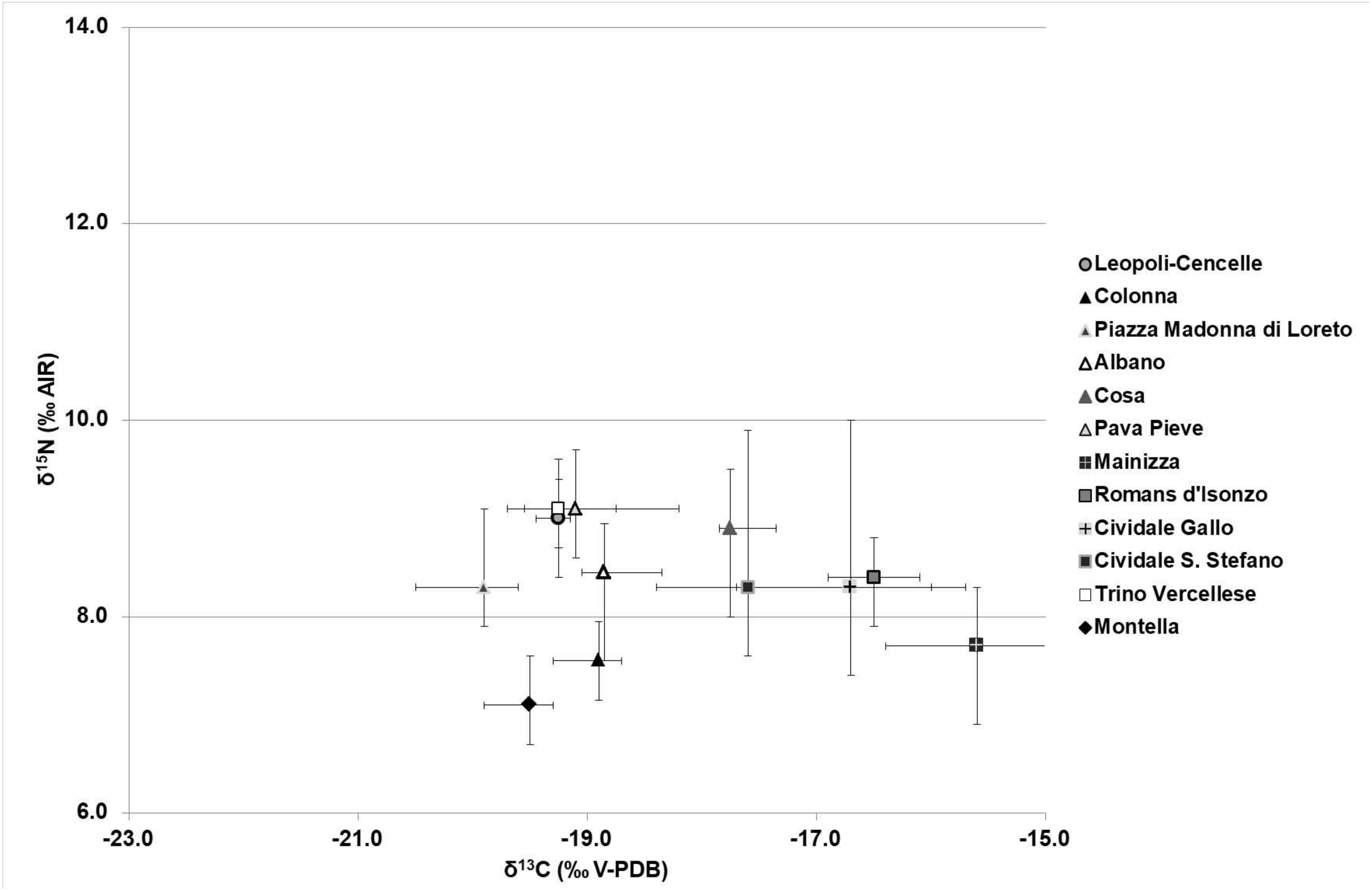
Fig. 5. Plots of carbon and nitrogen isotopic values for human samples from Leopoli-Cencelle and coeval Mediterranean sites: symbols (square: Greek sites; diamond: Spanish sites; triangle: Croatian sites) describe median values of the sites, horizontal and vertical lines end at the 25^{th} and 75^{th} percentile of the site sample.

Figure 6. Plots of carbon and nitrogen isotopic values for human samples from Leopoli-Cencelle and coeval Northern European sites: symbols (triangle: Scottish sites; square: English sites; diamond: Swedish sites) describe median values of the sites, horizontal and vertical lines end at the 25^{th} and 75^{th} percentile of the site sample.

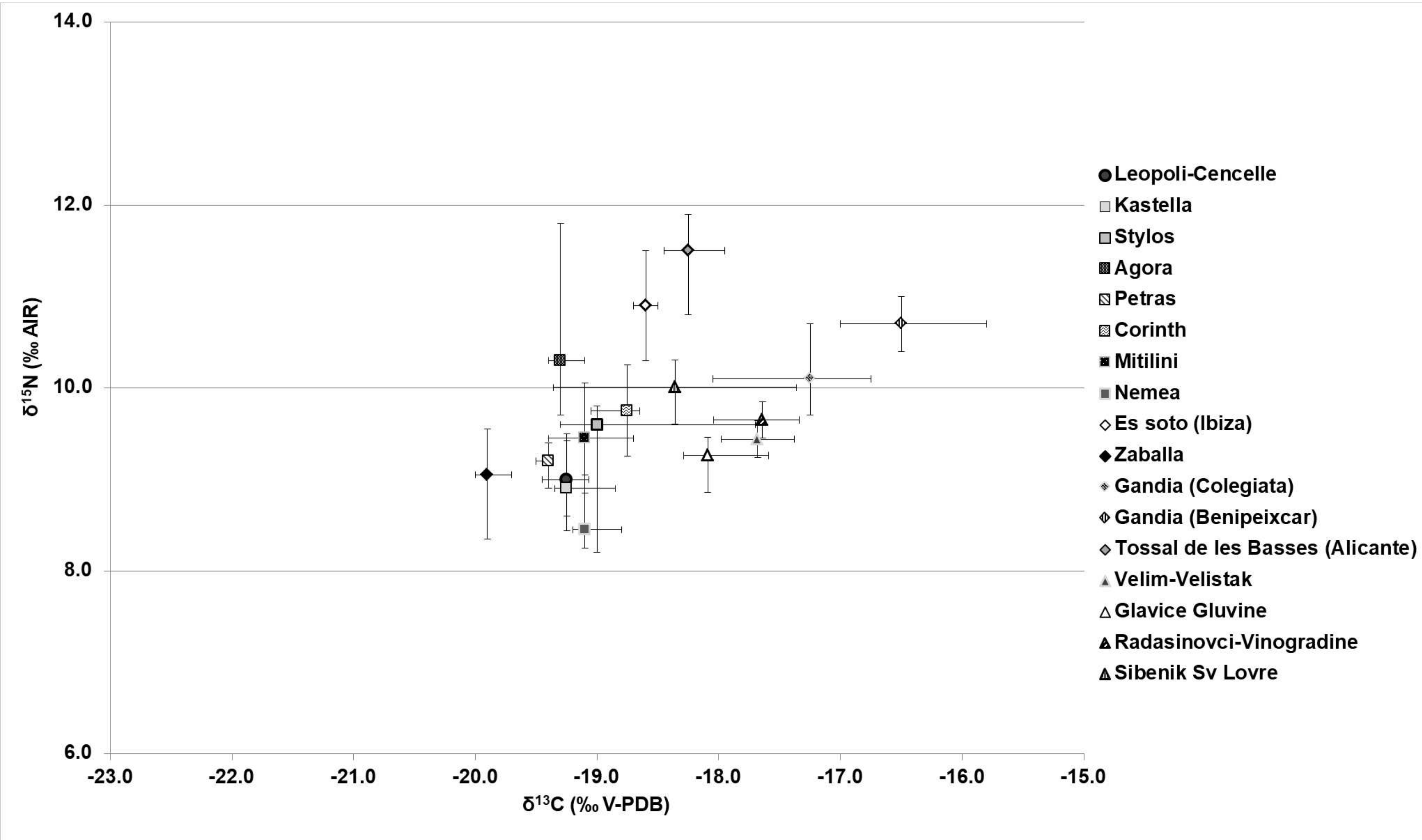

LEOPOLI-CENCELLE
CIVITAVECCHIA
ROME
Mignone river
LEOPOLI-CENCELLE
Melledra river
Allumiere
La Bianca
Tolfa
Aurelia
a
LEOPOLI-CENCELLE
b


15.0
13.0
11.0
9.0
7.0
5.0
3.0
-23.0
-22.0
-21.0
-20.0
-19.0
-18.0
-17.0
δ15N (‰ AIR)
δ13C (‰ V-PDB)
Humans (N=76)
Herbivores (N=3)
Omnivores (N=2)


14.0
12.0
10.0
8.0
6.0
4.0
-22.0
-21.0
-20.0
-19.0
-18.0
-17.0
δ15N (‰ AIR)
δ13C (‰ V-PDB)
Males (N=20)
Females (N=24)
Indeterminates (N=10)
Non-adults (N=22)



14.0
12.0
10.0
8.0
6.0
δ15N (‰ AIR)
-23.0
-21.0
-19.0
-17.0
-15.0
δ13C (‰ V-PDB)
Leopoli-Cencelle
Colonna
Piazza Madonna di Loreto
Albano
Cosa
Pava Pieve
Mainizza
Romans d'Isonzo
Cividale Gallo
Cividale S. Stefano
Trino Vercellese
Montella



14.0
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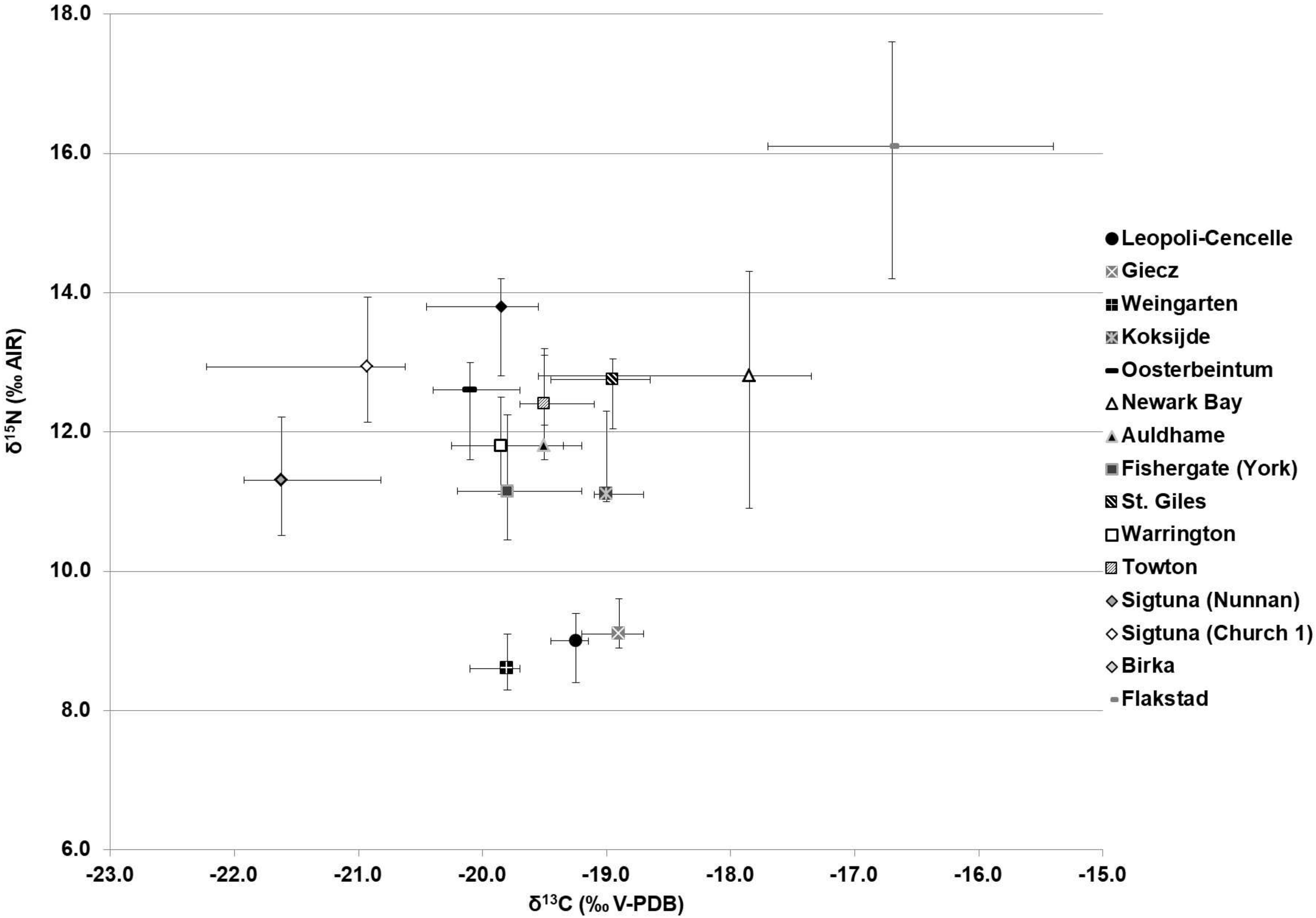
δ15N (‰ AIR)
-23.0
-22.0
-21.0
-20.0
-19.0
-18.0
-17.0
-16.0
-15.0
δ13C (‰ V-PDB)
Leopoli-Cencelle
Kastella
Stylos
Agora
Petras
Corinth
Mitilini
Nemea
Es soto (Ibiza)
Zaballa
Gandia (Colegiata)
Gandia (Benipeixcar)
Tossal de les Basses (Alicante)
Velim-Velistak
Glavice Gluvine
Radasinovci-Vinogradine
Sibenik Sv Lovre



18.0
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-18.0
-17.0
-16.0
-15.0
δ15N (‰ AIR)
δ13C (‰ V-PDB)
Leopoli-Cencelle
Giecz
Weingarten
Koksijde
Oosterbeintum
Newark Bay
Auldhame
Fishergate (York)
St. Giles
Warrington
Towton
Sigtuna (Nunnan)
Sigtuna (Church 1)
Birka
Flakstad

Table 1. Carbon and nitrogen stable isotope values and protein quality indicators of human and animal specimens from Leopoli-Cencelle (SU: Stratigraphic Unit). M indicates male, F female, IND indeterminate (for juvenile individuals for who no attempt of sex determination was made), ND not-determinable, GA generic adult (>18 years) and GNA generic non-adult (<18 years).

Human specimens								
SU	**sex**	**age at death (years)**	**$\delta^{13}C$**	**$\delta^{15}N$**	**%C**	**%N**	**C:N ratio**	**protein yield (%)**
8734	M	41-50	-19.2	9.2	42.5	14.9	3.3	4.6
8737	F	41-50	-19.0	9.4	41.7	15.3	3.2	1.0
8751	IND	7-12	-19.7	9.3	41.1	14.9	3.2	1.3
8761	F	31-40	-19.3	8.7	40.8	14.7	3.2	3.9
8765	M	31-40	-19.0	8.8	42.2	15.5	3.2	4.6
8773	M	GA	-19.1	8.0	38.2	13.7	3.2	1.1
8777	M	41-50	-18.8	10.4	40.3	14.7	3.2	3.3
8780	IND	13-18	-19.7	7.9	40.2	14.6	3.2	1.1
8786	F	41-50	-19.6	9.1	38.8	13.9	3.3	1.1
8798	IND	13-18	-18.7	10.0	39.3	14.2	3.2	1.1
8801	ND	GA	-19.5	9.3	41.2	15.0	3.2	3.4
8806	F	41-50	-19.4	8.7	38.0	13.7	3.3	1.1
8810	IND	1-6	-19.6	8.1	43.4	15.7	3.2	13.6
8823	IND	GNA	-19.4	7.8	37.6	13.7	3.2	1.8
8828	M	GA	-18.9	9.0	43.2	16.0	3.2	5.1
8831	M	31-40	-19.4	9.6	40.0	14.6	3.2	1.0
8833	M	GA	-19.2	8.4	42.7	15.5	3.2	6.4
8836	M	41-50	-18.8	10.1	42.1	15.5	3.2	9.0
8839	M	31-40	-19.5	7.9	42.1	15.2	3.2	5.5
8846	IND	7-12	-19.4	8.4	38.3	13.9	3.2	1.2
8849	F	GA	-19.3	8.2	42.0	15.3	3.2	6.6
8852	M	41-50	-19.2	9.0	41.7	15.3	3.2	5.7
8855	F	31-40	-17.6	7.6	42.2	15.3	3.2	4.1
8858	IND	7-12	-19.8	8.6	38.8	14.0	3.2	1.7

8865	ND	GA	-19.2	8.6	42.1	15.3	3.2	4.6
8871	ND	GA	-19.4	8.8	42.3	15.0	3.3	6.0
8874	M	GA	-20.5	6.6	39.7	14.7	3.1	1.9
8877	IND	7-12	-19.5	9.1	38.6	14.1	3.2	1.3
8880	F	GA	-17.9	10.0	39.6	14.3	3.2	3.3
8883	M	31-40	-19.4	9.0	40.0	14.5	3.2	1.0
8886	F	41-50	-19.1	9.4	42.3	15.7	3.1	5.5
8890	IND	GNA	-19.6	8.0	42.0	15.3	3.2	5.8
8893	ND	GA	-19.5	9.3	43.4	15.9	3.2	5.2
8899	F	GA	-19.5	6.4	40.1	14.6	3.2	1.2
8902	IND	GNA	-19.6	8.6	40.3	15.1	3.1	1.2
8908	ND	GA	-19.3	9.0	41.6	15.2	3.2	5.4
8911	F	19-30	-19.2	8.9	41.5	15.0	3.2	9.6
8915	F	31-40	-19.5	7.9	42.4	15.4	3.2	6.7
8918	IND	7-12	-19.4	8.5	37.6	13.5	3.2	1.1
8921	F	41-50	-19.4	9.4	41.7	15.0	3.3	6.0
8924	F	GA	-19.1	8.8	43.2	15.9	3.2	5.5
8936	M	41-50	-19.1	9.9	39.3	14.2	3.2	2.0
8939	M	31-40	-18.0	9.1	39.2	14.3	3.2	1.3
8942	F	GA	-19.3	8.3	43.0	15.9	3.1	4.8
8945	F	41-50	-19.4	9.4	38.9	14.2	3.2	1.9
8950	IND	13-18	-18.7	8.0	38.0	13.3	3.3	1.4
8952	IND	13-18	-19.4	8.7	42.6	15.3	3.2	5.7
8955	ND	GA	-19.5	7.1	41.7	15.5	3.1	3.2
8958	IND	GNA	-19.1	9.6	39.4	14.7	3.1	1.9
8961	IND	7-12	-19.2	9.4	43.2	16.0	3.1	9.3
8971	F	GA	-19.2	8.9	40.9	15.2	3.1	2.3
8975	M	GA	-19.1	9.9	38.5	14.6	3.1	1.4
8981	M	GA	-19.1	10.2	37.3	13.9	3.1	1.1

8984	IND	7-12	-19.3	8.0	39.0	14.5	3.1	1.9
8990	F	GA	-19.3	9.4	43.8	16.1	3.2	6.1
8991	M	GA	-19.5	8.8	39.7	14.5	3.2	1.7
8994	IND	7-12	-18.9	10.1	38.8	14.8	3.1	1.8
8997	M	19-30	-19.0	8.9	41.7	15.3	3.2	20.8
10038	IND	7-12	-18.5	10.1	34.9	13.7	3.0	1.4
11000	M	GA	-19.1	8.9	40.6	15.2	3.1	3.1
11003	ND	GA	-19.7	10.5	42.4	15.7	3.2	12.6
11009	M	41-50	-19.1	10.0	43.0	15.7	3.2	11.0
11012	F	GA	-19.2	9.1	41.8	15.6	3.1	8.7
11015	F	31-40	-19.0	9.4	37.5	14.5	3.0	1.7
11018	ND	GA	-19.3	8.7	39.7	14.8	3.1	2.4
11021	IND	13-18	-19.2	9.5	41.1	15.4	3.1	22.3
11024	IND	1-6	-18.6	12.5	41.2	15.3	3.1	3.0
11030	IND	GNA	-19.8	9.4	40.3	14.8	3.2	1.7
11033	IND	GS	-19.1	9.2	40.0	14.7	3.2	1.4
11040	F	31-40	-19.4	7.5	42.5	15.8	3.1	8.6
11043	ND	GA	-19.3	9.8	42.1	15.3	3.2	5.0
11046	F	GA	-19.1	9.3	42.2	15.7	3.1	3.4
11052	ND	GA	-19.2	8.8	41.8	15.6	3.1	13.4
11058	F	GA	-19.8	6.6	38.9	14.5	3.1	1.9
11061	F	41-50	-19.1	9.2	41.7	15.0	3.2	7.0
11061	F	41-50	-19.0	9.4	39.9	15.1	3.1	1.0
Faunal specimens								
US	**species**		**$\delta^{13}C$**	**$\delta^{15}N$**	**%C**	**%N**	**C:N ratio**	**protein yield (%)**
8849	Bovine		-21.9	4.1	45.6	17.2	3.1	15.8
11195	unspecified omnivorous		-18.6	7.4	43.1	15.9	3.2	2.3
11195	Bovine		-19.9	5.3	44.3	16.4	3.2	9.9
11195	Ovine		-19.8	4.8	44.6	16.7	3.1	12.6

11195	Suine	-20.9	6.8	43.9	16.4	3.1	13.2

Table 2. Median levels of $\delta^{13}C$ and $\delta^{15}N$ in Italian, Mediterranean and Northern European Medieval sites.

Italian Medieval sites									
Country	Site	N	$\delta^{13}C$ (‰)			$\delta^{15}N$ (‰)			References
			25th percentile	median	75th percentile	25th percentile	median	75th percentile	
Italy	**Leopoli-Cencelle**	**76**	**-19.4**	**-19.2**	**-19.1**	**8.4**	**9.0**	**9.4**	**Present research**
Italy	Colonna	58	-19.3	-18.9	-18.7	7.2	7.6	8.0	Baldoni et al., 2016
Italy	Albano	24	-19.1	-18.9	-18.4	7.6	8.5	9.0	Ciaffi et al., 2015
Italy	Piazza Madonna di Loreto	13	-20.5	-19.9	-19.6	7.9	8.3	9.1	Pescucci et al., 2013
Italy	Pava Pieve	19	-20.0	-19.1	-18.7	8.6	9.1	9.7	Ricci et al., 2012
Italy	Cosa	26	-17.9	-17.8	-17.4	8.0	8.9	9.5	Scorrano et al., 2014
Italy	Mainizza	16	-16.4	-15.6	-14.9	6.9	7.7	8.3	Iacumin et al., 2014
Italy	Romans d'Isonzo	42	-16.9	-16.5	-16.1	7.9	8.4	8.8	Iacumin et al., 2014
Italy	Cividale Gallo	7	-17.7	-16.7	-14.9	7.6	8.3	10.0	Iacumin et al., 2014
Italy	Cividale S. Stefano	11	-18.4	-17.6	-16.0	7.6	8.3	9.6	Iacumin et al., 2014
Italy	Trino Vercellese	28	-19.6	-19.3	-18.8	8.7	9.1	9.6	Reitsema and Vercellotti, 2012
Italy	Montella	48	-19.9	-19.5	-19.3	6.7	7.1	7.6	Torino et al., 2015
Mediterranean European sites									
Country	**Site**	**N**	$\delta^{13}C$ (‰)			$\delta^{15}N$ (‰)			**References**
			25th percentile	median	75th percentile	25th percentile	median	75th percentile	
Greece	Kastella	19	-19.1	-19	-18.6	8.6	8.9	9.5	Bourbou, 2011
Greece	Stylos	9	-19.3	-19	-18.3	8.2	9.6	9.8	Bourbou, 2011
Greece	Agora	9	-19.4	-19.3	-19.1	9.7	10.3	11.8	Garvie-Lok, 2001
Greece	Petras	5	-19.5	-19.4	-19.4	8.9	9.2	9.4	Garvie-Lok, 2001
Greece	Servia	8	-18.9	-18.75	-18.6	8.45	8.55	8.8	Garvie-Lok, 2001
Greece	Corinth	22	-19.1	-18.75	-18.6	9.3	9.75	10.2	Garvie-Lok, 2001
Greece	Mitilini	34	-19.4	-19.1	-18.7	8.9	9.45	10.1	Garvie-Lok, 2001
Greece	Nemea	18	-19.2	-19.1	-18.8	8.3	8.45	9.1	Garvie-Lok, 2001
Spain	Es Soto (Ibiza)	21	-18.7	-18.6	-17.5	10.3	10.9	11.3	Fuller et al., 2010
Spain	Zaballa	14	-20	-19.9	-19.2	8.4	9.05	9.6	Lubritto et al., 2013

Spain	Gandia (Colegiata)	24	-18.05	-17.25	-16.85	9.7	10.1	10.65	Alexander et al., 2015
Spain	Gandia (Benipeixcar)	20	-17	-16.5	-15.75	10.35	10.7	11	Alexander et al., 2015
Spain	Tossal de les Basses(Alicante)	14	-18.5	-18.25	-18	10.8	11.5	11.9	Salar-Garcia et al., 2016
Croatia	Velim-Velištak	105	-17.92	-17.68	-17.41	9.22	9.44	9.64	Lightfoot et al., 2012
Croatia	Glavice Gluvine	33	-18.32	-18.09	-17.62	8.87	9.26	9.545	Lightfoot et al., 2012
Croatia	Radasinovci-Vinogradine	68	-18.09	-17.64	-17.36	9.45	9.65	9.91	Lightfoot et al., 2012
Croatia	Sibenik Sv Lovre	54	-18.59	-18.36	-18.24	9.62	10.005	10.29	Lightfoot et al., 2012
Continental and Northern European sites									
Country	**Site**	**N**	**$\delta^{13}C$ (‰)**			**$\delta^{15}N$ (‰)**			**References**
			25th percentile	**median**	**75th percentile**	**25th percentile**	**median**	**75th percentile**	
Poland	Giecz	24	-19.2	-18.9	-18.7	8.9	9.1	9.6	Reitsema et al., 2010
Germany	Weingarten	37	-20.1	-19.8	-19.7	8.3	8.6	9.1	Schutkowski and Herrmann, 1999
Belgium	Koksijde	11	-19.1	-19.0	-18.7	10.0	11.1	12.3	Polet and Katzenberg, 2003
Netherlands	Oosterbeintum	28	-20.4	-20.1	-19.7	11.6	12.6	13.0	McManus et al., 2013
Scotland	Newark Bay	24	-19.6	-17.9	-17.4	10.9	12.8	14.3	Richards et al., 2006
Scotland	Auldhame	41	-20.1	-19.5	-19.2	11.6	11.8	13.1	Lamb et al., 2012
England	Fishergate (York)	48	-20.2	-19.8	-19.2	10.5	11.2	12.3	Müldner and Richards, 2007
England	St. Giles	16	-19.5	-19.0	-18.7	12.1	12.8	13.1	Müldner and Richards, 2005
England	Warrington	18	-20.3	-19.9	-19.4	11.1	11.8	12.5	Müldner and Richards, 2005
England	Towton	11	-19.7	-19.5	-19.1	12.1	12.4	13.2	Müldner and Richards, 2005
Sweden	Sigtuna (Nunnan)	17	-21.9	-21.6	-20.8	10.5	11.3	12.2	Kjellstrom et al., 2009
Sweden	Sigtuna (Church 1)	40	-21.6	-20.9	-20.6	12.1	12.9	13.9	Kjellstrom et al., 2009
Sweden	Birka	22	-20.5	-19.9	-19.6	12.8	13.8	14.2	Linderholm et al., 2008
Norway	Flakstad	10	-17.7	-16.7	-15.4	14.2	16.1	17.6	Naumann et al., 2014

Table 3. Results of Mann-Whitney test of comparisons of Leopoli-Cencelle with Medieval coeval sites.

Italian Medieval sites				
Sites	**$\delta^{13}C$**		**$\delta^{15}N$**	
	Mann-Whitney (Z)	**p-value**	**Mann-Whitney (Z)**	**p-value**
Leopoli-Cencelle/Colonna	-4.1123	3.9168×10^{-5}	-7.3582	1.8641×10^{-13}
Leopoli-Cencelle/Albano	-4.7323	2.2204×10^{-6}	-1.0468	0.2952
Leopoli-Cencelle/Piazza Madonna di Loreto	-3.0720	0.0020	-0.4469	0.6549
Leopoli-Cencelle/Cosa	-7.8459	4.2993×10^{-5}	-2.1528	0.0313
Leopoli-Cencelle/Pava Pieve	-1.0468	0.2952	-1.0667	0.2861
Leopoli-Cencelle/Trino Vercellese	-0.6660	0.5054	-0.8587	0.3905
Leopoli-Cencelle/Mainizza	-3.8879	0.0001	-3.8879	0.0001
Leopoli-Cencelle/Romans d'Isonzo	-9.2329	2.6335×10^{-20}	-3.8345	0.0001
Leopoli-Cencelle/Cividale Gallo	-4.3134	1.6079×10^{-5}	-4.1321	0.2576
Leopoli-Cencelle/Cividale S. Stefano	-5.1615	2.45×10^{-7}	-1.6049	0.1085
Leopoli-Cencelle/Montella	-4.4543	8.4185×10^{-6}	-7.5499	4.3552×10^{-14}
Mediterranean European sites				
Sites	**$\delta^{13}C$**		**$\delta^{15}N$**	
	Mann-Whitney (Z)	**p-value**	**Mann-Whitney (Z)**	**p-value**
Leopoli-Cencelle/Kastella	-0.2702	0.7870	-0.2802	0.7870
Leopoli-Cencelle/Stylos	-2.0025	0.0452	-0.7722	0.4400
Leopoli-Cencelle/Agora	-0.2372	0.8125	-3.5249	0.0004
Leopoli-Cencelle/Petras	-0.8393	0.4013	-0.8256	0.4090
Leopoli-Cencelle/Servia	-3.5914	0.0003	-1.3275	0.1844
Leopoli-Cencelle/Corinth	-4.9831	6.2573×10^{-7}	-3.5117	0.0004
Leopoli-Cencelle/Mitilini	-2.0778	0.0377	-2.2759	0.0229
Leopoli-Cencelle/Nemea	-2.2902	0.0220	-1.8570	0.0633
Leopoli-Cencelle/Es Soto (Ibiza)	-5.6606	1.5084×10^{-8}	-5.8518	4.8622×10^{-9}
Zaballa	-2.8693	0.0041	-0.2230	0.8236
Leopoli-Cencelle/Gandia (Colegiata)	-7.1337	9.7711×10^{-13}	-5.5745	2.4824×10^{-8}
Leopoli-Cencelle/Gandia (Benipeixcar)	-6.8500	7.385×10^{-12}	-6.2033	5.5276×10^{-10}

Leopoli-Cencelle/Tossal de les Basses (Alicante)	-5.2051	$1.8977x10^{-7}$	-5.4548	$4.9038x10^{-8}$
Leopoli-Cencelle/Velim-Velistak	-11.1390	$8.0689x10^{-29}$	-4.9435	$7.6720x10^{-7}$
Leopoli-Cencelle/Glavice Gluvine	-7.2875	$3.1581x10^{-13}$	-1.8741	0.0609
Leopoli-Cencelle/Radasinovci-Vinogradine	-9.9453	$2.6441x10^{-23}$	-6.1702	$6.8187x10^{-10}$
Leopoli-Cencelle/Sibenik Sv Lovre	8.6020	$7.8369x10^{-18}$	-6.7180	$1.842x10^{-11}$
Continental and Northern European sites				
Sites	**$\delta^{13}C$**		**$\delta^{15}N$**	
	Mann-Whitney (Z)	**p-value**	**Mann-Whitney (Z)**	**p-value**
Leopoli-Cencelle/Giecz	-4.0209	$5.7965x10^{-5}$	-1.1517	0.2494
Leopoli-Cencelle/Weingarten	-6.4516	$1.1067x10^{-10}$	-2.0581	0.0396
Leopoli-Cencelle/Koksijde	-2.4660	0.0137	-4.8329	$1.3459x10^{-6}$
Leopoli-Cencelle/Oosterbeintum	-7.3315	$2.2762x10^{-13}$	-6.9923	$2.7036x10^{-12}$
Leopoli-Cencelle/Newark Bay	-2.9681	0.0030	-6.7159	$1.8696x10^{-11}$
Leopoli-Cencelle/Auldhame	-3.2499	0.0012	-8.7538	$2.0629x10^{-18}$
Leopoli-Cencelle/Fishergate (York)	-4.5642	$5.0144x10^{-6}$	-8.6357	$5.8373x10^{-18}$
Leopoli-Cencelle/St. Giles	-1.7480	0.0800	-6.1863	$6.1604x10^{-10}$
Leopoli-Cencelle/Warrington	-4.0045	$6.214x10^{-5}$	-6.4386	$1.2056x10^{-10}$
Leopoli-Cencelle/Towton	-1.3031	0.1925	-5.2610	$1.4326x10^{-7}$
Leopoli-Cencelle/Sigtuna (Nunnan)	-5.2181	$1.8081x10^{-7}$	-5.2181	$1.8081x10^{-7}$
Leopoli-Cencelle/Sigtuna (Church 1)	-8.4279	$3.5207x10^{-17}$	-8.7311	$2.5231x10^{-18}$
Leopoli-Cencelle/Birka	-5.2056	$1.9336x10^{-7}$	-7.0935	$1.308x10^{-12}$
Leopoli-Cencelle/Flakstad	-4.1742	$2.9905x10^{-5}$	-5.1045	$3.3171x10^{-7}$