

Heading for the hills? A multi-isotope study of sheep management in first millennium BC Italy

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Highlights

- A multi-isotope pilot study offers a high-resolution investigation into sheep management in proto-historic Italy

- Sheep exploitation at an Orientalising aristocratic residence (7th century BC) was consistent with management in the local hinterland

- An Archaic Etruscan city (5th century BC) drew animals from a mosaic of iso-zones

- Neither Etruscan site produced clear evidence for long-distance vertical transhumance

Abstract

Livestock husbandry played a fundamental role in the economy of ancient Mediterranean communities. In central Italy, archaeological evidence for a significant re-organisation of animal production appears during the first millennium BC alongside the rise of urban settlements and an aristocratic class. Urban sites are interpreted as having a central role in the organisation of agricultural production, through control over their territories and the re-distribution/exchange of agricultural products. However, these hypotheses have never been bio-archaeologically demonstrated. Here, we present a detailed multi-isotope pilot study of sheep management and mobility – the first isotopic study dedicated to fauna from late prehistoric or Roman Italy – which investigates animal management and agricultural provisioning in two Etruscan sites (675–430 BC). We used ZooMS to confirm species identifications, and isotopic analyses ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$) to gain insight into differences in animal management at the ancient city of Velzna (5th century BC), modern Orvieto, and the aristocratic residence of Poggio Civitate (7th century BC). Results demonstrate that Orvieto received sheep raised in at least three distinct locations, while data from Poggio Civitate were compatible with herding in a single area. These results reinforce interpretation of Orvieto as a central place that collected resources from its hinterland, while Poggio Civitate employed a more isolated productive strategy. Analyses did not produce evidence for long-distance vertical transhumance at either site, with results suggesting more local variation in herding patterns, consistent with seasonal herding in the general hinterland of each location. This pilot study offers a first step towards higher-resolution understanding of animal management in the region, and demonstrates the potential of further isotopic studies to provide new insights on agricultural provisioning and territorial control in proto-historic Italy.

Key words

Mobility, animal husbandry, Etruscans, zooarchaeology, urbanisation, ZooMS, nitrogen isotopes, carbon isotopes, oxygen isotopes, strontium isotopes

1. Introduction

Throughout the Mediterranean, livestock had an important role in the economy of ancient societies. Sheep herding held particular value, due to the potential benefits to agriculture and

craft production. Sheep supplied manure, the fertiliser fundamental to the continued productivity of sedentary farming (Jones, 2012), and wool, a material central to textile production (Gleba, 2008). The wool, as well as the meat and milk, that sheep produced could be stored or processed into commodities for exchange. Sheep themselves were ‘animal capital’ that could be traded or passed down through generations (Halstead, 1996, Mulder et al., 2009). Archaeological evidence points to considerable investment in sheep breeding in Italy during the first millennium BC, a period defined by the emergence of cities and associated processes of population consolidation, economic intensification, and social heirarchisation (Pacciarelli, 2001, Nijboer, 2004, Riva, 2010, Fulminante, 2014). Textile tools became more standardized, suggesting the creation of finer products and greater specialisation in their production (Gleba, 2008). Analyses of wool fibre quality indicate selective pressures on sheep breeding, which intensified with the demand of urban communities for wool of diverse qualities (Gleba, 2012). Sheep mortality profiles shifted from Bronze Age patterns focused on sub- and young-adult animals to place greater emphasis on wool and lamb (de Grossi Mazzorin and Minniti, 2009, Minniti, 2012, Trentacoste, 2015), and metric evidence for an increase in the size of sheep illustrates a significant change in management strategies, potentially related to mobility routes or feeding regimes (Riedel, 1994, De Grossi Mazzorin and Minniti, 2017, Trentacoste et al., 2018, De Grossi Mazzorin and Minniti, 2019). By the Roman period, these processes had produced a diversity of sheep types suited to different landscapes and tasks (MacKinnon, 2004). Together, these changes point to a significant re-organisation of livestock management, undertaken, in part, to increase production of animal types and raw materials with specific characteristics.

Zooarchaeological analyses have been instrumental in establishing current understanding of livestock management in pre-Roman Italy, including how and why animals were kept (e.g. de Grossi Mazzorin and Minniti, 2009, Minniti, 2012, De Grossi Mazzorin and Minniti, 2017, 2019). However, these techniques do not permit detailed consideration of how individual animals were managed, or the location of herding and patterns of movement, including the circulation/exchange of livestock. Isotopic analyses, which can provide insight into animal diet and mobility strategies, have not been previously applied to fauna from late prehistoric or Roman Italy, other than to provide comparative data for results from human remains (e.g. Tafuri et al., 2009, Scheeres et al., 2013, Iacumin et al., 2014, Varalli et al., 2016, Emery et al., 2018, Tafuri et al., 2018, Cavazzuti et al., 2019). Here we present the first dedicated isotopic investigation of animal management in Italy between late prehistory and Late

Antiquity. This pilot study provides new data on livestock husbandry during the Orientalising and Archaic periods (7th–5th centuries BC) through an analysis of sheep remains from two Etruscan sites: a major city, *Velzna* (modern Orvieto), and the aristocratic homestead of Poggio Civitate (Murlo) (Fig. 1a). These sites were chosen on account of their large and well stratified faunal assemblages, and in order to compare livestock production within a single region. We used ZooMS to confirm species identifications, and isotope analyses ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$) to gain insight into animal diet, birth seasonality, and mobility. Through a small-scale but high-resolution investigation of sheep management at these central places, this pilot study demonstrates the potential of further research in this area and provides new evidence for the organisation of livestock production at two locations in pre-Roman Italy, with implications for the control and mobilisation of agricultural resources in the ancient Mediterranean.

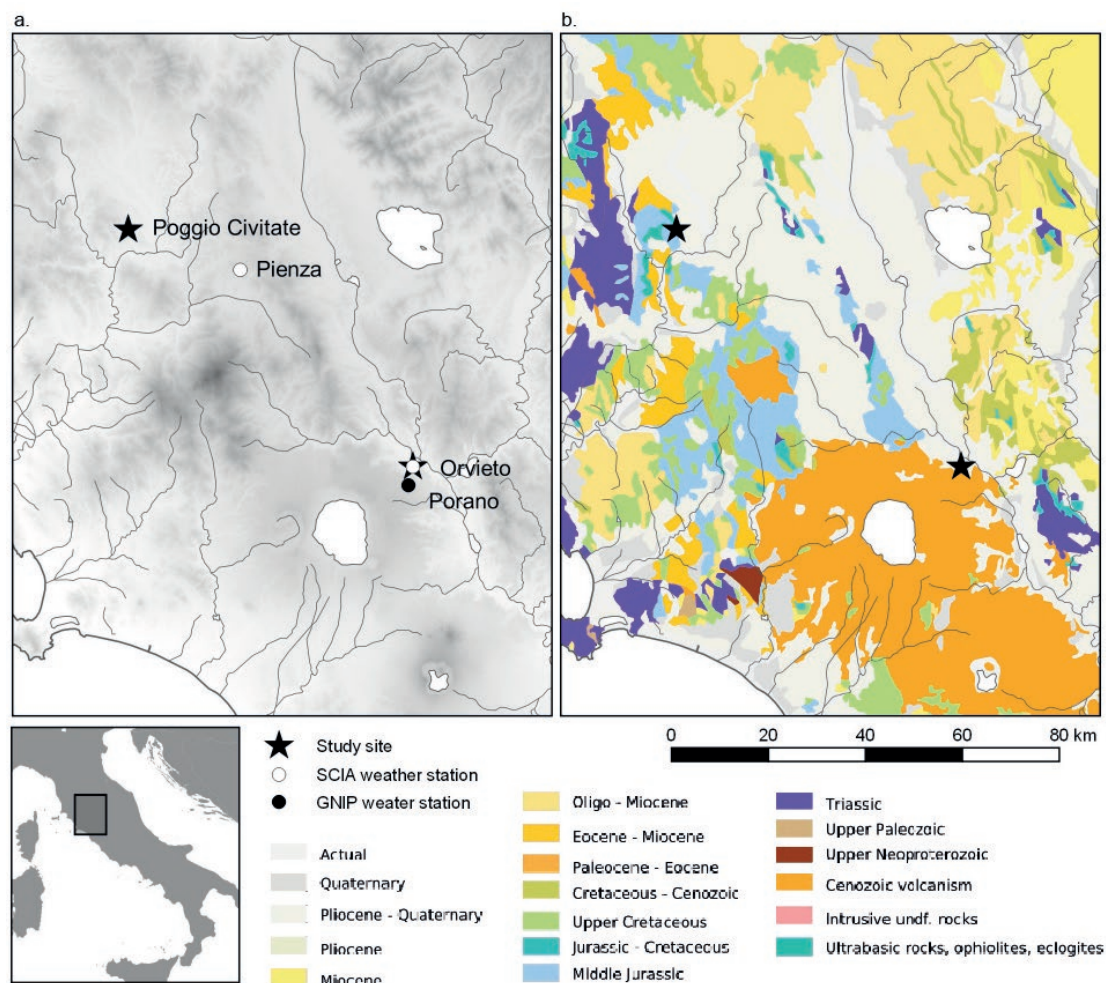


Fig. 1. Maps of central Italy showing (a) location of study sites and weather stations, and (b) bedrock age. Terrain data from the U.S. Geological Survey. Geological data from GISEurope.

2. Archaeological context

Between the 8th and 5th centuries BC, the development of Etruscan cities transformed the landscape of central Tyrrhenian Italy. Houses replaced huts, and continued population aggregation, which began in the late Bronze Age, created urban settlements that housed thousands of people (Nijboer, 2017b). From the late 7th century BC, increasing numbers of small settlements and construction of hydraulic works in the hinterland of main centres demonstrate intensification of resource exploitation, directed by large centres (Nijboer,

117 2017b, Zifferero, 2017). Social hierarchies become fully apparent in the funerary record
118 during this period, documenting the emergence of a wealthy elite (Bietti Sestieri, 1992, Iaia,
119 1999, Pacciarelli, 2001, Riva, 2010). Monumental architecture, initially in tombs and
120 subsequently temples and private residences, demonstrates the mobilisation of people and
121 materials on a huge scale (Potts, 2015). The exportation of large quantities of Etruscan wine
122 illustrates significant increases in agricultural output and coordinated organisation of food
123 production and exchange (Gras, 1985, Perkins, 2012). Changes in the relative proportions of
124 domestic livestock, mortality profiles, and animal body size indicate that livestock husbandry
125 also evolved to meet the needs of these increasingly urban and socio-economically complex
126 communities (de Grossi Mazzorin and Minniti, 2009, Minniti, 2012, Trentacoste, 2016, De
127 Grossi Mazzorin and Minniti, 2017, Trentacoste et al., 2018, De Grossi Mazzorin and
128 Minniti, 2019).

129 Seasonal transhumance between upland summer pastures and lowland winter grazing is often
130 assumed to be the primary pastoral strategy of prehistoric Italy, which then fed directly into
131 Roman practices (e.g. Forsythe, 2005:23). In this scenario, lowland herders moved animals to
132 higher ground, because local summer aridity – or arable agriculture – did not permit
133 sufficient graze for livestock. During recent history, this seasonal movement travelled from
134 coastal lowland areas, to higher Apennine pastures between c. 1200–2000 m asl, with the
135 largest flocks travelling furthest and exploiting the highest territories (Barker et al., 1991).
136 However, while there is ample testimony for large-scale seasonal herd mobility in the Roman
137 Italy (Frayn, 1984, Barker et al., 1995:34–37, MacKinnon, 2004), evidence for Etruscan
138 transhumance is ambiguous. Pollen analysis shows upland clearance in the Central
139 Apennines from c. 2000 BC (Brown et al., 2013), but open pasture was less common in other
140 landscapes before the Roman period (Magri and Sadori, 1999, Narcisi, 2001, Allen et al.,
141 2002, Borrelli et al., 2013, Ravazzi et al., 2013). Even in Roman times, much of the
142 Tyrrhenian coast appears to have been forest (Sadori et al., 2015).

143 Long-distance movement of animals also requires socio-economic structures whose presence
144 in pre-Roman Italy is unclear. Specialist herders are typically dependent on market
145 economies to acquire cheap staple foods (Halstead, 1987, 1996), and large-scale herd
146 movements require a political context capable of protecting drove roads and extensive
147 pastures (Barker et al., 1995:34–37, Horden and Purcell, 2000:87). Indeed, one of the most
148 notable pieces of evidence for transhumance in Roman Italy – the inscription on the north
149 gate of Saepinum – documents the need for state involvement in resolving disputes related to

the movement of flocks (Corbier, 1983). The ability to cross the hinterlands of several territorial centres was not necessarily extant in proto-historic Italy, especially in the politically fragmented landscape of hegemonic Etruscan city-states (cf. Bonghi Jovino, 2005, Cifani, 2010, Fulminante, 2014). Equally, the in-filling of the landscape with small open settlements from the late seventh century BC onward, would have offered additional barriers to herders attempting to move animals (cf. Cifani, 2002, Zifferero, 2017). These challenges are suggested by Roman laws guaranteeing rights-of-way for animals and access to water, which may date to as early as the fifth century BC (Bannon, 2010). Whether Etruscan cities adopted similar legal structures is unknown.

2.1 Poggio Civitate, Murlo

Poggio Civitate is located approximately 20 km south-west of Siena near modern Murlo. Over 50 years of excavation have identified two distinct chronological phases: the Orientalising, spanning 675–600 BC, and Archaic, dated to 600–535 BC (Tuck, 2016). The former is the object of this study. The remains of the Orientalising phase are believed to represent the homestead of a prominent local family, attested archaeologically through the remains of an elite residence (Orientalising Complex 1 - OC1) and an industrial area dedicated to a range of manufacturing activities (Orientalising Complex 2 - OC2): metal working (Tuck, 2014), textile production (Cutler et al., Forthcoming), bone and antler carving (Nielsen, 1995), and the processing and disposal of animal carcasses (Kansa and MacKinnon, 2014). A non-elite residential area has also been identified. Over 1,600 textile tools (including spindle whorls, loom weights, and spools) have been recovered at the site – the largest number at any Etruscan settlement documented to date (Cutler et al., Forthcoming). These tools are standardised and indicate relatively large-scale textile production, which would have required large quantities of wool. Materials recovered from within the OC1 structure and its environs indicate that the space hosted high-status banquets, which were served from bronze cauldrons, imported drinking cups, and elaborate local finewares (Phillips, 1989, Berkin, 2003).

To date, 13,222 specimens have been identified in the faunal assemblage, the vast majority of which come from the Orientalizing Period (Kansa and MacKinnon, 2014). High concentrations of worked and butchered animal bone clustered within and around the OC2 and non-elite residential areas point to both industrial and food preparation activities. The mandibles used in this study date to the Orientalizing period: five from the vicinity of the

elite residence and one from the workshop area. The representation of taxa in the faunal assemblage is common for this period and region, with a predominance of pigs, cattle, sheep, and goats. Sheep and goats make up c. 30% of the domestic livestock at Poggio Civitate, with similar proportions occurring in the OC1 residence and the OC2 workshop. Sheep are more abundant than goats overall, but there is a higher ratio of sheep to goats in the OC2 workshop (7:1) than in the OC1 residence (5:1). Age data for sheep and goats indicate an initial cull of young animals (less than one year old), followed by another kill-off of prime-aged animals, and a final cull of older animals (Kansa and MacKinnon, 2014). This supports a mixed strategy, where females were kept to adulthood for milk and probably wool, young males killed for meat and to free up the lactating ewes, and some males, most likely wethers, were kept to adulthood for wool. In sum, the data suggest that wool exploitation was likely part of a complex economy that also involved meat and milk products, onsite butchery and distribution at a local scale (Kansa and MacKinnon, 2014).

2.2 Cavità 254, Orvieto

Velzna (Latin *Volsinii veteres*, modern Orvieto in Umbria) was one of the principal Etruscan cities and the likely seat of the Etruscan federal sanctuary *Fanum Voltumnae* (Stopponi, 2013). The city occupied a commanding position atop a prominent butte of volcanic tuff, which has been inhabited continuously since late Roman times. As a result, the Etruscan city is best known through investigation of its cemeteries (Binaco and Bizzarri, 2018) and the thousands of caves and subterranean features cut into the rock beneath it (Bizzarri, 2013). Since 2012, excavation of a large subterranean structure on the south west edge of Orvieto, Cavità 254, has been providing new evidence regarding the material culture of the city (Bizzarri and Binaco, 2015, George and Bizzarri, 2015, George et al., 2017). The structure originally functioned as a quarry, before being filled in a short period of time (perhaps a single act) at the end of the fifth century BC (George and Bizzarri, 2015). The finds within the fill appear to represent residual materials from the restructuring of the urban area around this time (Bizzarri and Binaco, 2015: 523).

In addition to the rich ceramic assemblage, architectural fragments and loom weights, a significant quantity of animal bones was recovered from the fill of the Cavità, allowing for investigation of the production and consumption of animals at Orvieto (George et al., 2017). Thus far, over 4500 animal remains have been identified. The faunal assemblage is dominated by the remains of common domestic livestock (cattle, sheep, goats, and pigs).

After pigs, sheep and goats are the second most common taxa, accounting for *c.* 45% of livestock remains. Sheep are significantly more abundant than goats (7:1). Mortality patterns suggest that sheep and goats were herded in a mixed strategy for tender meat, milk, and wool. Mandible wear stages indicate a cull of animals in the later part of their first year of life, followed by another kill off of young adult animals, with a final significant cull of mature individuals (stage G; Payne, 1973). The recovery of foetal/neonatal caprine bones suggests that sheep and/or goats were bred in the immediate vicinity of the site. The character of the faunal assemblage and its location in a sealed deposit of ceramics and architectural debris suggest that the bones may result from a large-scale consumption event (i.e. a feast) associated with the refurbishment of the urban area during the fifth century BC (Trentacoste, submitted).

3. Scientific Background

ZooMS and multi-isotopic analyses were used to investigate sheep management and mobility at these two Etruscan sites.

3.1 ZooMS

The structure of collagen varies between species. By analysing the peptide sequences of collagen in animal bones it is possible to acquire an accurate taxonomic identification of that bone (Buckley, 2018). This is particularly useful for distinguishing sheep and goat, which have a different peptide sequence (Buckley et al., 2010), but are difficult to separate on the basis of bone morphology (Salvagno and Albarella, 2017).

3.2 Isotope analyses

Isotope analysis is based on the premise that the body is constructed from the food and drink consumed during an individual's life. Chemical differences (isotope ratios) in food and drink are recorded in animal tissues, and the analysis of body chemistry can therefore provide information about an individual's diet and the location from which it was sourced. Isotopic ratios in tooth enamel reflect food and drink consumed during the time of tooth formation (Ambrose and Norr, 1993, Tieszen and Fagre, 1993). Although enamel deposition and maturation in sheep is complex, an intra-annual chronological sequence can be measured by taking sequential samples along the crown of the tooth (Balasse, 2003, Balasse et al., 2003).

Tooth enamel forms in waves of mineralization, which are laid in different layers between the dentine and outer surface of the enamel (Suga et al., 1979, Suga, 1982). In sheep, this maturation process has an approximately six-month delay compared to tooth growth, producing a time-averaged signal over this period (Zazzo et al., 2010, Balasse et al., 2012b). The isotopic signal recorded in tooth enamel also is attenuated relative to the real variation experienced by the animal during tooth mineralization, based on the nature of the input signal and duration of the enamel maturation process (Balasse, 2002, Passey and Cerling, 2002, Zazzo et al., 2010). Stable isotope ratios from adult bone protein (collagen) reflect diet over a period of months to years, depending on the taxon and age of the animal (Hedges et al., 2007).

3.2.1 Strontium

Strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) provide evidence for the geographic origins and mobility patterns of livestock (e.g. Pellegrini et al., 2008, Minniti et al., 2014, Valenzuela-Lamas et al., 2018). $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in geological formations vary based on the age and original ratio of rubidium (Rb) to strontium (Sr) in the bedrock (Faure and Mensing, 2005, Bentley, 2006). Through weathering, strontium becomes incorporated into the soil and groundwater, where it can be taken up by plants with little isotopic fractionation (Graustein, 1989). The bioavailable strontium taken up into the food cycle can differ from the strontium isotope composition of bedrock, for instance through the differential weathering of various minerals (Sillen et al., 1998). Rainfall, pollution, and modern fertilizers can also contribute significantly to the isotopic composition of bioavailable strontium (Böhlke and Horan, 2000, Maurer et al., 2012, Techer et al., 2017, Thomsen and Andreasen, 2019). Thus, while there is a direct relationship between $^{87}\text{Sr}/^{86}\text{Sr}$ values in tooth enamel and the source area, establishing the signature of a region is complicated by the many factors that influence bioavailable strontium isotope values; furthermore, geological heterogeneity and signal mixing (in the case of animals ranging regularly across different iso-zones) must also be taken into account in interpretation of archaeological results (Bentley, 2006).

In archaeological applications, strontium isotopic ratios are typically used to identify ‘local’ versus ‘non-local’ individuals based on the establishment of a ‘local’ strontium baseline, created through sampling of local bioavailable strontium (e.g. Valenzuela-Lamas et al., 2018). Our investigation does not include sampling of the local biosphere, and therefore does not aim to assign a specific geographic location to individual animals. Instead, this study

seeks to investigate whether there is any isotopic evidence for long-distance movement, and to compare the representation of strontium ‘iso-zones’ at the two sites, i.e. the homo- versus hetero-geneity of the localisation of sheep management.

The area surrounding the study sites presents a complex geology (Fig. 1b) (ISPRA, 2011). Poggio Civitate is located on the Murlo Ridge formation, an area of pre-Neogene bedrock formed of Jurassic and Cretaceous deposits, bordered by areas of Eocene–Miocene sediment to the north and south, and to the east by the Pliocene marine mudstones of the Siena Basin (Martini et al., 2011, Arragoni et al., 2012, Martini and Sandrelli, 2014). Older Triassic units of the Middle Tuscan range are exposed to the west. The historic town of Orvieto occupies a butte of volcanic tuff at the north-eastern edge of the Vulsini Volcanic District, an area of Pleistocene volcanic deposits dominated by the crater lake of Bolsena (Cencetti et al., 2005). Orvieto overlooks marine and continental deposits (Pliocene–Pleistocene) and recent alluvial sediments in the valley of the River Paglia. East of the river, the hills of Monte Peglia are formed from Middle to Late Pliocene marine deposits of the Tenaglie-Fosso San Martino formation. Further east and southeast the geology is mostly carbonatic and siliciclastic successions of various ages (Triassic–Miocene) (Mancini et al., 2003–2004).

Previous strontium isotope studies of ancient fauna and human dentine provide comparative strontium isotope data (Table 1). Little sampling of bioavailable strontium has been undertaken in the central Italy, and the data provided by these studies represent few, but relevant, points of comparison. Pellegrini’s (2008) investigation of animal teeth from four Palaeolithic sites in central Italy – one located in volcanic tuff and three on sedimentary marine carbonates – produced $^{87}\text{Sr}/^{86}\text{Sr}$ values between 0.7086 and 0.7090. These values are consistent with other marine carbonate sediments and limestone areas (McArthur et al., 2001, Montgomery et al., 2007, Argentino et al., 2017). Pig enamel and human dentine samples from Scheeres et al.’s (2013) study of the Iron Age necropolis at Monte Bibele, where the local geology is dominated by Miocene shallow-water sediments, yielded $^{87}\text{Sr}/^{86}\text{Sr}$ values between 0.7089 and 0.7091. Palombo et al.’s (2005) study of Pleistocene *Elephas antiquus* teeth from volcanic geology near Rome produced relatively high $^{87}\text{Sr}/^{86}\text{Sr}$ values ranging between 0.7098 and 0.71026. These values fall with the range expected for pyroclastic rocks in the region (Holm and Munksgaard, 1982, Federico et al., 1994). Recent investigation of two Imperial Roman necropoli in the vicinity of Rome (Killgrove and Montgomery, 2016) is of limited use in establishing regional strontium variation. Compared to the other studies, humans from the Casal Bertone and Castellaccio Europarco cemeteries produced a very large

range of $^{87}\text{Sr}/^{86}\text{Sr}$ values, which reflected significant mobility to Rome during the Imperial period, as well as the potential influence of water transported via aqueducts. Two pig teeth included in the study yielded strontium ratios of 0.70933 and 0.71031, respectively. These values are consistent with the volcanic geology of the Colli Albani (Federico et al., 1994), where the sites are located.

Site	Taxa and individuals sampled	n. of samples		Reference
		enamel	dentine	
Grotta di Settecannelle	<i>Cervus elaphus</i> (n=1)	5	1	Pellegrini 2008
	<i>Equus hydruntinus</i> (n=1)		1	
Grotta di Vado all'Arancio	<i>Equus hydruntinus</i> (n=1)	5	1	Pellegrini 2008
Grotta Polesini	<i>Cervus elaphus</i> (n=1)	5	1	Pellegrini 2008
	<i>Equus hydruntinus</i> (n=1)	5	1	
Grotta di Pozzo	<i>Cervus elaphus</i> (n=1)	5	1	Pellegrini 2008
	<i>Equus hydruntinus</i> (n=1)	5	1	
La Polledrara	<i>Elephas (Palaeoloxodon) antiquus</i> (n=19)	12	7	Palombo et al. 2005
Casal dei Pazzi	<i>Elephas (Palaeoloxodon) antiquus</i> (n=19)	18	1	Palombo et al. 2005
Monte Bibele	<i>Sus scrofa domesticus</i> (n=5)	5	5	Scheeres et al. 2013
	Human (n=5)		5	
Castellaccio Europarco	<i>Sus scrofa domesticus</i> (n=1)	1		Killgrove and Montgomery 2016
Casal Bertone	<i>Sus scrofa domesticus</i> (n=1)	1		Killgrove and Montgomery 2016

Table 1. Central Italian strontium isotope studies used for comparison

Emery et al. (2018) have proposed a strontium isotope map for Italy based on disparate modern and archaeological sources. Data were drawn from ancient humans and fauna, in addition to modern foods (beef, wine, cheese, tomato sauce), spring water, and sediments. Considering the samples used to create the map, there is potential for influence from modern contamination and agricultural practices (Böhlke and Horan, 2000, Techer et al., 2017, Thomsen and Andreasen, 2019), and data from geological samples may not accurately reflect the bioavailable strontium in the sampled area (Bentley, 2006). Considering baseline strontium isotope values may vary significantly within even a small area (e.g. Madgwick et al., 2019b), especially in a geologically diverse region like central Italy, this map provides a low-resolution prediction of approximate, potential $^{87}\text{Sr}/^{86}\text{Sr}$ values. Emery et al. (2018) acknowledge the map as an interim step in the development of an iso-scape for Italy.

Although its application is constrained by these limitations, the map is currently the only strontium isotope map of Italy; like the comparative studies above, it is employed in this research as a point of comparison, rather than to assign a particular origin to analysed animals. This map predicts that $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios in the immediate vicinity (5 km) of the sites will fall between 0.7096–0.7099 for Poggio Civitate, and 0.7088–0.7099 for Orvieto. A larger range of $^{87}\text{Sr}/^{86}\text{Sr}$ values is expected in the immediate hinterland (5–20 km): 0.7088–0.7106 for Poggio Civitate, and 0.7072–0.7099 for Orvieto. The range of $^{87}\text{Sr}/^{86}\text{Sr}$ values is similar for the broader hinterland (20–50 km) of both locations: 0.7072–0.7106.

3.2.2 Oxygen isotope analysis

Oxygen isotope analysis are used to document seasonality, mobility and palaeoclimate in archaeological contexts (e.g. Evans et al., 2012, Killgrove and Montgomery, 2016, Lightfoot and O’Connell, 2016, Makarewicz, 2017). Intra-tooth $\delta^{18}\text{O}$ sequences can also be used to infer the distribution of births, in instances where the $\delta^{18}\text{O}$ curve displays seasonal minimum and maximum values (Balasse et al., 2012b). Oxygen isotopes of meteoric water vary geographically with climate and season (Dansgaard, 1964, Rozanski et al., 1992, Rozanski et al., 2013). In herbivore tooth enamel these isotopes primarily reflect the isotopic composition of imbibed water (Fricke and O’Neil, 1996, Kohn et al., 1998). As semi-obligate drinkers, oxygen-isotope ratios from sheep will reflect both open/ground water (largely derived from precipitation), as well as leaf water obtained from plants (Makarewicz and Pederzani, 2017).

In central Italy, altitude is the most significant factor correlated with $\delta^{18}\text{O}$ values in precipitation, with an altitudinal gradient of, on average, -0.22‰ per 100 m ($\delta^{18}\text{O}$) (Longinelli and Selmo, 2003, Giustini et al., 2016). There is significant seasonal variation in $\delta^{18}\text{O}$ values, although these are variable and poorly correlated with temperature (Longinelli and Selmo, 2003). The Apennine ridge produces a shadow effect along the Adriatic coast, yielding lower isotopic values on the eastern side of the mountains. This altitudinal and east–west gradient is also found in the isotopic composition of spring water, which reflects the $\delta^{18}\text{O}$ values of source precipitation (Raco et al., 2013). Between 2000 and 2003, average $\delta^{18}\text{O}$ values in precipitation recorded at Porano, c. 4 km from Orvieto, ranged from a January low of -10.48‰ to a high of 0.01‰ in August (Fig. 2b) (IAEA/WMO, 2019). The annual mean for this period was -6.49‰ . Within a 30 km radius of the sites, annual means for oxygen isotope ratios in rainfall occur within a limited range, between c. -6‰ and -7‰ , although some elevated areas (>500 m asl) produced lower means below -7‰ (Giustini et al., 2016).

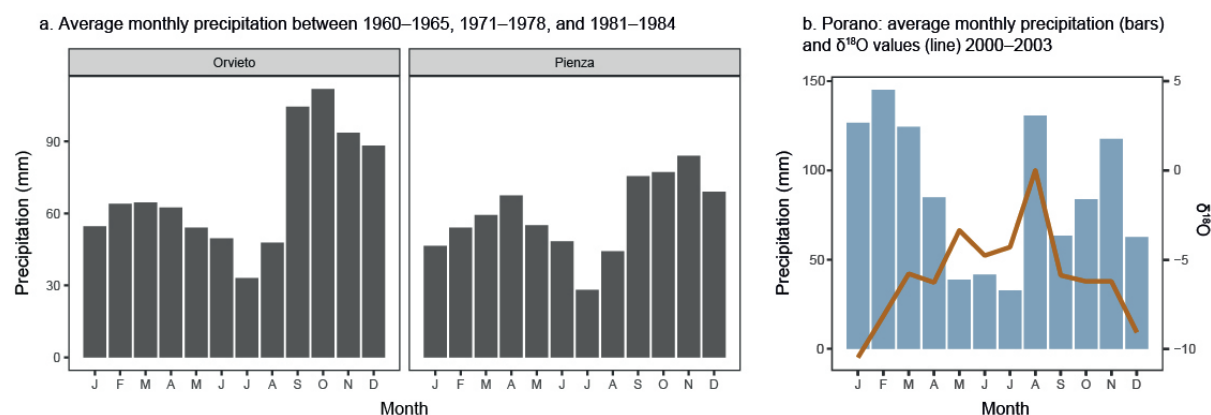


Fig. 2. Mean monthly precipitation and $\delta^{18}\text{O}$ values from (a) SCIA and (b) GNIP weather stations near the study sites. Data from SCIA (<http://www.scia.isprambiente.it/>) and IAEA/WMO (2019). Only select years 1960–1984 from SCIA stations were included, in order to ensure data were available from both stations for the entirety of the period considered.

3.2.3 Carbon isotope analysis

Stable carbon isotope analysis of bone collagen and tooth enamel allows an estimation of the proportion of two different types of plant in the diet, C_3 and C_4 , which have different carbon isotope ratios due to their different photosynthetic pathways (Vogel and van der Merwe, 1977). In practice, the only C_4 plant likely to have been available for consumption in significant quantities in Europe during this period was millet, which is documented in both late prehistoric and Roman Italy (Spurr, 1983, Tafuri et al., 2009, Varalli et al., 2016). Carbon isotope ratios can also indicate the proportion of marine as opposed to terrestrial foods; however, marine vegetation (e.g. seaweed) is unlikely to be relevant to this study, considering the sites' distance from the coast (*c.* 60 km). Plant carbon isotopes also vary with season, altitude, and forest cover. Seasonally, $\delta^{13}\text{C}$ differs primarily in response to aridity and water use strategies within the plant (Farquhar et al., 1989, Smedley et al., 1991, Ehleringer and Monson, 1993, Moreno-Gutiérrez et al., 2012). Atmospheric pressure affects $\delta^{13}\text{C}$ values, as there is less discrimination in high mountain compared to lowland plants (Körner et al.,

1991), and the reduced light intensity found in dense forest produces a ‘canopy effect’ with lower $\delta^{13}\text{C}$ values (van der Merwe and Medina, 1991, Berthon et al., 2018).

In previous studies of seasonal vertical sheep/goat transhumance, stable carbon isotopic values behaved inversely compared to the annual sinusoidal $\delta^{18}\text{O}$ curve: minima for $\delta^{13}\text{C}$ correspond to maximum $\delta^{18}\text{O}$ values. This has been found in both semi-arid environments containing C_4 plants (Makarewicz, 2017, Makarewicz and Pederzani, 2017) as well as C_3 ecosystems (Tornero et al., 2018). In the Pyrenees, depletion in plant $\delta^{13}\text{C}$ values at higher altitudes probably results from greater levels of precipitation at high elevations (Tornero et al., 2018) and global altitudinal trends (Körner et al., 1991). In central Italy, rainfall is similarly correlated with elevation, with relatively more summer precipitation in the Apennines compared to lowland areas, especially at locations over 1000 m asl (Fick and Hijmans, 2017). Consideration of average monthly precipitation from near-by weather stations (Fig. 2a; see Fig. 1a for locations) provides an indication of seasonal variation in precipitation. Historically, the lowest rainfall has occurred during summer months, with greater precipitation in the spring and especially autumn. The two study areas receive comparable quantities of annual rainfall (Hijmans et al., 2005).

No comparative data on stable carbon isotopes from bone collagen were available for the Etruscan period, although analysis of animal remains from Roman sites in central and southern Italy has been performed as part of human paleodietary studies. Investigation of the Imperial human population buried near the port of Velia (1st to 2nd century AD), in southern Italy, included analysis of local fauna as a comparison (Craig et al., 2009). Similarly, isotopic analyses of skeletons from the cemetery of Isola Sacra (Rome, 1st to 3rd century AD) included analysis of fauna from the necropolis (Prowse et al., 2004). Bovid remains from these studies produced $\delta^{13}\text{C}$ values between -22.9‰ and -19‰ . Investigation of human diet in Bronze Age and Lombard Italy has also employed faunal remains (Tafuri et al., 2009, Iacumin et al., 2014, Varalli et al., 2016), although their more distant geographic and chronological context precludes direct comparison with Etruscan results.

3.2.4 Nitrogen isotope analysis

Stable nitrogen isotopes provide further information on past animal diets (Lee-Thorp, 2008). As body protein is primarily constructed from the dietary protein intake, the stable isotope ratios of collagen reflect the protein portion of the diet (Ambrose and Norr, 1993, Tieszen and Fagre, 1993, Howland et al., 2003, Jim et al., 2006). As herbivores, the nitrogen isotopic

composition of tissues in sheep will be primarily affected by biogeochemical processes in plant–soil systems. Many factors influence plant $\delta^{15}\text{N}$ values, which can vary based on the type of plant, climate, nitrogen cycle openness, and mycorrhizal associations, as well as other factors (Szpak, 2014). Anthropogenic modification of soils through agricultural and pastoral practices can also have a significant impact on the $\delta^{15}\text{N}$ levels in plants. Burning and fertilisation/manuring have been shown to increase $\delta^{15}\text{N}$ values (Bogaard et al., 2007, Bogaard et al., 2013, Szpak, 2014); similarly, grazing intensity and stocking rate can also significantly raise plant $\delta^{15}\text{N}$ values (Makarewicz, 2014, Szpak, 2014). Roman bovids from Velia (Craig et al., 2009) and Isola Sacra (Prowse et al., 2004) yielded $\delta^{15}\text{N}$ values between 1.2‰ and 7.4‰.

4. Materials and methods

4.1 Materials

Twelve sheep/goat mandibles were selected for analysis, six from each site (Table 2). A bone sample was taken from each mandible for carbon and nitrogen isotope analyses. The second molar of each mandible was sampled for strontium, oxygen, and carbon isotopes from tooth enamel. Second molars were chosen because they demonstrate lower inter-individual variation in enamel mineralisation compared to the third molar (Blaise and Balasse, 2011, Tornero et al., 2013).

Individual	Site	Context	Side	Payne (1973) mandible wear stage
PC_01	Poggio Civitate	2008/238 (Workshop)	Left	F/G
PC_02	Poggio Civitate	1971/1045 (Residence)	Left	G/H
PC_03	Poggio Civitate	1971/1043 (Residence)	Right	F
PC_04	Poggio Civitate	1976/185 (Residence)	Left	F
PC_05	Poggio Civitate	1971/1044 (Residence)	Left	G
PC_06	Poggio Civitate	1971/1048 (Residence)	Left	H
Or_07	Orvieto Cavità 254	US 37	Left	G
Or_08	Orvieto Cavità 254	US 37	Left	F
Or_09	Orvieto Cavità 254	US 37	Left	E
Or_10	Orvieto Cavità 254	US 37	Left	G
Or_11	Orvieto Cavità 254	US 37	Left	G
Or_12	Orvieto Cavità 254	US 37	Left	G

Table 2. Sheep mandibles used in isotope analyses.

436

437

438 **4.2 Methodology**

439 **4.2.1 Species identification and mandible wear stage**

440 Species identifications were performed in the field following common criteria (Zeder and
441 Pilaar, 2010) and assigned to a mandible wear stage following Payne (1973).

442 **4.2.2 ZooMS**

443 Approximately 25–50 mg bone powder was demineralised with 1 mL 0.6 M hydrochloric
444 acid overnight and then centrifuged at 12,400 rpm for 5 min. The supernatant was then added
445 to 10k molecular weight cut-off ultrafilters, and then also centrifuged but for 20 min, prior to
446 the addition and centrifugation of 1 mL 50 mM ammonium bicarbonate (ABC). The retained
447 acid-soluble ‘collagen’ was then re-suspended with 100 uL 50 mM ABC and digested with
448 0.4 ug sequencing grade trypsin overnight for approximately 18 hours. The digests were then
449 acidified to 0.1% trifluoroacetic acid (TFA) and purified by C18 solid phase extraction
450 pipette tips into 10% and 50% acetonitrile fractions following Buckley et al. (2009). These
451 were then dried to completion by centrifugal evaporation and re-suspended with 0.1% TFA,
452 with 1 uL being spotted onto a stainless steel MALDI target plate along with a further 1 uL
453 10 mg/mL alpha-cyano hydroxycinnamic acid matrix. After crystallisation, these samples
454 were analysed using a Bruker Ultraflex II MALDI-ToF mass spectrometer, collecting up to
455 2,000 laser acquisitions. Resultant mass spectra were compared with those that represent
456 sheep (*Ovis aries*) and goat (*Capra hircus*) published previously (e.g. Buckley et al., 2010).

457 **4.2.3 Strontium isotope analysis**

458 The posterior pillar of the tooth was sampled for strontium isotopes. Three strontium isotope
459 samples were taken per tooth to capture variation in $^{86}\text{Sr}/^{88}\text{Sr}$ values over different periods of
460 tooth formation; high resolution analysis was beyond the scope of the pilot project. The teeth
461 were first cleaned with MilliQ water and ultrasonicated several times. The buccal face of the
462 posterior pillar was cut off and the dentine removed with a hand held drill with a diamond
463 drill attachment. Three slices (2–3 mm) were then taken down the enamel and powdered prior
464 to analysis. Each sample was weighed into closed teflon beakers and digested for 1 hour at
465 140°C in 65% 2B HNO₃. It was then dried down and re-dissolved in 1.5ml 2M HNO₃ for

strontium separation chemistry following the procedure as described in Pin et al. (1994). The separated strontium fraction for each sample was dried down, dissolved in 0.2% HNO₃ solution and diluted to 200ppb Sr concentrations for isotope ratio analysis on a Nu Instruments NuPlasma high resolution multi-collector inductively coupled plasma mass spectrometer (HR MC-ICP-MS). Analyses were referenced to bracketing analyses of NIST SRM987 using a ⁸⁷Sr/⁸⁶Sr normalising value of 0.710255. All strontium isotope data were corrected for isobaric rubidium interference at 87 amu using the measured signal for ⁸⁵Rb and the natural ⁸⁵Rb/⁸⁷Rb ratio. Instrumental mass fractionation was corrected using the exponential law, measured ⁸⁶Sr/⁸⁸Sr ratios and an accepted ⁸⁶Sr/⁸⁸Sr value of 0.1194. Results for repeat analysis of an in-house carbonate reference material processed and measured with the samples from this study (⁸⁷Sr/⁸⁶Sr 0.708878; 2 sigma 0.000007; n=2) are in agreement with long-term results for this in house reference material (⁸⁷Sr/⁸⁶Sr 0.708911; 2 sigma 0.000040; n=414).

4.2.4 Enamel carbonate isotope analysis

Tooth enamel powder was sampled for carbon and oxygen isotope analyses using a hand held drill with a diamond drill attachment. Enamel samples were taken at c. 2 mm perpendicular increments along the buccal face of the anterior pillar of the tooth. Samples were taken at these intervals down the full length of the enamel in order to capture sub-annual variation in carbon and oxygen isotopes and construct a seasonal curve. The pre-treatment method was based on that described in Balasse et al. (2002). 0.1ml of 2–3% aqueous sodium hypochlorite was added per mg of sample. The samples were then left for 24 hours at 4°C before being rinsed five times with distilled water to remove the sodium hypochlorite. 0.1mg of acetic acid was then added per mg of sample. The samples were then left for four hours at room temperature, before the acetic acid was removed and the samples rinsed. Samples were then freeze-dried to remove any remaining liquid.

The samples were then transferred to a vial with a screw cap holding a septa and PCTFE washer to make a vacuum seal, and the samples reacted with 100% orthophosphoric acid at 90°C using a Micromass Multicarb Sample Preparation System. The carbon dioxide produced was dried and transferred cryogenically into a VG SIRA mass spectrometer for isotopic analysis. Carbon and oxygen isotopic ratios were measured on the delta scale, in comparison to the international standard VPDB calibrated using the NBS19 standard (Craig,

1957, Coplen, 1995). Repeated measurements on international and in-house standards show that the analytical error is better than $\pm 0.08\text{‰}$ for carbon and $\pm 0.10\text{‰}$ for oxygen.

4.2.5 Bone collagen isotope analysis

Collagen was extracted following the method described in Privat et al. (2002). Approximately 0.5g of bone was sampled using a drill. Samples were demineralized in 0.5M aq. HCl for up to 2 weeks and then gelatinized at 75°C for 48 hours in pH 3 water. The 'collagen' was then lyophilized before weighing for isotopic analysis. All collagen samples were analysed in triplicate using a Costech elemental analyser coupled in continuous-flow mode to a Thermo Finnigan MAT253 mass spectrometer. Carbon and nitrogen stable isotope values are expressed as delta values (for example $\delta^{13}\text{C}$) relative to international standards (VPDB and AIR, respectively) in units of per mille (parts per thousand, ‰; Hoefs, 2004). Repeated measurements on international and in-house standards showed that the analytical error was less than $<0.2\text{‰}$ for both carbon and nitrogen.

Measured collagen is deemed to be of good quality if it fulfils the following criteria: an atomic C:N ratio of 2.9 to 3.6 (DeNiro, 1985); a 'collagen' yield of $>1\%$ by mass; final carbon yields of $>13\%$; and final nitrogen yields of $>4.8\%$ (Ambrose, 1990). All samples fulfilled these criteria and were therefore deemed to be of good quality.

4.2.6 Modelling of $\delta^{18}\text{O}$ sequences and statistical analyses

Variability in the season of birth was investigated using the function described by Balasse et al. (2012b) (Supplement 1). Only teeth that produced reliable maximum and minimum $\delta^{18}\text{O}$ values were included. This method uses measured $\delta^{18}\text{O}$ values to model $\delta^{18}\text{O}$ curves for individual teeth. Normalisation of the maximum $\delta^{18}\text{O}$ value (x_0) to the total cycle period (X) allows for comparison inter-individual variation in the timing of births, independent of differences in tooth size.

T-tests were used to test differences between groups. Where the variance at one site was twice or more that of the other, a heteroscedastic t-test was used. Correlation coefficients (Pearson's r and p -values) were used to investigate correlation between carbon and nitrogen isotope values, and the minimum, maximum, and mean of intra-tooth analyses at each site. All tests were conducted in R (R Core Team, 2019).

5. Results

5.1 ZooMS

All twelve mandibles identified as sheep based on morphological criteria were confirmed as *Ovis aries* by ZooMS.

5.2 Isotopes from tooth enamel

The tooth enamel isotope data (carbon, oxygen and strontium) are summarised in Table 3 and reported in full in Supplements 2 and 3. Reported concentration values for strontium in tooth enamel are typically 50–300 ppm (Evans et al., 2012). The data presented here fall within this range, with the exception of data from sheep Or_07 and Or_12. Four (of six) of these values fall between 600 and 750 ppm; similar values have been found in faunal enamel from Italy when dentine from the same tooth was also analysed and found to have much higher concentrations of strontium (>900 ppm) (Pellegrini et al., 2008). We therefore include these samples in our discussion. The remaining two samples (Or_07_Sr1 and Or_07_Sr2) have much higher ppm values, above c. 1600 ppm, which we have excluded from discussions below, although we note that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of these samples are similar to Or_07_Sr3.

	$\delta^{18}\text{O}_{\text{carb}}$						$\delta^{13}\text{C}_{\text{carb}}$						$^{87}\text{Sr}/^{86}\text{Sr}$		
Individual	n	min	max	mean	range	sd	n	min	max	mean	range	sd	n	min	max
PC_01	10	-6.21	-3.42	-5.13	2.79	0.90	10	-13.28	-11.99	-12.75	1.29	0.43	3	0.7090	0.7091
PC_02	7	-4.99	-2.36	-3.25	2.63	0.92	7	-13.49	-11.97	-12.66	1.52	0.62	3	0.7091	0.7092
PC_03	11	-6.99	-2.83	-4.87	4.16	1.43	11	-13.02	-10.88	-12.04	2.14	0.71	3	0.7093	0.7094
PC_04	9	-6.35	-4.21	-5.35	2.14	0.68	9	-13.22	-12.17	-12.92	1.05	0.33	3	0.7090	0.7091
PC_05	8	-6.41	-3.25	-4.46	3.16	1.21	8	-13.44	-10.00	-12.16	3.44	1.30	3	0.7089	0.7090
PC_06	6	-4.38	-3.19	-3.74	1.19	0.44	6	-12.47	-11.73	-12.03	0.74	0.27	2	0.7091	0.7092
PC all samples	51	-6.99	-2.36	-4.59	4.63	1.21	51	-13.49	-10.00	-12.44	3.49	0.76	17	0.7089	0.7094
Or_07*	7	-4.49	-2.11	-3.33	2.38	0.96	7	-13.17	-11.28	-12.37	1.89	0.77	1	0.7099	0.7099
Or_08	11	-6.17	-3.33	-4.64	2.84	0.93	11	-12.91	-11.63	-12.26	1.28	0.46	3	0.7095	0.7096
Or_09	10	-6.13	-3.63	-5.17	2.50	0.94	10	-12.79	-11.23	-12.17	1.56	0.47	3	0.7095	0.7096
Or_10	11	-5.33	-2.96	-4.00	2.37	0.69	11	-13.47	-11.45	-12.51	2.02	0.69	3	0.7096	0.7097
Or_11	9	-6.29	-4.68	-5.57	1.61	0.58	9	-12.58	-11.56	-12.12	1.02	0.32	3	0.7085	0.7086

Or_12	7	-3.98	-2.33	-2.91	1.65	0.58	7	-13.51	-10.99	-12.59	2.52	0.91	2	0.7103	0
Or all samples	55	-6.29	-2.11	-4.37	4.18	1.18	55	-13.51	-10.99	-12.33	2.52	0.61	15	0.7085	0

Table 3. Summary statistics for isotope results from sheep tooth enamel. *Samples Or_07_Sr2 and Or_07_Sr3 excluded.

5.2.1 Enamel strontium isotopes

When compared to previous studies of central Italian fauna (Fig. 3), the $^{87}\text{Sr}/^{86}\text{Sr}$ isotope data from Orvieto have a very large range, from 0.7085– 0.7103.. The teeth from Orvieto can be divided into three groups on the basis of these isotope values (Fig. 4a): two individuals (Or_07 and Or_12) produced high Sr ratios of over 0.710; three individuals (Or_08, Or_09, and Or_10) registered within a small range between 0.70950–0.70963 (mean 0.70957); and one individual (Or_11) yielded low values under 0.7087.

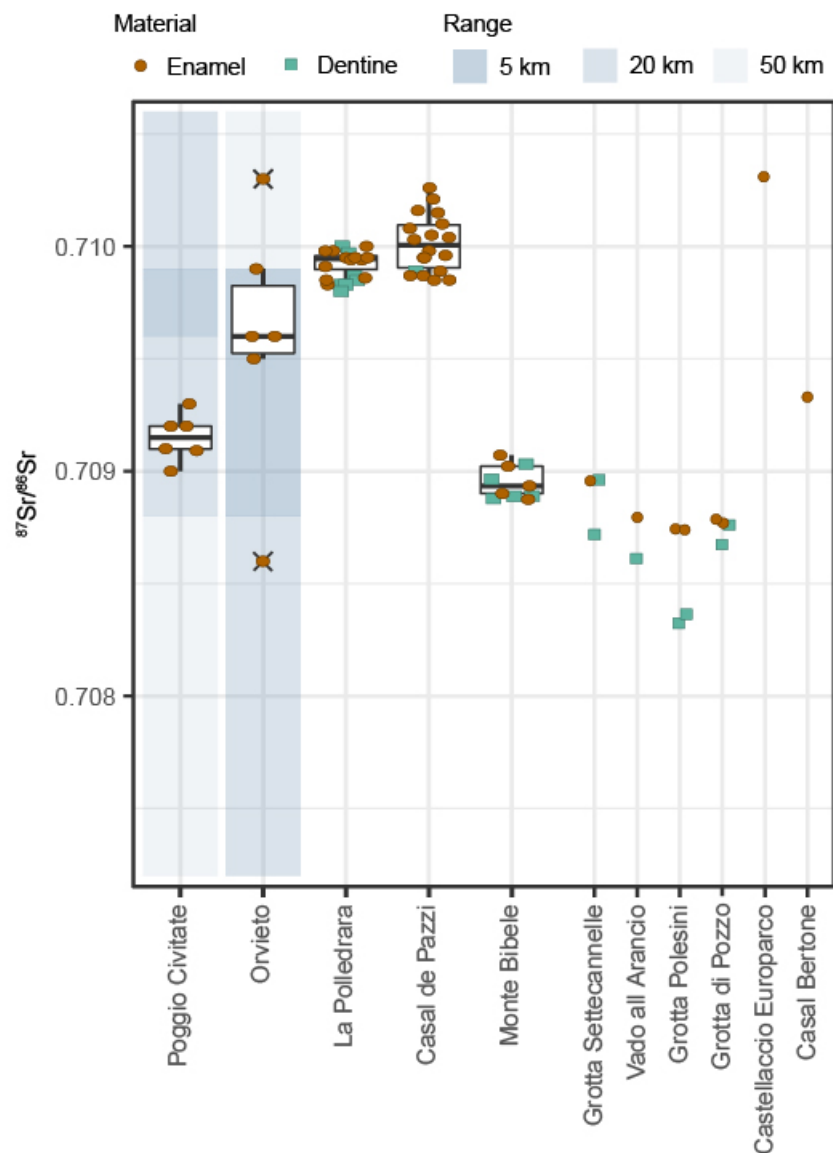


Fig. 3. Strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) isotope ratios from Poggio Civitate and Orvieto compared to other sites in central Italy (see Table 1). Points represent individuals, with intra-tooth analyses represented by the mean. Box plots describe enamel $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for sites with ≥ 5 individuals. Strontium values for estimated geographic ranges from Emery et al. (2018).

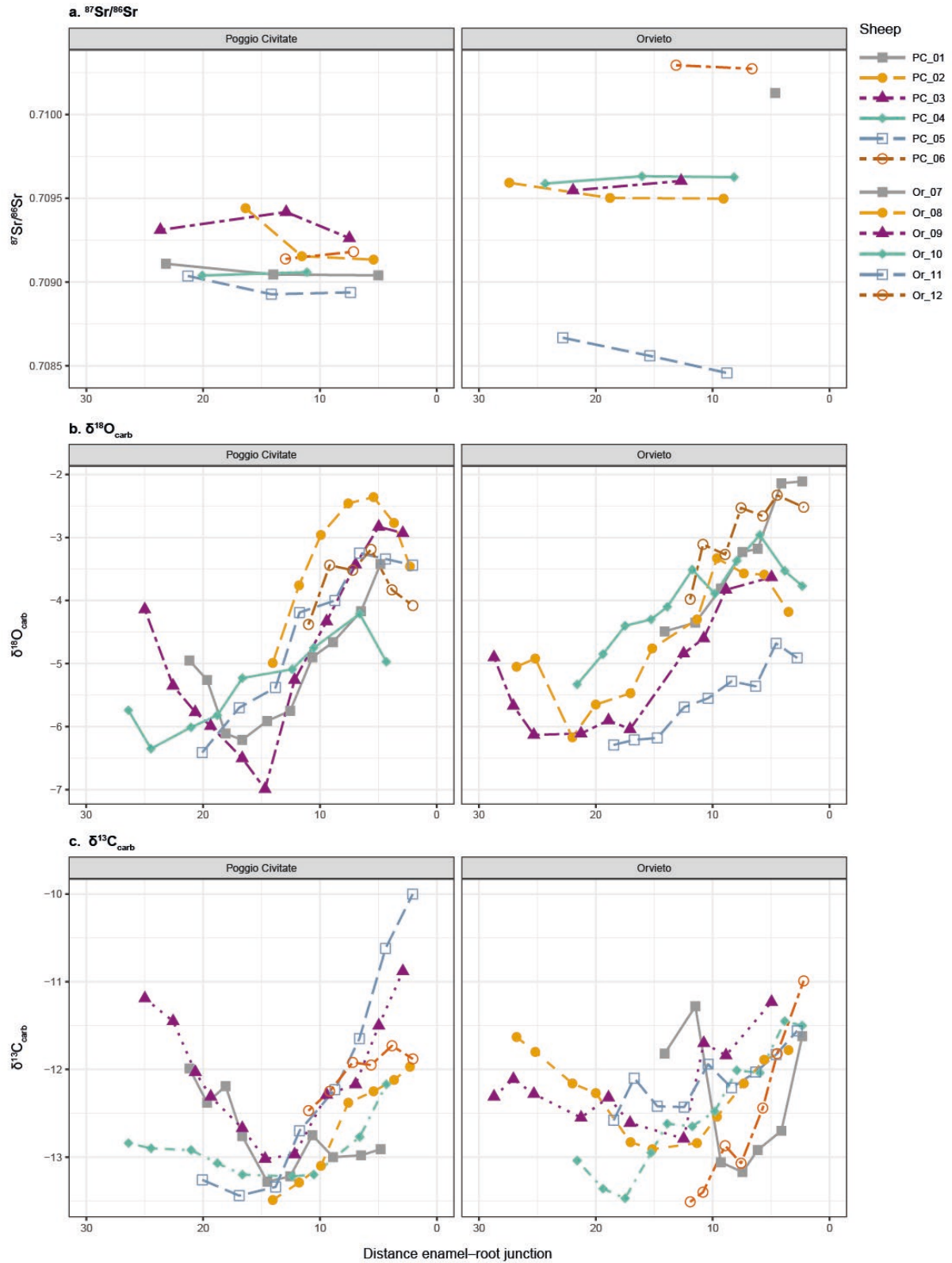


Fig. 4. Intra-tooth variation in (a) $^{87}\text{Sr}/^{86}\text{Sr}$, (b) $\delta^{18}\text{O}_{\text{carb}}$, and (c) $\delta^{13}\text{C}_{\text{carb}}$ from sheep mandibular second molars.

567

568 The $^{87}\text{Sr}/^{86}\text{Sr}$ signature for Orvieto, as estimated by Emery et al. (2018), is between *c.* 0.7088
569 and 0.7099. The middle group of samples (Or_08, Or_09 and Or_10) have values consistent
570 with this estimate. The remaining three individuals have strontium isotope values higher
571 (Or_07 and Or_12) or lower (Or_11) than the predicted local range, although still within the
572 estimated values for the immediate to broader hinterland (5–50 km). Nevertheless, $^{87}\text{Sr}/^{86}\text{Sr}$
573 values between 0.7090–0.7105 are consistent with volcanic geologies in central Italy (Holm
574 and Munksgaard, 1982, Palombo et al., 2005, Pellegrini et al., 2008, Marchionni et al., 2013,
575 Tescione et al., 2015) as well as the value (0.710216) of spring water bottled at Orvieto
576 (Voerkelius et al., 2010). Strontium isotope ratios from individual Or_11 (less than 0.7087)
577 fall below the 0.7092 value of modern seawater (McArthur et al., 2001). This result would be
578 consistent with marine carbonate sediments, which are abundant in central Italy.

579 Compared to Orvieto, Poggio Civitate produced a much smaller range of $^{87}\text{Sr}/^{86}\text{Sr}$ values,
580 between 0.7089 and 0.7094. Within this range, there are two data points identified as outliers
581 (PC_02_Sr1, PC_03_Sr2). Values from Poggio Civitate are not consistent with the range
582 predicted by Emery et al. (2018) for the immediate (5 km) vicinity of the site; however, such
583 values are predicted for a radius of >6km. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from Poggio Civitate do not have
584 any clear parallels in the published faunal studies for central Italy, although they do overlap
585 with results from Monte Bibele, a site located on shallow-water Miocene sediments (Scheeres
586 et al., 2013). $^{87}\text{Sr}/^{86}\text{Sr}$ values from Poggio Civitate also fall within the range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios
587 produced by Tuscan marlstones and by wines grown on sedimentary terrains in the east of the
588 Siena basin (Marchionni et al., 2013).

589 Intra-tooth variation in $^{87}\text{Sr}/^{86}\text{Sr}$ values for individual sheep was relatively small at both sites
590 (Fig. 4a). Sheep PC_02 produced the largest change in strontium values (0.0003), followed
591 by PC_03 (0.0002) and Or_11 (0.0002). Approaching the enamel–root junction, $^{87}\text{Sr}/^{86}\text{Sr}$
592 values in PC_02 decreased. Sr ratios PC_03 increased before decreasing again, and $^{87}\text{Sr}/^{86}\text{Sr}$
593 values from Or_11 decreased across the length of the tooth approaching the enamel–root
594 junction.

595 5.2.2 Enamel oxygen and carbon isotopes

596 At both sites, the $\delta^{18}\text{O}_{\text{carb}}$ values generally follow a sinusoidal pattern, with some molars
597 producing a near-complete curve, while others record only a portion of it (Fig. 4b). The
598 oxygen isotope results from Poggio Civitate range from –7.0 to –2.4‰. The amplitude of

variation within a single tooth ranges from 1.2 to 4.2‰. At Orvieto, the oxygen isotope results range from –6.3 to –2.1‰. The amplitude of variation within a single tooth ranges from 1.6 to 2.8‰. The minimum, maximum, and range of $\delta^{18}\text{O}_{\text{carb}}$ values for different individuals were strongly influenced by the completeness of the recovered sinusoidal curve. The t-test did not identify significant differences in mean $\delta^{18}\text{O}_{\text{carb}}$ values between the sites (P=0.725).

Tooth enamel $\delta^{13}\text{C}_{\text{carb}}$ results (Fig. 4c) from Poggio Civitate range from –13.5 to –10‰. The amplitude of variation within a single tooth ranges from 0.7 to 3.4‰. At Orvieto, the tooth enamel carbon isotope results range from –13.5 to –11‰. The amplitude of variation within a single tooth ranges from 1.0 to 2.5‰. There were no significant differences in mean $\delta^{13}\text{C}_{\text{carb}}$ values between sites (P=0.629).

In general, $\delta^{13}\text{C}_{\text{carb}}$ values decrease and increase with $\delta^{18}\text{O}_{\text{carb}}$ values (Fig. 5). Sheep PC_04, PC_05, Or_08, and Or_10 are slightly offset from this pattern, with increases in $\delta^{13}\text{C}_{\text{carb}}$ values following increases in $\delta^{18}\text{O}_{\text{carb}}$ values. Sheep PC_01 and Or_04 are divergent from the prevailing trend. PC_01 does not register $\delta^{13}\text{C}_{\text{carb}}$ enrichment concurrent with maximum $\delta^{18}\text{O}_{\text{carb}}$ values, and Or_04 demonstrates a notable decrease in $\delta^{13}\text{C}_{\text{carb}}$ just after the $\delta^{18}\text{O}_{\text{carb}}$ minimum.

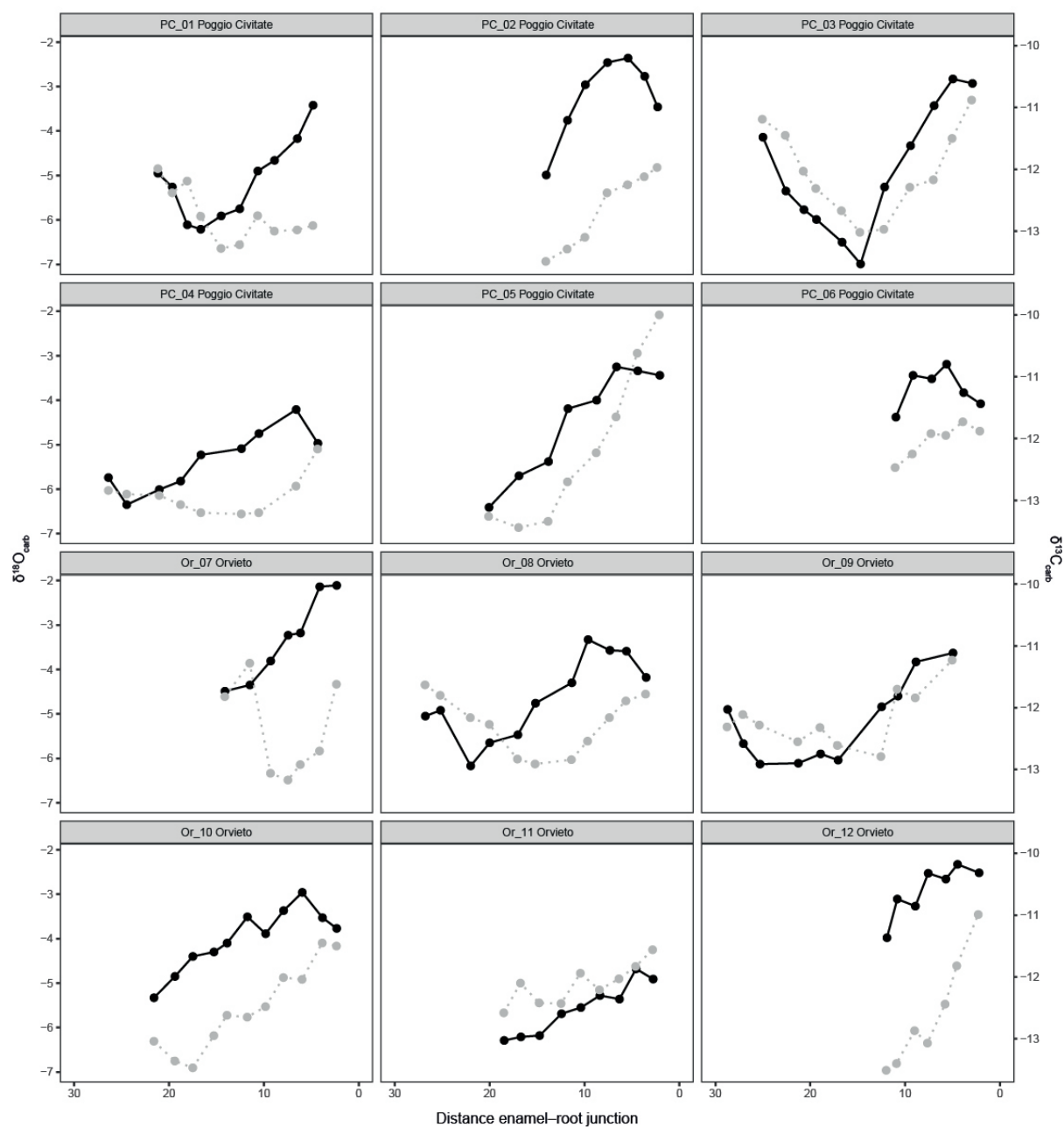


Fig. 5. Intra-tooth variation of oxygen isotope values ($\delta^{18}\text{O}_{\text{carb}}$, black) and carbon ($\delta^{13}\text{C}_{\text{carb}}$, grey) from sequentially sampled second mandibular molars of sheep.

5.3 Bone collagen carbon and nitrogen isotopes

The bone collagen isotope results are given in Table 4 and presented in Fig. 6. At Poggio Civitate $\delta^{13}\text{C}$ values range from -21.0 to -19.5‰ ($\sigma=0.51$), and $\delta^{15}\text{N}$ values range from 4.5 to 7.2‰ ($\sigma=0.81$). At Orvieto, $\delta^{13}\text{C}$ values in bone collagen range from -20.8 to -19.5‰ ($\sigma=0.45$), and $\delta^{15}\text{N}$ values range from 4.0 to 6.5‰ ($\sigma=0.87$). There was no statistical difference between the two sites in either $\delta^{13}\text{C}$ ($P=0.397$) or $\delta^{15}\text{N}$ ($P=0.301$) values.

Site	Individual	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C:N	σ
Poggio Civitate	PC_01	-21.0	5.6	3.2	0.04
Poggio Civitate	PC_02	-20.4	4.5	3.2	0.03
Poggio Civitate	PC_03	-19.5	5.6	3.2	0.02
Poggio Civitate	PC_04	-20.9	5.2	3.2	0.02
Poggio Civitate	PC_05	-20.1	7.2	3.2	0.01
Poggio Civitate	PC_06	-20.2	5.3	3.2	0.03
Orvieto	Or_07	-20.1	4.4	3.1	0.03
Orvieto	Or_08	-20.8	4.6	3.1	0.03
Orvieto	Or_09	-20.4	6.5	3.1	0.03
Orvieto	Or_10	-19.5	4.0	3.1	0.03
Orvieto	Or_11	-20.1	4.6	3.1	0.03
Orvieto	Or_12	-19.6	5.8	3.1	0.04

Table 4. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from sheep mandible bone collagen.

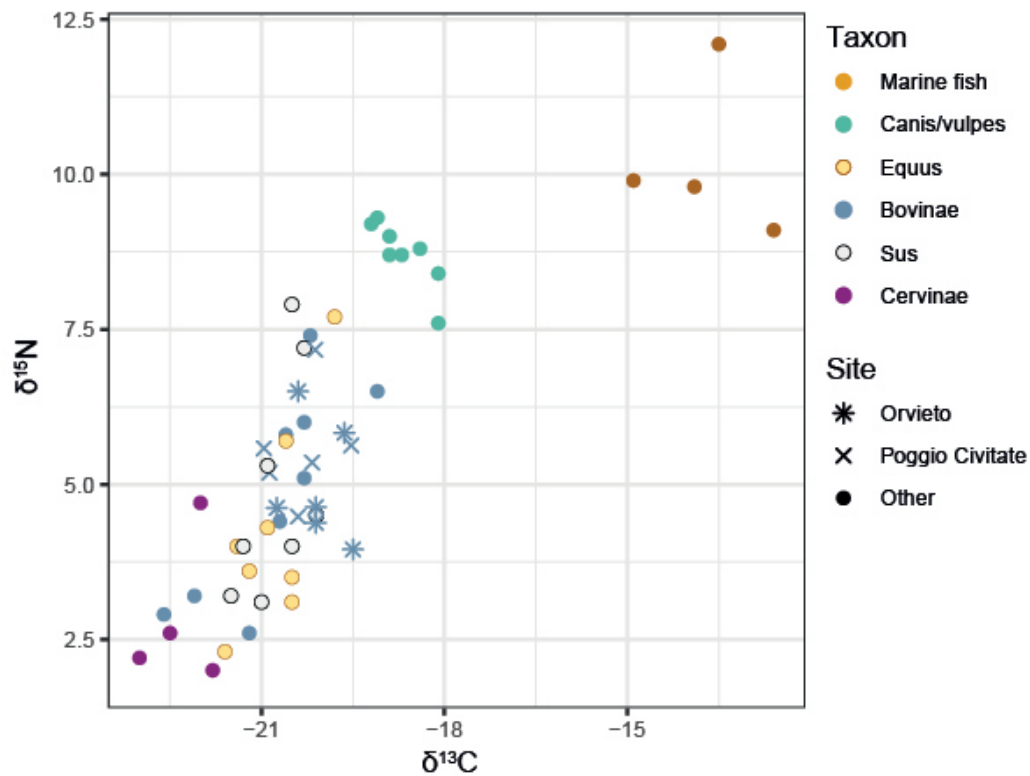


Fig. 6. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in bone collagen from Italian fauna. Comparative data from Roman Velia (Craig et al., 2009) and Isola Sacra (Prowse et al., 2004) via Isoarch (Salesse et al., 2018).

No other collagen stable isotope data were available from Etruscan Italy; however, the data can be compared to that from Roman sites in central and southern Italy (Fig. 6). The Etruscan sheep presented here have similar collagen isotope results to those from Roman bovids, pigs and equids. Compared to deer, however, sheep from Poggio Civitate and Orvieto appear to be enriched in $\delta^{13}\text{C}$ and, to a lesser extent, $\delta^{15}\text{N}$.

5.4 Modelled $\delta^{18}\text{O}$ sequences

Only three teeth produced $\delta^{18}\text{O}_{\text{carb}}$ curves that included reliable minimum and maximum values: PC_03, PC_04, and Or_08. Oxygen isotope sequences were modelled for these individuals (Table 5), with the position of the maximum $\delta^{18}\text{O}_{\text{carb}}$ value (x_0) normalised by the total cycle period (X) for each individual. Inter-individual variability in the x_0/X ratio was low, ranging from 0.14 to 0.30.

	X	A	x_0	M	p	X/x_0
PC_03	26.32	1.88	30.04	-4.74	0.98	0.14
PC_04	30.06	0.78	38.12	-5.32	0.94	0.27
Or_08	26.00	1.18	33.83	-4.69	0.96	0.30

Table 5. Results from the modelling of the $\delta^{18}\text{O}$ sequences following Balasse et al. (2012b). See Supplement 1 for details.

5.5 Correlation between isotopic results

Supplement 4 presents r and p values from correlation tests. At Orvieto, maximum $\delta^{18}\text{O}_{\text{carb}}$ values had a significant correlation ($p < 0.01$) with maximum, minimum, and mean $^{87}\text{Sr}/^{86}\text{Sr}$ values. No other correlations were observed when different isotopes were compared.

6. Discussion

6.1 Localisation of sheep management

The strontium isotope results from Orvieto suggest that sheep were raised in at least three different localities during formation of the second molar and subsequently brought to the summit of the plateau. The precise location of these localities requires further Sr baseline sampling of the area; however, related studies provide an indication of possible areas of management. Two sheep (Or_07, Or_12) derived from an area with relatively high bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values (> 0.7010) consistent with central Italian volcanic rocks, probably the eastern slopes of the Bolsena volcano. A second management location is represented by the intermediate values of sheep Or_08, Or_09 and Or_10, which may represent a different area of the Vulsini Volcanic district with lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (cf. Pellegrini et al., 2008, Tescione et al., 2015) or regular ranging between a volcanic geology and area(s) with lower bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values. Sheep Or_11 had an origin in an area with low strontium isotope values (< 0.7087) distinct from the previous zones. Minimal intra-

tooth variation in $^{87}\text{Sr}/^{86}\text{Sr}$ values indicates that animals were not moved to geology with a different strontium baseline during formation of the second molar.

Correlation of maximum $\delta^{18}\text{O}_{\text{carb}}$ values and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from Orvieto reinforces interpretation that these individuals were raised in distinct management locations. Sheep with high $^{87}\text{Sr}/^{86}\text{Sr}$ values (Or_07, Or_12) also produced the highest $\delta^{18}\text{O}_{\text{carb}}$ values, while sheep Or_11 yielded the lowest Sr ratios as well as a dampened $\delta^{18}\text{O}_{\text{carb}}$ curve. The low summer values produced by sheep Or_11 suggest that it consumed water relatively depleted in $\delta^{18}\text{O}$ during warm months. This pattern suggests management at higher elevation or more easterly location, where rain and spring water are relatively depleted in $\delta^{18}\text{O}$ (Raco et al., 2013, Giustini et al., 2016). For this animal, an origin in the Apennines would also be consistent with $^{87}\text{Sr}/^{86}\text{Sr}$ values predicted by Emery et al. (2018).

$^{87}\text{Sr}/^{86}\text{Sr}$ results from Poggio Civitate demonstrate that sheep were raised in an area with a different strontium baseline to any of the individuals from Orvieto. Variation in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios indicates some differences in the management of individual sheep, but inter-individual variation was small compared to Orvieto. The sheep that produced high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (PC_02, PC_03) also have the highest maximum $\delta^{18}\text{O}_{\text{carb}}$ values, although this correlation was not statistically significant. The high $^{87}\text{Sr}/^{86}\text{Sr}$ results from PC_02 and PC_03 correspond with low points on their $\delta^{18}\text{O}_{\text{carb}}$ curve, which may indicate a seasonal change in location or mobility pattern during winter months, although to an area with similar $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. However, these intra-annual changes are very small (*c.* 0.0002–0.0003) and may simply reflect variation within a single iso-zone. Considering Poggio Civitate's position at the edge of a ridge of Jurassic–Cretaceous age, immediately adjacent to the Miocene sedimentary rocks and more recent marine deposits of the Siena Basin, herding within a few kilometres of the site might be expected to produce changes in Sr isotope values, especially if there was seasonal or inter-annual variation in the territory exploited, e.g. if animals were enclosed on the Murlo ridge for part of the year and herded in the Siena Basin at other times.

6.2 Diet and seasonality

Bone collagen $\delta^{13}\text{C}$ data are consistent with the enamel carbonate $\delta^{13}\text{C}$ data at both sites, and these provide evidence for a C_3 dominated diet with little or no evidence for C_4 consumption. Despite a long history of millet exploitation spanning Bronze Age (Tafari et al., 2009, Varalli et al., 2016), Etruscan (e.g. Malone et al., 2014) and Roman (Spurr, 1983, Murphy, 2016)

Italy, the sheep considered in this study were not regularly foddered with the crop. Similarity in carbon isotope values suggests that sheep at Orvieto and Poggio Civitate consumed a comparable diet; no statistical differences were noted in inter-site comparison of $\delta^{13}\text{C}$ results from bone collagen or tooth enamel, and intra-site variability was similar at both locations. When compared to data from other central and southern Italian fauna, there is little difference in diet between Etruscan and Roman bovids (cf. Fig. 6). However, the higher $\delta^{13}\text{C}$ values in collagen samples from Etruscan sheep compared to Roman red deer suggests that the sheep fed in more open and/or drier environments than wild deer, for example, open pastures or crop fields (see Berthon et al., 2018). All Etruscan sheep teeth have minimum $\delta^{13}\text{C}_{\text{carb}}$ values above -13.5‰ . Considering a 14.1‰ enrichment between tooth enamel bioapatite and dietary $\delta^{13}\text{C}$ (Cerling and Harris, 1999), these values would correspond to $\delta^{13}\text{C}$ values for diet well above the suggested -28.3‰ cut-off for closed-canopy forest environments (Balasse et al., 2012a). However, leaves from the upper layer of Italian beech trees can reach $\delta^{13}\text{C}$ values of -27‰ (Scartazza et al., 2004). Minimum $\delta^{13}\text{C}_{\text{carb}}$ results from the majority of sheep from Poggio Civitate as well as individuals Or_17, Or_10, and Or_12 would therefore be compatible with seasonal foddering with tree leaves from open environments.

The comparable range and standard deviation of nitrogen isotope values at Poggio Civitate and Orvieto indicates that sheep consumed plants with a similar $\delta^{15}\text{N}$ baseline, with no statistical differences noted between the two samples. Compared to the $\delta^{15}\text{N}$ values produced by Roman deer, Etruscan sheep have higher $\delta^{15}\text{N}$ values, which may suggest greater consumption of manured plants or plants subject to other organic inputs (e.g. middening/composting) by domestic sheep than wild cervids (Bogaard et al., 2013). Sheep may have grazed on crop fields/fallow land, or been foddered with manured grain or crop processing debris. Similarly, repeated use of the same pasture or high herd density could also produce an enrichment in the $\delta^{15}\text{N}$ values of vegetation, and consequently the $\delta^{15}\text{N}$ signature of any sheep folded in the area (Makarewicz, 2014, Szpak, 2014). Considering the high $\delta^{15}\text{N}$ values ($>6\text{‰}$) found in heavily manured cereal crops (Bogaard et al., 2013), the relatively modest range of values produced by Etruscan sheep ($4.0\text{--}7.2\text{‰}$) does not suggest that highly manured cereals made a major contribution to livestock diet. Foddering with legumes, a practice well attested by Roman authors (White, 1970), may also contribute to variation in domestic animals by lowering $\delta^{15}\text{N}$ values (Bogaard et al., 2013, Szpak et al., 2014). Considering the minimal variation in $\delta^{15}\text{N}$ values from Orvieto and Poggio Civitate, if employed this practice does not appear to have been markedly different between the two

sites; however it may have a greater role in diachronic differences between some Etruscan and Roman fauna: alfafa (*Medicago sativa*), a legume and major fodder crop, is thought to have been introduced to Italy around the second century BC (White, 1970).

Variation in plant $\delta^{13}\text{C}$ values is closely linked with moisture availability, reflecting precipitation regimes and the availability of soil water (Schnyder et al., 2006, Tornero et al., 2018). Seasonal $\delta^{13}\text{C}_{\text{carb}}$ values rise and fall in tandem with $\delta^{18}\text{O}_{\text{carb}}$ values in the majority of analysed sheep. The close relationship between the timing and amplitude of $\delta^{18}\text{O}_{\text{carb}}$ and $\delta^{13}\text{C}_{\text{carb}}$ curves in most individuals suggests local, seasonal variation, probably reflecting natural oscillations in vegetation and leaf water. Interestingly, $\delta^{13}\text{C}_{\text{carb}}$ curves from Poggio Civitate show very little variation in their low point, both in terms of minimum values and position along the tooth (cf. Fig. 4c), compared to greater heterogeneity in $\delta^{13}\text{C}_{\text{carb}}$ curves from Orvieto. This seasonal compression in $\delta^{13}\text{C}_{\text{carb}}$ values at Poggio Civitate suggests that sheep consumed an isotopically similar food source during colder months, with greater variability in summer, e.g. as a result of similar winter foddering strategies or enclosure. Wider summer variability would be compatible with more extensive herding in warm months, ranging over a large area with differences in plant $\delta^{13}\text{C}$ values (pasture, crop fields, river valleys, etc.).

The offset in $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{carb}}$ values in sheep PC_02, PC_04, and Or_08 may reflect differences in the timing and intensity of seasonal rains, or a change in animal location, for instance if sheep were grazed on floodplains during the growing season, and moved to drier areas in late summer (e.g. stubble fields) (cf. Winter-Schuh et al., 2018). The abrupt transition from high to low $\delta^{13}\text{C}_{\text{carb}}$ values in Or_07 during late winter indicates a change in feeding strategy. This change would be compatible with foddering with summer harvested crops/processing debris in winter months, since dried summer vegetation tends to be enriched in $\delta^{13}\text{C}$ (Cernusak et al., 2009, Osorio et al., 2011), followed by a shift to foddering with leaves/winter-cut crops or a return to grazing in spring. In contrast, the lack of seasonal change in $\delta^{13}\text{C}_{\text{carb}}$ values in PC_01 suggests a different feeding strategy, possibly foddering with leaves or winter-cut vegetation into summer months. The general coincidence of minimum and maximum $\delta^{18}\text{O}_{\text{carb}}$ values suggests a single lambing season, which is similar at both sites. Results from the three teeth subject to modelled $\delta^{18}\text{O}$ sequences also support a restricted birthing season. Based on the accounts of Roman authors (MacKinnon, 2004) and documentation of traditional pastoral practices in central Italy (Barker et al., 1991), this period probably fell between September and December.

6.3 Implications for agricultural provisioning at Orvieto and Poggio Civitate

6.3.1 Animal provisioning in context

Results from isotope analysis demonstrate differences in sheep management at Orvieto and Poggio Civitate. At Orvieto, sheep were drawn from several different locations, while animals from Poggio Civitate ranged across an area with a similar bioavailable Sr baseline. The geology around Orvieto is not notably more diverse than around Poggio Civitate, so greater variability would not necessarily be expected. Sheep from Poggio Civitate may have been raised in different locations within the same geology (e.g. the Siena Basin), but our results indicate that Orvieto received sheep from a broader range of management locations, even if these locations were from within a similar radius. $\delta^{13}\text{C}_{\text{carb}}$ values from tooth enamel also demonstrate greater homogeneity in sheep feeding practices at Poggio Civitate, at least during winter months. The greater heterogeneity in results from Orvieto is especially striking given that all mandibles came from the same deposit: material that represents a single depositional event or perhaps sequence of dumps made in a short period of time, in contrast to the mandibles from Poggio Civitate, which derive from a range of contexts.

Although the small sample size limits the conclusions that can be drawn from this study, results align with broader understanding of the productive strategies employed by the two study sites. Isotope data support the view established by manufacturing evidence and the circulation of material culture at Poggio Civitate, which suggests that the aristocratic homestead was largely self-sufficient, with production taking place on site and little interaction with the ‘outside world’ (Tuck, 2014, 2016). Recent research on textile production also supports a model of independent production for local needs (Cutler et al., Forthcoming). None of the material manufactured at Poggio Civitate appears to have left the site in any volume, suggesting that ceramic, tile, metal, textile production, as well as animal husbandry, were undertaken locally to satisfy the site’s inhabitants.

At Orvieto, the multi-centered mode of production demonstrated by this study would be consistent with understanding of the Etruscan city as central place which exercised territorial control over in its hinterland (Zifferero, 2017). Alternatively, results may reflect a special provisioning strategy for the event that created the deposit in cave 254. Animal consumption in association with the restructuring of the urban area of Etruscan *Velzna*, potentially undertaken in a civic or religious context, would not necessary follow typical modes of provisioning. Monumental construction events in other archaeological contexts have been

associated with the aggregation of animal animals from wide territories (e.g. Henton et al., 2014, Madgwick et al., 2019a), and similar models have been proposed for the movement of surplus animals to Etruscan religious places. Based on the abundance of livestock taxa at different site types, Barker (1989) hypothesized that animals consumed at pre-Roman sanctuaries in Samnium were aggregated from sites in the surrounding hinterland (see also Trentacoste, 2016). Our results illustrate the mobilisation of animal resources at a fifth-century BC Etruscan site, although understanding of the motivation for – and the scale of – this activity is coarse.

Even if results from Orvieto represent activity conducted within a religious or public sphere, such activity was not necessarily rare or economically marginal. Although much larger in scale, the fill of *cavità* 254 recalls other examples where deposits rich in animal bones were used to close subterranean structures during the re-organisation of urban space, for instance a semi-subterranean shrine at Caere (Colivicchi et al., 2016), wells at Veii (Cucinotta et al., 2010) and Pyrgi (Caloi and Palombo, 1988–1989), and tunnel at Centocelle (de Grossi Mazzorin, 2004). Even if a multi-centered animal provisioning strategy was employed only for public, ceremonial, or religious events, this type of activity was nevertheless common and integrated into wider economy of central Italy during the mid and latter part of this first millennium BC. Before the diffusion of formal market places, religious spaces and ritual activities had an important economic role, from market regulation to hosting periodic fairs and supporting the circulation of goods (Frayn, 1993, Becker, 2009, Potts, 2015:113–115). Such activity is believed to have been directed by aristocratic families (Nijboer, 2017b), for whom the conspicuous consumption and distribution of food in a religious context served to reinforce their status and control over agricultural production (Barker, 1989, Becker, 2009). The finds from *Cavità* 254 do not suggest the deposit relates to a sanctuary or temple, but the overlap in aristocratic, civic, and religious interests during this period prevent neat division of these spheres of activity, and warrant consideration of ‘special’ deposits in their wider socio-economic context (although contextualisation on this scale is beyond the scope of the immediate contribution).

The nature of the event that created the deposit at Orvieto may have dictated a special provisioning strategy, but the archaeological visibility of banqueting at Poggio Civitate suggests that inter-site differences do not primarily arise from the presence/absence of communal or ceremonial consumption. Communal banqueting is attested at Poggio Civitate’s Orientalising residence through the recovery of large cauldrons, a large collection of fine

drinking and dining ceramics, and abundant animal remains (Phillips, 1989, Berkin, 2003, Kansa and MacKinnon, 2014). The limited number of mandibles analysed in this pilot study precludes strong conclusions; however, the evidence for communal dining at both sites suggests that differences in provisioning strategy relate to factors beyond the simple presence of banquets or communal consumption events, and result, rather, from differences in chronology, site size or type, the nature or symbolic value of the event, or a combination of the above.

6.3.2 Tracking transhumance

None of the sampled sheep produced clear evidence for long-distance seasonal vertical transhumance to upland pastures. Intra-tooth $^{87}\text{Sr}/^{86}\text{Sr}$ variation was minimal and compatible with comparative data in the hinterland of each site, and the close positive relationship between $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{carb}}$ is indicative of seasonal oscillations. Sampling of modern plants is needed to establish whether vertical herding would produce an inverse $\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{18}\text{O}_{\text{carb}}$ in Italy, as it has in Spain (Tornero et al., 2018); however, considering the significant differences in summer precipitation at the study sites (c. 160–220 mm) compared to elevated areas in the Apennines (360–450 mm at places >750 m asl), some impact might be expected. Further investigation is required to establish whether the trends presented here are representative of wider management patterns, but the lack of evidence for a large-scale, long distance herding strategy raises questions as to the origin of Roman sheep transhumance. Seasonal movement on the scale recorded during the Roman period may not have been ecologically or economically necessary in Etruscan central Italy or, even if desirable, precluded by a lack of political integration.

Although results are not indicative of long-distance vertical transhumance, they do not suggest that sheep were stationary. Isotope results are compatible with herding patterns that ranged around a landscape, for example seasonally moving animals from lowlands or river valleys, to agricultural fields, and pastures; indeed, this type of movement is suggested by intra-tooth variation. Like in traditional *stanziale* herding systems, animals may have been enclosed in the evening (and perhaps during some winter months), and grazed across an area of a few kilometres during the day (Barker et al., 1991). Results from Poggio Civitate suggest that sheep may have been herded together, and possibly enclosed, during winter months; summer herding practices were more diverse, possibly due to differences in herding location or feeding strategy on an inter-annual (precipitation) or individual scale (e.g. differences

between males, females, castrates). Comparison with other strontium isotope studies only provides a coarse view of the central Italian iso-scape, and sampling for bio-available strontium is needed, but what data were available suggest the full range of $^{87}\text{Sr}/^{86}\text{Sr}$ values could be produced within a few days walk, with 50 km of each site. These patterns would be consistent with the relatively local (50 km) rearing of small to mid-range size herds (50–500 sheep) managed in various areas of each site's hinterland, rather than the long-distance vertical movement practiced, in recent history, by larger herds of over 1000 animals (Barker et al., 1991).

7. Conclusion

In central Italy, agriculture underwent a significant re-organisation in the first millennium BC, with the rise of urban settlements and an aristocratic class. This study, the first dedicated to isotope analysis of fauna from late prehistoric or Roman Italy, presents new data on the management and mobilisation of livestock at two Etruscan sites. Orvieto, a major city, was able to muster herds of sheep – animal capital – from its hinterlands during the fifth century BC, drawing on a mosaic of productive locations. Sheep herding at the aristocratic homestead of Poggio Civitate was more homogenous and consistent with the self-sufficient character of the earlier, seventh-century BC site. Neither site produced evidence of long-distance vertical transhumance, but other seasonal forms of mobility were probably practiced. The limited scope of this pilot study does now allow us to firmly establish broader patterns of site provisioning, and further baseline sampling – both of bioavailable strontium, as well as $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values from modern plants and sheep – is needed to realise the full potential of this and similar research. However, results demonstrate the value of further isotopic studies focused on ancient fauna, and the ability of such research to address questions relevant to the broader socio-economic development of Etruscan and Roman Italy, including issues of land use, site catchment, and political territorial control.

The accrual of wealth in first-millennium BC Italy depended on access to materials and natural resources, supported by control over human capital and territory (Nijboer, 1998, Nijboer, 2017a). In agrarian societies, crop and animal husbandry would have been a primary vehicle for wealth acquisition, and changes in the agricultural economy that helped to feed urban populations may also have driven wealth inequality (Styring et al., 2017). Orvieto's access to a mosaic of iso-zones may imply greater control over the landscape and potentially private systems of land holding or, alternatively, communal input, where access was shared

amongst groups (cf. Stevens et al., 2013). In this context, the lack of clear evidence for long-distance vertical transhumance is interesting, and suggests that sheep management systems common in Roman Italy may have had an origin later than the Etruscan period, at least in the region investigated here. Long-distance seasonal transhumance is one of a range of possible mobility regimes, dependant on ecology, arable farming regimes, political context, and availability of common land (Costello and Svensson, 2018). The diverse cultural and topographic landscape of proto-historic Italy would have promoted different livestock strategies throughout the peninsula, tailored to local environments and the socio-economic organisation of communities. While the criteria for long-distance transhumance may not have existed in Archaic central Italy, other regions (e.g. Puglia) likely followed different trajectories. Further work is needed to contextualise the results of this pilot study, but such analyses have the potential to revolutionise the way in which we investigate Italian urbanisation, by drawing a totally new line of evidence to forefront of the discussion of urban subsistence and the organisation of agricultural production.

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