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## A Species Specific Investigation Into Sheep and Goat Husbandry During the Early European Neolithic

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### ABSTRACT

Archaeozoological assemblages are important sources of information on past management strategies, which are influenced by cultural practices as well as the physical geography and climate. Sheep, goat and cattle arrived in Europe with early Neolithic migrants. Their distribution is believed to have been mainly influenced by the geography of European regions although individual species may have held symbolic importance for specific Neolithic cultures. Domesticated animal mortality data derived from dental eruption, wear and replacement can provide insights into slaughter management and consequently animal husbandry practices. Previous studies have focused on caprines (sheep and goat) collectively as a results of their morphological similarity. Here we present a species specific study of sheep and goat mortality data from early European and Anatolian Neolithic contexts using correspondence analysis. The results show that for sheep there were significant differences in slaughter management practices between regions, cultures and site types whereas for goats there was none. This initial examination into sheep and goat husbandry during the Neolithic suggests that cultural practices as well as regional geography played an important role in shaping management practices.

### ARTICLE HISTORY

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### KEYWORDS

Sheep (*Ovis aries*); goats (*Capra hircus*); Neolithic; Europe; mortality data; correspondence analysis

## Introduction

Sheep (*Ovis aries*) and goat (*Capra hircus*) are an important component of modern livestock systems, producing renewable products such as milk, hair/wool, manure and traction as well as final products such as meat, skin, horn and bone. Their osteological morphology is very similar but they, however, have different physiological and productive capacities (Prendergast et al. 2018; Gillis, Chaix, and Vigne 2011; Balasse and Ambrose 2005; Halstead, Collins, and Isaakidou 2002; Haenlein 2001). Sheep are natural grazers, with short lactation lengths that produce milk with a high fat content, ideal for cheese making. In comparison, goats are browsers and can exist in areas of rough grazing to such a degree that they have been used deliberately to remove unwanted vegetation in some areas. They have a long lactation length earning them the synonym 'the poor man's cow' (Haenlein 2007). Both species can survive in arid regions with infrequent water sources. Present day husbandry systems for these species vary greatly between southern and northern Europe. In the Mediterranean region, there is a focus towards systems that produce milk, lambs (<12 months) and wool. In the Balkans, transhumance with a focus on milk production was widely

practised by stockherders who range from Northern Greece to Croatia and Serbia (Ryder 1999). In central and northern Europe, sheep were traditionally used for wool and meat production. Specialised milk breeds for cheese production have been developed during the last century from traditional breeds with the capacity for good milk production such as Lacaune and East Friesian sheep and the Saanen Goat.

Direct morphological evidence for sheep and goat domestication has been identified at Pre-Pottery Neolithic (PPN) sites in the northern Levant and Zagros regions respectively, dating to the 9th millennium cal BC (Vigne et al. 2011; Peters et al. 1999; Zeder 1999). They were introduced into Europe by early Neolithic farmers, which is evident by the absence of a putative wild ancestor (Poplin 1979; Uerpmann 1987). From this point onwards, caprines formed an important cornerstone of prehistoric subsistence practices (Helmer, Gourichon, and Vila 2007; Arbuckle et al. 2014). They were the predominate species for Early Neolithic settlements of southern Europe; this is in part a reflection of their success in drier climates in comparison to cattle (Manning et al. 2013). Neolithic cultures spread or were adopted by local hunter-gatherer groups along two main routes: following the northern Mediterranean seaboard to the west and major European

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rivers to the north. Along the Mediterranean seaboard, caprines dominated the Impressa and Cardial culture assemblages with some exceptions in south-eastern Italy (Rowley-Conwy et al. 2013). As Neolithic groups spread northwards into central and eastern Europe via the Balkans the proportions of sheep and goats kept at sites became more variable with an overall shift through time towards a greater reliance on the herding of cattle and pigs (Orton, Gaastra, and Linden 2016). This shift in focus towards cattle continued as the Neolithic way of life spread further into the north. Cattle were the predominate animal of the early Neolithic cultures, such as the Linearbandkeramik of central and northern Europe. In some areas, such as Southern Bavaria, caprines were more numerous than cattle (Lüning 2000). Moreover, Marciniak (2013) proposed that caprines may have used as the meat source with cattle being used for ritual consumption in LBK sites in southern Poland.

Individual domesticated species have different productive capacities, which may have been exploited by herdsman since their domestication. Understanding the individual roles of sheep and goats since their domestication has been hampered by poor identification due to the similarity in their osteological morphology (Boessneck, Müller, and Teichert 1964). In the last twenty years, there has been methodological advances in identifying sheep and goats using dental morphology (Gillis, Chaix, and Vigne 2011; Zeder and Pilaar 2010; Balasse and Ambrose 2005; Halstead, Collins, and Isaakidou 2002). Animal teeth are an excellent source of information about past slaughter management and consequently husbandry practices. Here we present an analysis of species specific mortality profiles to investigate, compare and characterise sheep and goat husbandry practices during the early phases of the European Neolithic (7th to 5th millennium cal BC).

## Material and Methods

Caprine age-at-death determination using eruption and replacement of dental remains was first established by Ewbank et al. (1964). This methods was followed by age determination methods using occlusal dental wear stages based on the study of modern Turkish sheep (Payne 1973, 1987) and observations of caprines from English Iron Age sites Grant (1982). Additional methods using the crown height and width were introduced by Ducos (1968) and re-examined by Gaastra (2016), the former was integrated into Payne's original age classes by Helmer, Gourichon, and Vila (2007).

Species specific age-at-death methodologies specifically for eruption and wear stage have been devised by Silver (1963; based 'improved breeds' and hill sheep '1790'), Weinreb and Sharav (1964), Payne (1973, 1987; Turkish sheep) and Jones (2006; based on observations of modern hill sheep). Goat age-at-

death schemes are reported by Silver (1963), Bullock and Rackham (1982; based on feral Scottish goats) and Deniz and Payne (1982; Turkish goats). There are slight differences between species in terms of eruption of the deciduous premolars (erupt later in goats), premolars and molars (erupt earlier in goats; Gillis (2012)). Many of the studies concerning goats were dominated with male goats, whose teeth have been observed to have erupted earlier than in females (Melado et al. 2007).

We included isolated teeth in the final count (deciduous premolar 4, premolar 4, molars 1–3), because of the fragmented nature of Early Neolithic remains and the infrequent recovery of complete or large portions of mandibles. First and second molars can often be mistakenly identified as each other, to prevent this we took measurements (height and distance anterior/posterior) of known M1 and M2s and compared with loose M1and M2s. Isolated teeth found to belong to several age classes were divided between them according to the respective time length of the age classes according to Payne (1973).

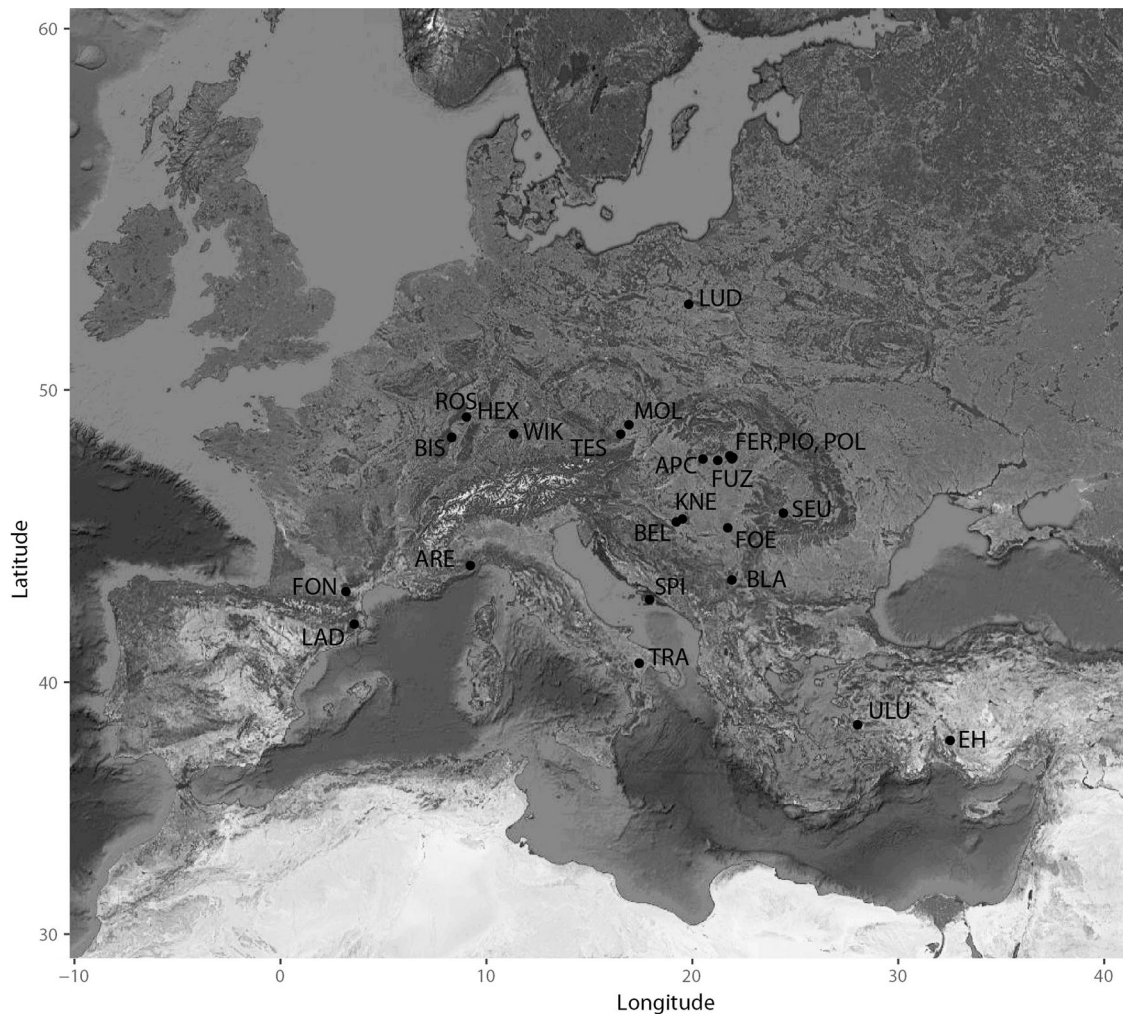
Age-at-death determinations were made using Payne (1973), RG and JSG additional used Ducos (1968) and Gaastra (2016) respectively to refine the age of adults using crown-height indexes. Those sites studied by RG and JSG, sheep and goat were distinguished using methodologies established by (Helmer 2000; Halstead, Collins, and Isaakidou 2002; Balasse and Ambrose 2005; Zeder and Pilaar 2010; Gillis, Chaix, and Vigne 2011; Boessneck, Müller, and Teichert 1964).

## The Dataset

We collected mortality data based on dental remains from 35 sheep profiles from 25 sites and 17 goat profiles from 18 sites (Figure 1; Table 1). RG studied and differentiated the caprine remains from 17 sites (La Draga (LAD), Font Juvenal (FON), Trasano (TRA), Füzseabony-Gubakút (FUZ), Apc-Berekalja (APC), Polgár-Piócási-dűlő (PIO), Polgár-Ferenci-hát (FER), Ludwinowo (LUD), Mold (MOL), Těšetice-Kyjovice (TES), Dillingen-Steinheim (WIK), Herxheim (HEX) and Bischoffsheim (BIS)). While JSG studied and differentiated the caprine remains from 3 sites (Spila Nakovana (SPI), Kneževi Vinograd (KNE), Belišće (BEL)). The remaining sties were collected from published sources detailed in SDATA1. The sites are representative of early Neolithic cultures from Anatolia, the Balkans, north-western Mediterranean, central Europe and northern European plain. Sites/phases with a total less than 6 teeth per species were removed. On average the total sample size per site/site phase was 33 for sheep and 24.5 for goats.

The sites Erbaba Höyük (ERB, central Anatolia (Arbuckle 2008)) and Ulucak Höyük (ULU, western





**Figure 1.** Map of site locations: Erbaba Höyük (ERB), Ulucak Höyük (ULU), Spila Nakovana (SPI), Belišće (BEL), Blagotin (BLA), Seuša-Cararea Morii (SEU), Foeni-Salaş (FOS), Polgár 10 (POL), Kneževi Vinograd (KNE), Font Juvenal (FON), La Draga (LAD), Trasano (TRA), Arene Candide (ARE), Füzseabony-Gubakút (FUZ), Apc-Berekalja (APC), Polgár-Piócási-dűlő (PIO), Polgár-Ferenci-hát (FER), Ludwinowo (LUD), Mold (MOL), Těšetice-Kyjovice (TES), Dillingen-Steinheim (WIK), Herxheim (HEX) and Bischoffsheim (BIS). Map was produced using gmaps (Kahle and Wickham 2013), satellite base map from Google maps Imagery © Terrametrics.

Anatolia (Çakırlar 2012)) are contemporary with pre-pottery to middle Neolithic sites in Greece (6700–5700 cal BC). The caprine remains from Ulucak Höyük have recently been the focus of a multi-proxy biomolecular examination (Pilaar-Birch et al. 2018), in particular using collagen fingerprinting to identify sheep and goat from a sample of 15 mandibles (ZooMS).

Sites from the Balkans are representative of the initial inland spread of the Neolithic. These are attributed to the Starčevo-Körös-Criş (SKC) cultural complex (c.61/6000-55/5400 cal BC) and include the open-air settlements of BEL (Serbia, Gaastra *unpub.*), Blagotin (BLA, (Greenfield and Jongsma Greenfield 2014)), Seuša-Cararea Morii (SEU, Romania, (El Susi 2000)), Foeni-Salas (FOE, Romania, (Greenfield and Jongsma Greenfield 2014)). The early Neolithic open-air settlement of KNE (Gaastra (2016)) dates to c.6015-5846 cal BC represents a local early Neolithic cultural variant of Starčevo-Körös-Criş (SKC) cultural complex, which is currently not well understood.

Adriatic sites are the maritime cave site of SPI (Croatia, Gaastra *unpub.*) and open air site of TRA (Italy, Gillis 2012), and are associated with the *impresso/impressa* culture (c.6000-5500 cal BC). Franco-Iberian sites are represented by *cardial* sites (FON (France, Gillis 2012)); LAD (Spain, Gillis 2012); ARE (Italy, (Rowley-Conwy 1997)) which date from 6400 to 4800 BC cal. All the sites are open-air settlements apart from FON and ARE Candide, which are cave/rock shelters. Given the similarities in pottery styles between the *impresso/impressa* and *cardial* culture, these sites collectively are classed as the *impressa-cardial* ware complex (ICW).

Polgar 10 (POL) represents the Körös culture apart of the Starčevo-Körös-Criş (SKC) cultural complex in the Hungarian Plain (central European region) (Brighton, Dobney, and Chapman 2010). Also within this region are four sites that represented the Transdanubia (TLP; APC) and Alföld Linear Pottery (ALP; FUZ, PIO and FER) cultures. These date to the

**Table 1.** Details of species identified, culture, region, climate and site type for studied sites.

Site	Code	Ovis/ Capra	Culture	Region	Climate	Site type	Citation
Ulucak Höyük	ULUVI-IV	O	PPN/NA	Anatolia	Csa	open	Çakırlar 2012
Erbaba Höyük	ERB1-3	O/C	LNA	Anatolia	Csa	open	Arbuckle 2008
Belisce	BEL	O	SKC	Balkans	Dfb	open	Gaastra unpublished
Knezevi Vinograd	KNE	O/C	SKC	Balkans	Dfb	open	Gaastra unpublished
Foeni-Salas	FOE	O	SKC	Balkans	Dfa	open	Greenfield and Jongsma Greenfield 2014
Seusa-Cararea Morii	SEU	O	SKC	Balkans	Dfc	open	El Susi 2000
Blagotin	BLA	O	SKC	Balkans	Csb	open	Greenfield and Jongsma Greenfield 2014
Mold	MOL	O/C	LBK	Central	Dfb	open	Gillis unpublished
Těšetice-Kyjovice	TES	O	LBK	Central	Dfb	open	Gillis unpublished
Polgár 10	POL	O	SKC	Central	Dfb	open	Brighton, Dobney, and Chapman 2000
Polgár-Piócási-Dülő	PIO	O	LBK	Central	Dfb	open	Gillis unpublished
Apc-Berekalja	APC	O	LBK	Central	Dfb	open	Gillis unpublished
Polgár-Ferenci-Hát	FER	O/C	LBK	Central	Dfb	open	Gillis unpublished
Füzseabony-Gubakút	FUZ	O/C	LBK	Central	Dfb	open	Gillis unpublished
Ludwinowo	LUD	O/C	LBK	NW Plain	Dfb	open	Gillis unpublished
Bischoffsheim	BIS	O/C	LBK	NW Plain	Cfb	open	Gillis submitted
Rosheim	ROS	O/C	LBK	NW Plain	Cfb	open	Gillis unpublished
Herxheim	HEX	O/C	LBK	NW Plain	Cfb	open	Gillis in press
Dillingen-Steinheim	WIK	O/C	LBK	NW Plain	Cfb	open	Gillis unpublished
Font Juvenal	FON	O/C	ICW	Franco-Iberian	Cfb	cave/rockshelter	Gillis 2012
Arene Candide	ARE	O	ICW	Franco-Iberian	Csa	cave/rockshelter	Rowley-Conwy 1997
La Draga	LAD	O/C	ICW	Franco-Iberian	Cfb	open	Gillis 2012
Spila Nakovana	SPI	O	ICW	Adriatic	Dfb	cave/rockshelter	Gaastra unpublished
Trasano	TRA	O/C	ICW	Adriatic	Csa	open	Gillis 2012

Hungarian middle Neolithic (5600–4600 cal. BC) and follow the Starčevo (Transdanubia) and the Körös (Hungarian Plain) cultures. The TLP is believed to be the progenitor of the Linearbandkeramik cultural phenomenon while the ALP lies east of the Danube and differs in style although it has many similarities with TLP/LBK phenomenon (Whittle et al. 2013). Previous analysis of cattle from these sites together with remains from LBK sites have shown there is little difference in terms of husbandry practices (Gillis et al. 2017). Therefore we have amalgamated the data from these sites with those from LBK sites in central and north western European regions. If there is a difference between management strategies of these cultural groups then it will be apparent in the correspondence analysis.

Other sites from the central region of Europe are MOL (Austria, *Gillis unpub.*), TES (Bohemia, *Gillis unpub.*) and date to the LBK culture (5500–4900 BC). Other LBK sites are located within the NW European plain region. These are LUD (Poland, *Gillis unpub.*), WIK (Germany, *Gillis unpub.*), HEX (Germany, *Gillis unpub.*) and BIS (France, *Gillis unpub.*) and they all date from 5500 to 4900 cal. BC.

Climate reference codes were given to each site based on the revised Köppen's classification (Peel, Finlayson, and McMahon 2007) for their location. These zones are one of five climate types: Temperate without dry season and hot summer (Cfa) and warm summer (Cfb); Temperate dry summer with hot summer (Csa) and warm summer (Csb); Cold without dry summer with warm summer (Dfb). As several climatic oscillations have been recorded during the Early Neolithic time periods under consideration in this study (e.g. Fiorentino et al. (2013); Feeser et al. (2016)), these reference codes are incorporated only as an

approximate representation for the climatic zones of sites used in this study.

### Statistical Methodology

Common methods to compare mortality data, such as, Chi<sup>2</sup> (Helmer et al. 2005) and Mann–Whitney U-test (Greenfield and Arnold 2015), do not adequately assess the high level of sampling uncertainty in age-at-death data due to numerous factors, such as differential preservation and recovery, and particularly small sample sizes associated with early Neolithic assemblages. Correspondence analysis (CA) has been used as an alternative to these methods by several researchers (e.g. Gillis et al. 2017; Helmer, Gourichon, and Vila 2007). CA is a descriptive statistical analysis that can be used to visualise data and elucidate the 'correspondence' between datasets to generate hypotheses rather than testing the data using statistical inferences. This analysis produces data that plots two clouds of data; rows (number of teeth within 7 age classes for site) and columns (7 age classes) (Benzécri 1973). Thus it can, on the one hand, clearly illustrate the age classes that are the most common within a dataset, and on the other, elucidate relationships between sites and their association with particularly age classes.

Gerbault et al. (2016) proposed to use Dirichlet distribution to account for the sampling uncertainties within each age class for a given age-at-death profile. This distribution is the conjugate prior of a multinomial distribution within a Bayesian framework analysis. In this case, the Dirichlet distribution, with an appropriate prior (here Jeffrey's prior of 0.5), is used to generate random deviates of the population relative frequencies based on a given age-at-death profile (number of simulations here is 5000). This is carried

out using the 'rdirichlet' function from the R package LaplacesDemon (V16.0.1, (Statisticat 2016)). Each Dirichlet deviate is then multiplied by the sample total observed in the original age-at-death profile in order to obtain a comparable simulated dataset. These deviates can be analysed using CA, creating data point clouds around the original data point thus providing an indication of the potential distribution of the sample from each site. Therefore where a data cloud is widely dispersed may suggest issues within the sample, such as small sample size, and where the data cloud is small may suggest that the original age-at-death profile is a true reflection of mortality at that site.

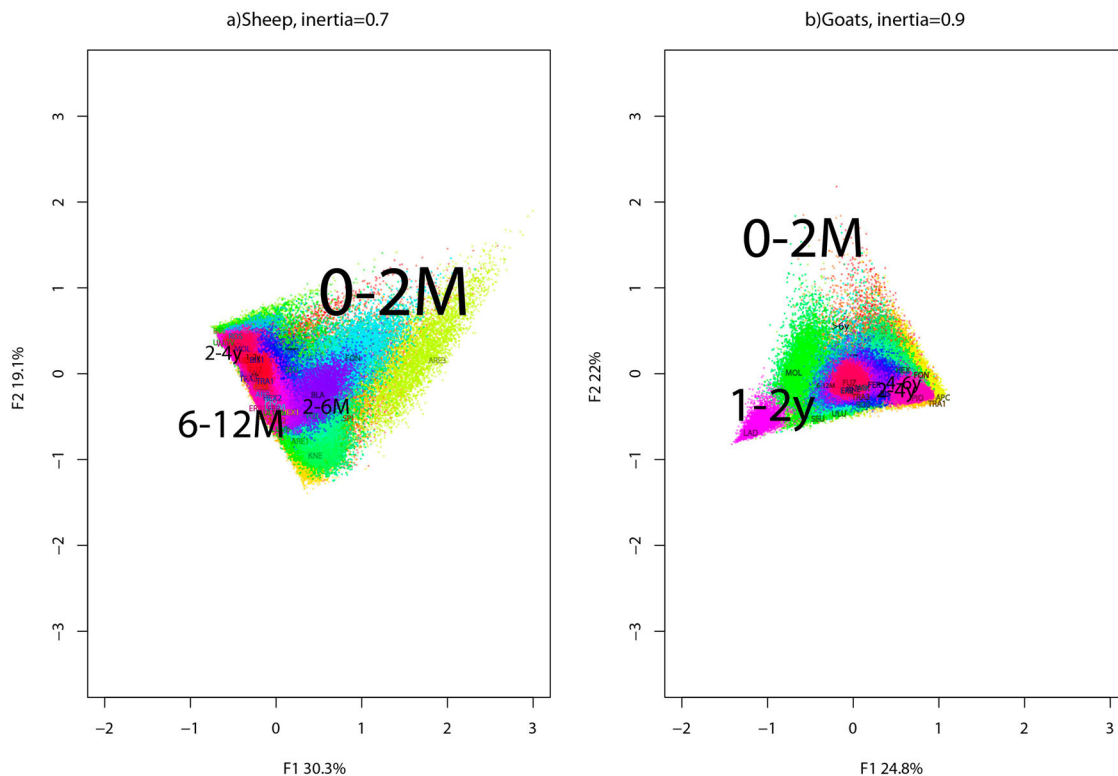
The CA coordinates represent the distances between rows and columns respectively. To test trends visualised within the CA biplots, we used several non-parametric statistical tests, such as Mann–Whitney and ANOSIM, on the mean value of CA F1 and F2 coordinates (including deviates) respectively generated for each site using culture, climate, site type and region as grouping factors. The ANOSIM (analysis of similarities) is a non-parametric test used in ecology (vegan R package (Oksanen et al. 2017)). Although similar to the ANOVA-like dissimilarities test, ANOSIM uses a ranked dissimilarity matrix. The test statistic  $R$  varies within the range  $[-1, 1]$  when  $R$  is close to 1 suggests dissimilarity between groups, whereas when  $R$  is close to zero suggests even distribution of high and low ranks within and between groups and

when it is below zero, it suggests dissimilarity is greater within groups than between groups. All analyses and biplots were produced using the free platform R programme (V3.03.3; R Team 2017) using R studio (R Studio Team 2016). The R packages used were: ggplot2 (V1, (Wickham 2009)), ca (Nenadic and Greenacre 2007), LaplacesDemon (V16.0.1, (Statisticat 2016)) and MASS (V7.3-37, (Venables and Ripley 2002)).

## Results

We carried out 5000 simulations for each site sheep/goat profile following the Gerbault et al. (2016) methodology for caprines. Correspondence analysis (CA) was then carried out on for the sheep and goat datasets. The age class 0–2M dominates both CA plots due to the low representation in this age class, which has been seen in other CA analysis of caprines (Helmer, Gouri-chon, and Vila 2007).

For sheep (Figure 2a), the CA had a global inertia of 0.71 with the F1 and F2 axis explaining 30% and 21.9% respectively of the total variation. Overall the CA analysis for sheep is explained by the opposition on the F1 axis between age classes 6–12 months and 2–4 years (-ve coordinates) and 2–6 months (+ve coordinates) as well as the opposition between age classes 6–12 months (-ve coordinates) and 2–4 years (+ve coordinates) on the F2 axis. Sites associated with SKC and ICW cultures are located between 6–12 months and 2–4 months with several ICW cave sites more



**Figure 2.** (a) Sheep correspondence analysis biplots; (b) Goat correspondence analysis biplots, with 5000 Dirichlet simulations for each site. The colour of points refers to individual sites and the site code are labelled with the corresponding colour. The size of the age class lettering reflects the contribution of each age class to the axes.



closely associated with age class 2–4 months (ARE, FON). In comparison LBK sites (MOL, WIK, BIS1/3, HEX, LUD and ROS) are more closely associated with adult age classes. There are exceptions; for example, Trasano (TRA) and La Draga (LAD), both ICW sites are more closely associated with age classes 2–4 and 4–6 years. Furthermore, Anatolian (ERB and ULU) sites and those from central Europe (TES, PIO, FER and APC) lie between 6–12 months and 4–6 years.

The global inertia for the goats CA (Figure 2b) was 0.91 where F1 and F2 explained 24.9 and 21.9% of the variation respectively. The CA goat biplot was structured on the F1 axis between age classes 1–2yrs (-ve coordinates) versus 2–4 yrs and 4–6yrs (+ve coordinates). There are some indication of differences between sites of the same region or similar regions, such as the opposition between LAD and FON, with the latter site situated close to age class 2–4/4–6 years. This can also be seen between FUZ, PIO and APC where the first site is associated with age class 6–12 months while the remaining two are more closely associated with 2–4/4–6 year. Other LBK sites from central and north-western plain regions, such as WIK, BIS, HEX1 and MOL are located between age classes 6–12 months and 2–4/4–6 years.

We calculated the mean F1 and F2 coordinates for sheep and goat from each site (Figure 3a–g, using F1 coordinates). We used these to produce boxplots using the four grouping factors (culture, climate, site type and region). For sheep, we found a significant difference between site attributed to SKC and LBK (Mann–Whitney  $p = 0.01$ ) and site types (Mann–Whitney  $p > 0.05$ ). We can observe that sites with ICW phases have a similar distribution to SKC sites. This appears to be reflected in F1 mean coordinates grouped by regions, where sites from the Balkans and Franco-Iberian peninsula have more negative coordinates than other regions. For goats, there is little difference between coordinates for cultural phases, regions, climate type or even site types.

To further examine similarities and differences between groups, we carried out an analysis of similarity (ANOSIM, permutations = 999) on the mean CA F1 and F2 coordinates using culture, climate, site type and region as grouping factors (Table 2). For goats, no significance was found for any of the categories nor was there any correlation between coordinates and longitude and latitude. For sheep, the ANOSIM was significant for culture, site type and region. The R statistic is low but suggests that there is dissimilarity between variables within each of the grouping factors: culture, site type and region.

Overall, the results suggest that sheep management strategies differed between cultural groups within specific regions, i.e. stockherders of the SKC sites within the Balkans managed their sheep differently to LBK ones from central Europe and NW plain. This is

suggested by the tendency of SKC sites towards -ve F1 coordinates (Figure 3a). These coordinates are associated with younger age classes (0–2 months, 2–6 months). However, there is a wide distribution of CA F1 mean coordinates for ICW sites (Figure 3a), which is also seen within the Franco–Iberian region. This suggests that within this cultural group, particularly within the Franco–Iberian region, that sheep management strategies were diverse and stockherders adapted sites in relation to specific practices. Cave sites within this dataset have a tendency towards negative coordinates, suggesting that they were used as seasonal camps for birthing stations or dairies within a short-ranged pastoral system (Vigne and Helmer 1999).

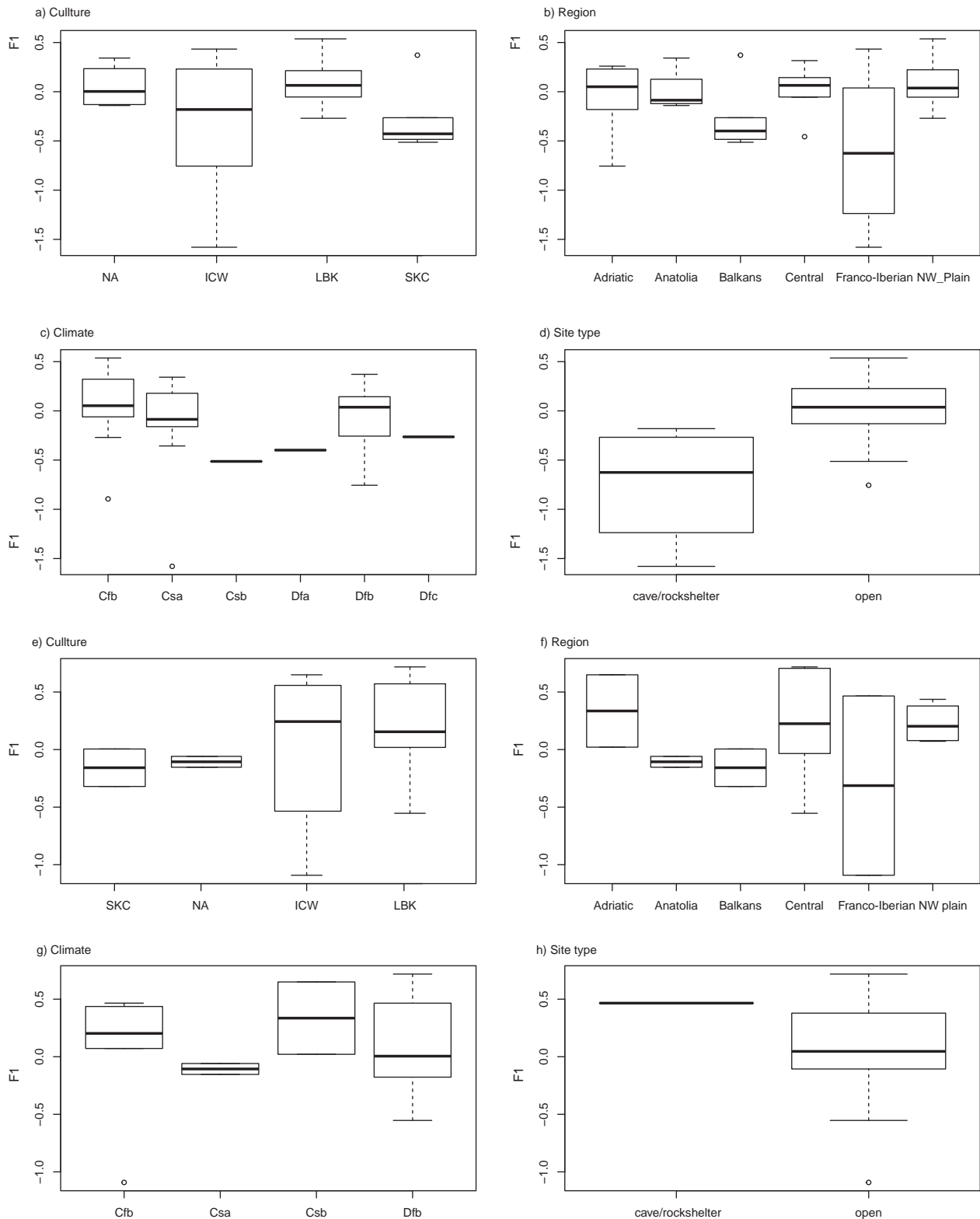
## Discussion

Sheep and goats are often herded together but have different productive capacities, such as milk quantity and quality, as well as physiological differences. These are and have been exploited by pastoralists and stock herders around the world. However, it is not clear whether these differences were recognised and utilised by stockherders at the beginning of the Neolithic. Ethnological observations, particularly of sheep for the Middle East and Anatolia, have been used to develop a framework to interpret/model age-at-death mortality profiles (Payne 1973; Redding 1981; Halstead 1998; Vigne and Helmer 2007). Here we were considering the effect of species identification and age-at-death methodologies on sheep and goat mortality analysis. We discuss the results in light of these potential biases and use ethnographic studies of European sheep and goats as a framework to interpret early Neolithic husbandry practices.

## Methodological Issues

We previously highlighted that the use of age-at-death methodology based on sheep could skew age-at-death determination. Comparison between species specific age determination methodologies has shown there is a slight differences between sheep and goats dental eruption (Gillis 2012). The molars on average erupt 1–2 months later in goats than in sheep whereas the deciduous premolars erupted later in sheep. There may also be differences between sexes in terms of eruption and wear stages with males having increased dental wear (Deniz and Payne 1982; Mellado et al. 2007). These differences in eruption and wear stages can have an impact on mortality analysis. For example, age class 6–12 months, 1–2 years and 2–4 years was defined by the eruption of M1, M2 and M3 respectively in sheep. Using this methodology – given that goat molars on average erupt later – would produce incorrect age estimates. Further studies are needed on





**Figure 3.** Boxplots for F1 sheep and goat F1 coordinates: (a) Sheep F1~ Region; (b) Sheep F1~Culture; (c) Sheep F1~ Site type; (d) Sheep F1~Climate; (e) Goat F1~ Region; (f) Goat F1~Culture; (g) Goat F1~ Site type; (h) Goat F1~Climate.

**Table 2.** The results of the ANOSIM (R statistic/ probability) test on the mean CA F1 and F2 coordinates for sheep and goats from each site using cultural group, climate, site type and region as grouping factors.

	Culture	Climate	Site type	Region
Goat F1	-0.04/0.6	-0.07/0.7	-0.05/0.4	0.02/0.4
Goat F2	-0.02/0.5	-0.07/0.7	0.4/0.1	0.02/0.4
Sheep F1	0.2/0.005*	2.9e-5/0.4	0.4/0.008*	0.14/0.03*
Sheep F2	0.06/0.2	0.2/0.3	0.02/0.3	0.07/0.1

\*indicates statistical significance.

large cohorts of goats to extend and establish goat specific age determination methodologies.

Other factors, such as human error and age of specimen, can also affect species identification. Confidence and rate of attribution to species can differ between archaeozoologists, between samples and within samples. This and the effect of age on the visibility of different criteria can lead to misidentified sheep as

goat and vice versa (Orton pers. comm.). In addition, sheep and goats from different geographical regions may have slightly different morphological characteristics. Although, this has not been the subject to scientific study, it is a common dissuasive point amongst archaeozoologists. Consequently, future studies are needed to assess whether there are differences in morphological characteristics between regions (i.e. Middle East versus Europe), and its impact on species identification as well as the effect on age on criteria and determinations. This could be done in conjunction with biomolecular approaches to determine sheep and goat where research funds are sufficient for analytical costs (Pilaar-Birch et al. 2018; Prendergast et al. 2018).

### Sheep

Our results suggest that there were differences in slaughter practices between cultural groups and regions. In general, the southern Europe and north-western Mediterranean SKC and ICW sites are associated with age classes 6–12 months and to a lesser extent 2–6 months in comparison to LBK sites where sites are more closely associated with adult age classes.

Infant animals are a rich source of fat as well as meat, however, the age of slaughter is dependent on husbandry practices (i.e. slaughter of young to increase dairy production), the needs of the society and their culinary tastes. The cheese and yoghurt from sheep and goat milk is particularly economically important for modern Mediterranean and Balkan countries where 55% of the world's sheep milk is currently produced (Boyazoglu and Morand-Fehr 2001). Ethnographic examples have shown that lambs and kids can be removed without affecting the flow of milk (Halstead 1998) however sheep do require lambs to stimulate milk ejection from the aveoli to the cistern at the beginning of the lactation period (Balasse 2003). If sheep milk is being exploited, the weaning age varies between 2–6 months and is dependent on the intensity of the production and whether milk or lamb meat is the focus of the operation (Hadjikoumis 2017). The traditional Mediterranean management, where sheep milk is highly prized, the lambs are separated and weaned at early so that full milking can take place for five months (Halstead 1998; Hadjikoumis 2017).

Previous multi-proxy analysis of organic residues from ceramics and mortality data analysis has demonstrated that milking was practised from the beginning of the Neolithic in the north-western Mediterranean (Debono Spiteri et al. 2016). Furthermore, cave sites may have played an important role in milk production and were used as a part of a pastoral systems where animals were brought to cave sites for surrounding pasture resources and temporary birthing stations. Transhumant practices have long been a tradition in the Balkans and Greece. For example, the Vlach

communities, who ranged from Greece to former Czechoslovakia and built special housing on summer pastures for milking ewes and processing milk (Ryder 1999). Previous analysis of caprines from cave and open sites in Southern France has shown that sites were used complementary with cave sites acting as seasonal birthing stations (Bréhard, Beeching, and Vigne 2010; Helmer and Vigne 2004; Vigne and Helmer 1999).

If we accept that the slaughter focused of animals aged 2–6 months is associated with dairying and slaughter of older lambs (6–12 months) is the result of a staggered slaughter throughout the year to provide meat (Helmer, Gourichon, and Vila 2007; Vigne, Carrière, and Guilaine 2017; Hadjikoumis 2017; Halstead 1998). Then our results from sites in the Balkans and Mediterranean seaboard would suggest that sheep were used for dairying as well as for meat in these regions, which would correlate with previous analysis by Debono Spiteri et al. (2016). We do not suggest large-scale sheep milking that is seen at present, as it is labour intensive and for good milk returns the evolution of specialised breeds is required. However, as sheep's milk is very rich in fat and excellent for cheese making it is not unreasonable to postulate that early Neolithic farmers exploited this resource seasonally on a small scale within a mixed pastoral economy. In comparison, stockherders of the LBK appear to have slaughtered animals as young adults and adults supporting previous analysis that has shown cattle as the primary dairy animal (Gillis et al. 2017) and sheep were only used as a source of meat as suggested by Marciniak (2013). This could also explain why Trasano and La Draga are also associated with adult age classes as at these sites cattle appear to have been the primary dairy animal (Gillis et al. 2016).

### Goats

Previous ethnographic studies of Near Eastern societies have shown that goats are generally managed for household production (Redding 1981). Vigne and Helmer (1999) pointed out that goats were much more frequently used for milk in the early Neolithic of the Mediterranean area than sheep, and explained this difference by the fact that it is easier to milk goats than sheep. Greenfield and Arnold (2015) have also suggested that goats were managed for milk from the beginning of the Neolithic in the Balkans. Female goats, does can be easily milked without need of the presence of their infants and their milk is more digestible than cow's milk (Haenlein 2007, 2004). Does have long productive lives as well as long lactation period (198–285 days, (Gillis 2012)). Consequently, adult age classes particularly those greater than 4 years could support a dairy hypothesis. Young slaughter (0–6 months) could also be a reflection of dairying

with infants being removed early in the lactation period to increase milk for human consumption. However, in a recent ethnographic study of Cypriot herders, kids were reported to be slaughtered later than lambs due to the faster growth rate of lambs and the richer milk of ewes (Hadjikoumis 2017). Furthermore, bucks were commonly slaughtered around two years old in comparison to rams as it was herders believed that younger bucks produced bigger kids and had greater fertility success. Therefore a typical goat mortality profile may have peaks for kid slaughter in age class 2–6 months, bucks in age classes between 1–3 years and does in age classes >4 years.

The interpretation of the results is hampered by the sample sizes, as well as other methodological issues. Two of the sites, Polgár-Piócási-Dúló (PIO) and Füzeseabony (FUZ) have large sample sizes (>50) and if omitted the mean sample size is 16.5, which makes it difficult to discern specific management strategies for all sites. However, for PIO, FUZ and La Draga (LAD), it is possible to distinguish different management strategies. LAD plots close to age class 1–2 years while FUZ lies between age classes 6–12 months and 2–4/4–6 years while PIO is associated with the latter classes. Therefore we propose that at FUZ mixed strategies of both meat and milk were probably practised, whereas at PIO goats may have been used primarily for milk. While the goat profiles at LAD may have been dominated with male goats, possibly suggesting goats were slaughtered for meat. The lack of significance between region, climate and culture may be the result of low sample sizes, which is probably a direct reflection of small goats herds.

## Conclusions

Sheep and goats are similar osteologically but are currently exploited differently as a result of their individual productive capacities and environmental tolerances. The results from the analysis of species specific mortality data from early Neolithic contexts here suggest that sheep were managed differently between regions and cultural groups. In southern European contexts primarily young animals were slaughtered, which may reflect dairy husbandry as well as a cultural preference for young tender meat. In northern regions, sheep and goat are used as a source of meat rather than milk. This change in management strategies may be related to cultural preferences and practices as well as the geography and hydrology of the region being ideal for cattle. For goats overall, due to small samples it was not clear whether they were managed for specific purposes, such as milk production, nor whether there were regional/cultural differences. This may be related to the fact that only small numbers of goats were kept.

To further investigate the evolution and development of sheep and goat husbandry, future analysis is required to further increase the number of species specific mortality datasets and extend this study to other periods of the Neolithic. Here we have taken a large corpus of species specific data from several regions unlike previous analyses, which have focused on one region or site (Greenfield and Arnold 2015). There are a number of methodological issues that need to be resolved, such as species specific age-at-death determination methods, as well as the security of the correct identifications, and whether the age distribution can have an impact on these determinations. However, as an initial examination it offers a tantalising glimpse into early goat and sheep husbandry practices and how the first farmers of Europe adapted these domesticates to new environments and moulded husbandry practices in response to cultural tastes and preferences.

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