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ORIGINAL PAPER

Was the English medieval goat genuinely rare? A new morphometric approach provides the answer

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Abstract

There are important gaps in the historical and archaeological evidence that have, so far, precluded us from reliably assessing the role of the goat in the English Middle Ages. This, in part, is the direct consequence of the absence of a methodology allowing the confident identification of sheep and goat bones. On the other hand, the fact that the goat has always been perceived as rare has led us to think that medieval goats did not deserve much attention. Thanks to a recently developed new morphometric approach, which allows taxonomic identifications to be based on more objective criteria and results to be scrutinised, we are provided with a new tool to re-assess the role that this species played in English medieval husbandry. This paper presents the results of the application of this new methodology on three archaeological medieval sheep/goat assemblages. Previous research suggested that the goat was not abundant in medieval England, but has also raised the possibility that this may be a consequence of an under-estimation by zooarchaeologists, due to identification difficulties. The basic outcome of our paper is to provide, for the first time, unambiguous evidence that the goat was genuinely uncommon. In the medieval archaeological record, sheep remains are overwhelmingly better represented than goat remains—all three case studies confirmed the pattern. Although these examples cannot be taken to represent the situation everywhere in the country, they provide clear-cut indication that the zoorchaeological interpretation of caprine remains from English medieval sites has so far been largely reliable. The three sites offer the opportunity to investigate different dimensions of the problem and to discuss the role of the goat in different contexts.

Keywords England · Medieval · Post-medieval · Goat · Sheep · Zooarchaeology · Morphometry

Introduction

The goat has largely been neglected in British archaeology. This is partially due to the fact that this species appears to have been rare throughout the British history: finds of goat bones have always been numerically scanty compared to those of other main food domesticates (cattle, sheep and pig), and this situation has led us to think that this species did not deserve much attention. On the other hand, the methodological problems which affect our ability to distinguish between the bones of goat (*Capra hircus*) and sheep (*Ovis aries*) have also contributed to this attitude.[1]

With the availability of new data coming from recent urban archaeological investigations and the completion of some comprehensive reviews of the zooarchaeological records for medieval England (Albarella 2019; Holmes 2018; Stallibrass 1995)—which can be integrated with the written resources available for the period—a more comprehensive account of the English medieval goat has emerged.

The impression that one gains from the written sources for the Middle Ages is that the goat was mainly valued as a milk producer. As Fitzherbert (1534, p. 20) writes in his *Book of Husbandry*, "In the British Islands… it is chiefly

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[1] For recent studies that provide genetic estimates for when the sheep lineage separated from the goat lineage, see Randi et al. (1991) and Bibi (2013).

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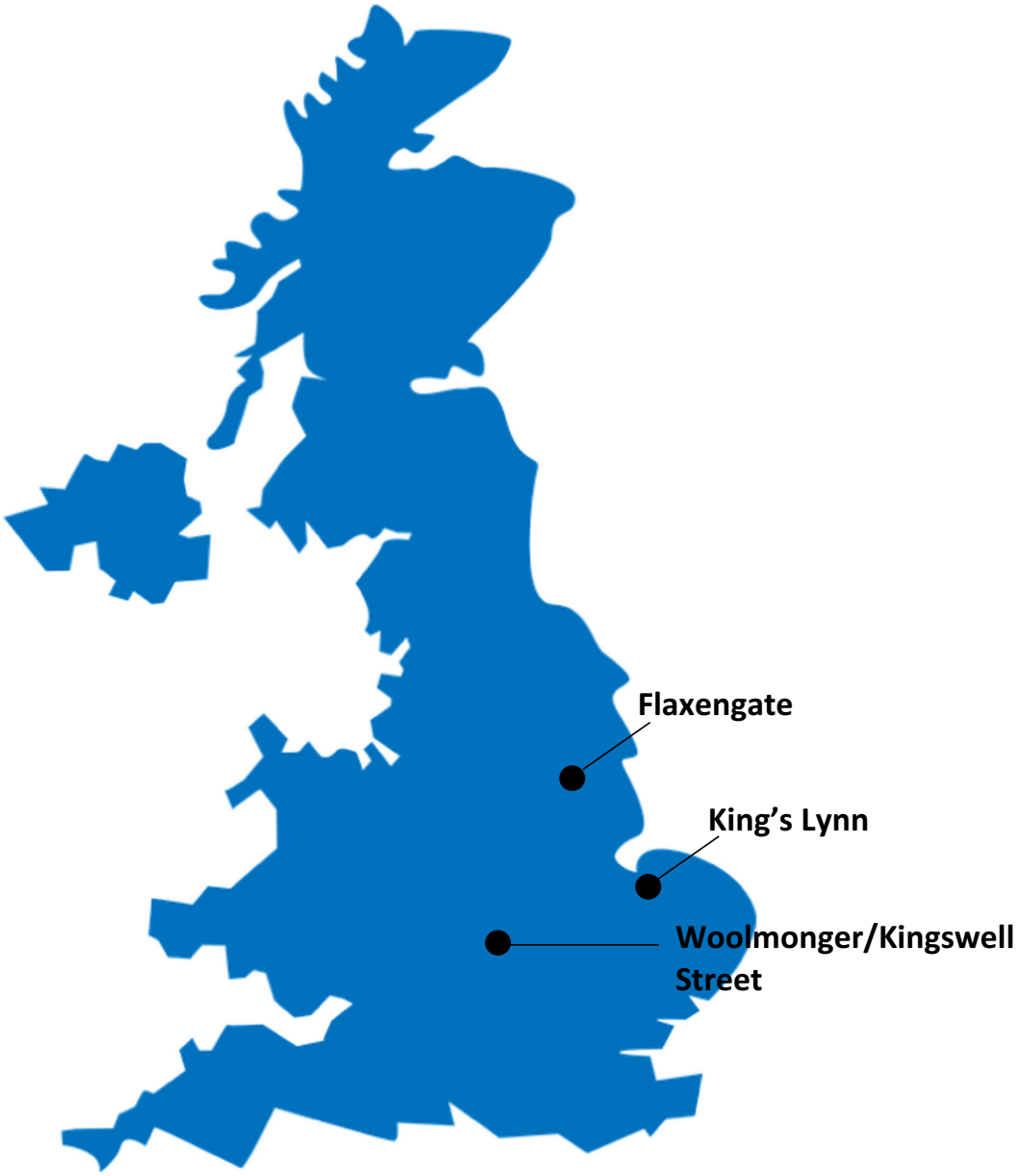

Fig. 1 Map showing the location of the archaeological sites selected for this study (from pixabay.com)

for the supply of the domestic dairy that the goat can be regarded as of economic value". Clearly, goat dairy products and, to a lesser extent, meat must have represented a useful additional contribution to the family economy; milk, cheese and butter surplus, along with (occasional) kids, would have been sold at the market. The meat of older goats was more likely to be consumed by the lower echelons of society, while kid meat was consumed by the wealthy, as evidenced by the accounts of several monasteries and noble households (Dyer 2004, 2006; Noddle 1994; Wilson 1973) as well as the archaeological evidence (Albarella and Davis 1996; Sykes 2006; Thomas 2005).

The Domesday Book, completed in 1086 (Darby 1977), contains details about the numbers of goats present in some English counties (Cambridgeshire, Cornwall, Devon, Dorset, Essex, Norfolk, Somerset and Suffolk). The impression gained is that goats, though far less common than sheep, were present in fairly high numbers (Albarella 1999; Dyer 1991, 2004; Hallam 1988). After the eleventh century, a drop in goat numbers is attested by manorial accounts and archival documents: goats become so scarcely mentioned that this species seems to have become almost completely absent (Dyer 2004; Woolgar 2006). Nevertheless, this situation does not

Table 1 NISP (number of identified specimens) for each of the three analysed sites

Anatomical element	King's Lynn (KL)			Flaxengate (FL)			Woolmonger/Kingswell Street (WKS)		
	Sheep (*Ovis aries*)	Goat (*Capra hircus*)	Sheep/goat (*Ovis/Capra*)	Sheep (*Ovis aries*)	Goat (*Capra hircus*)	Sheep/goat (*Ovis/Capra*)	Sheep (*Ovis aries*)	Goat (*Capra hircus*)	Sheep/goat (*Ovis/Capra*)
Horncore	30	72	–	31	3	–	32	6	–
Jaw	117	–	40	95	–	36	68	–	36
Teeth	15	–	3	29	–	28	61	–	36
Scapula	76	2	12	49	–	21	27	–	16
Humerus	107	1	8	111	–	6	76	–	4
Radius	99	1	–	89	–	2	48	1	1
Ulna	55	–	5	31	–	4	25	–	2
Tibia	132	–	7	116	–	30	93	1	16
Metacarpal	42	–	1	44	–	3	47	–	–
Metatarsal	46	–	–	53	–	3	43	2	1
Metapodials	–	–	1	10	–	2	8	–	–
Astragalus	37	–	–	49	–	2	9	–	–
Calcaneum	41	–	–	36	–	3	26	–	2
Phalanx 1	44	1	2	90	–	9	127	4	10
Phalanx 2	4	–	3	14	–	–	23	–	–
Phalanx 3	–	–	–	3	–	–	7	–	–
Total identified specimens	845	77	82	850	3	149	720	14	124
Sheep:goat ratio Horncores included	11:1			283:1			51:1		
Sheep:goat ratio Horncores excluded	163:1			819:0			86:1		

reflect the complete reality, and in the western and northern regions of England, the goat continues to be present, though possibly in small numbers (Berkeley Castle accounts 1346 AD; Alkington accounts 1311–12 AD). From the written records, it is clear that in the late Middle Ages, goats were uncommon and were mainly confined to specific localities, to the west and north of the country (Dyer 2004).

The zooarchaeological records seem to agree—to a certain extent—with the written resources. Despite medieval archaeological sites in which goat bones have been found are scattered over many parts of the country, the number of remains belonging to goat is always extremely low compared to other domestic animals, and it is particularly low when compared to the most commonly found sheep bones. Whenever sheep and goat are mentioned in the same report, sheep is almost invariably and overwhelmingly the most common species (Albarella and Davis 1996). In addition, in continuity with the Roman period, goat remains in the Saxon period (fifth to eleventh centuries AD) appear to be more common in urban than rural sites (Albarella 2019). This is mainly due to accumulations of goat horncores in towns, which have been interpreted as the result of industrial activities, probably reflecting an interest in horn-working. In the later Middle Ages (eleventh to fifteenth centuries), the number of goat remains decreases further (Albarella 1997, 2003; Dyer 1991). Consistently with what was observed in previous periods, goat horncore deposits have mainly been found at urban sites located on the East Coast. Specific assemblages indicating the use of goat skins and horns are scantier in the southern and northern regions of England, where deposits of cattle horncores are more frequently reported (Holmes 2018; Stallibrass 1995).

Since horncores bear very clear morphological traits, allowing sheep and goat to be easily distinguished, the possibility needs to be considered that identification bias

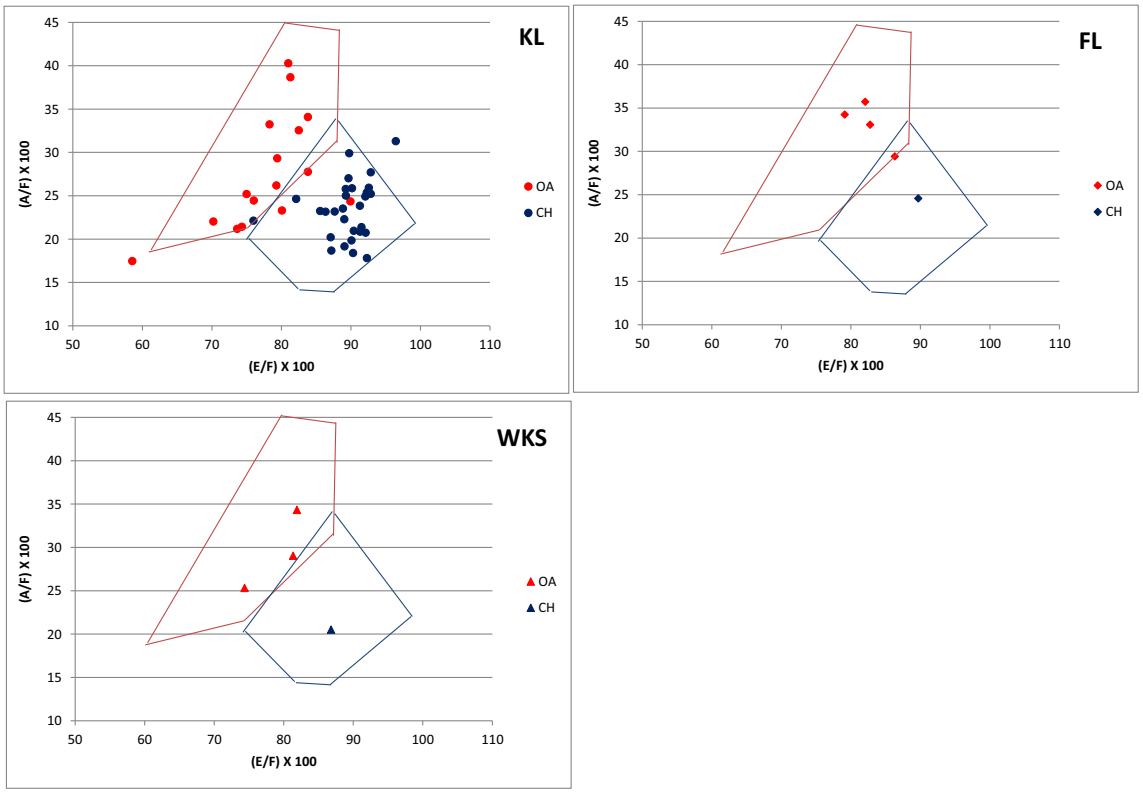

Fig. 2 Horncore: ratio between the length (E) and length of the outer curvature (F) plotted against the ratio between the maximum diameter taken at the base (A) and length of the outer curvature of the horncore (F). OA = *Ovis aries* (sheep); CH = *Capra hircus* (goat); OC = *Ovis*/*Capra* (sheep/goat); KL = King's Lynn; FL = Flaxengate; WKS = Woolmonger/Kingswell Street. The blue line defines the area of the graph where the horncores of the modern goat specimens fall. The red line defines the area of the graph where the horncores of the modern sheep specimens fall

may have caused an over-representation of these elements. However, this bias would not explain why other fairly easily identifiable anatomical elements, such as metapodials, are almost completely absent from the English medieval archaeological record (Albarella 2003). In the post-Saxon period, the tanning industry had become predominant and the horn trade declined (Albarella 2003), which means that goats were more likely used for their skins than horns. According to Prummel (1978, 1982) and Schmid (1969), when the skins were prepared for further treatments, which eventually led to the final transformation of skin into leather, foot bones were retained. This raises the question of why these goat elements are usually missing from the archaeological record in England. The absence/under-representation of goat post-cranial bones points towards the hypothesis of a trade in goat skins with southern Europe, where this species was more abundant (Albarella 1999, 2003; Noddle 1994). With this in mind, the body part distribution anomaly reinforces the theory of long-distance trade, for which it would have been useful to eliminate as much weight as possible in order for the goods to be more easily stored and traded. It follows that the parts of the skin most suitable to be discarded were indeed the foot bones, which were not considered as valuable a source of working material as the horncores (Albarella 2003; Noddle 1994). A similar situation has been identified in other countries (Albarella 1999; Noddle 1994), such as the Netherlands (Prummel 1982), Germany (Anschutz 1966; Kühnhold 1971; Reichstein and Tiessen 1974; Schatz 1963) and Norway (Lie 1988).

The situation discussed above in relation to urban industrial sites cannot be applied to rural sites (or to urban sites outside industrialised areas), for which no evidence of goat horncore accumulations exists. Goat remains have been recorded at a few rural sites such as the twelfth- to early thirteenth-century Boteler's Castle, Oversley, Warwickshire (Pinter-Bellows 1997) and the twelfth-century site of Walton, Aylesbury, Buckinghamshire (Noddle 1976). At both, a small number of goat bones were unearthed and concentrations of goat horncores were not found, suggesting that goat was only occasionally used and was husbanded rather than used in industrial activities. Unfortunately, the western and more rural areas of the country remain, to this day, insufficiently

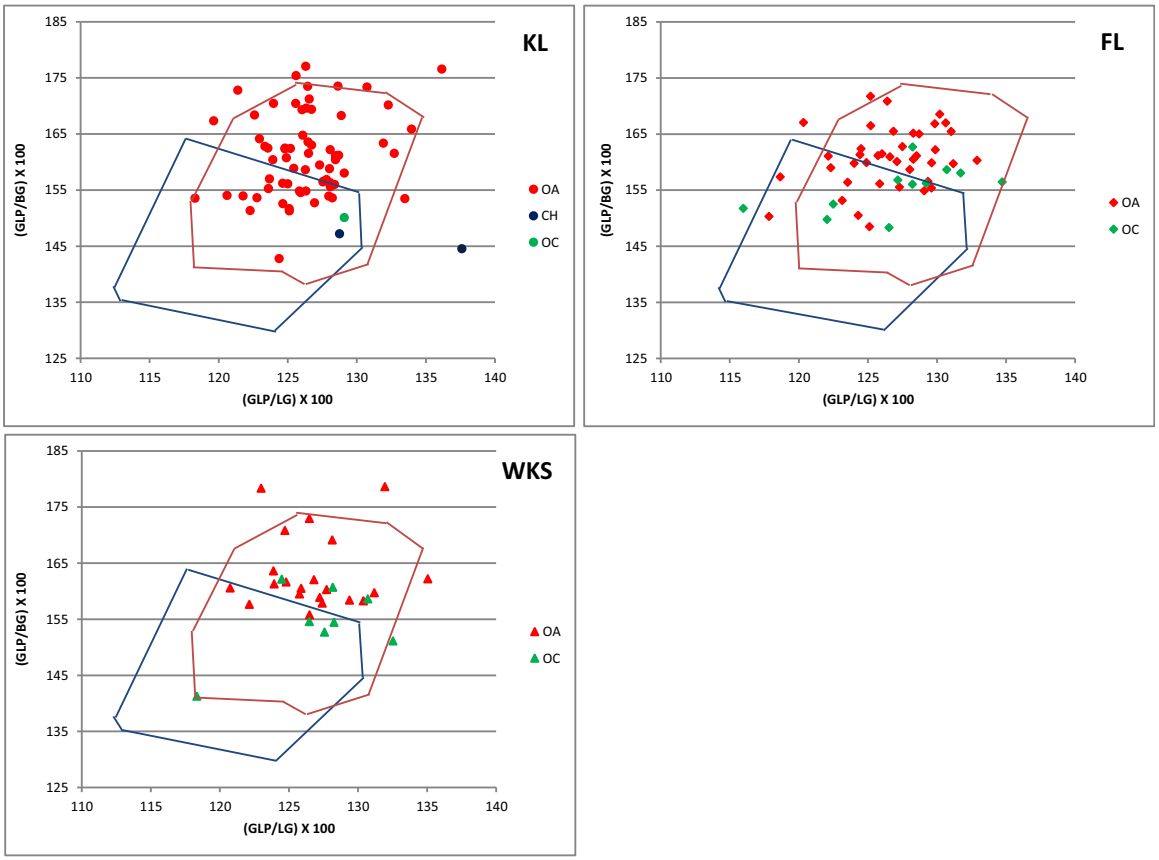

Fig. 3 Scapula: ratio between the greatest length of the *processus articularis* (GLP) and the length of the glenoid cavity (LG) plotted against the ratio between the greatest length of the *processus articularis* (GLP) and the breadth of the glenoid cavity (BG). Symbols and lines as explained in Fig. 2

documented (Albarella 2019) preventing us from undertaking an in-depth study of regional patterns.

Through an exploration of the zooarchaeological literature, a further problem arises. Due to the perceived rarity of the goat and the well-known difficulty of distinguishing between sheep and goat bones, an attempt to separate these two taxa has not always been made by zooarchaeologists. In the cases in which discrimination is carried out, the numbers related to the goat are so low that raw data are often omitted and further information excluded from the report. In many cases, attempts to differentiate have not been carried out at all, so that the two taxa appear combined in the joint category of 'sheep/goat'. Sometimes, zooarchaeologists take for granted the absence of the goat and all remains are attributed to sheep. Such an attitude limits the possibility of accurately assessing the presence of the goat and to quantify the relative proportions of sheep and goat.

To sum up, there are still important gaps in the historical and archaeological evidence that preclude us from reliably assessing the role of the goat in the English Middle Ages. These gaps are in part a consequence of the absence of a transparent methodology, which allows to scrutinise the reliability of the identification of sheep and goat bones. Morphological criteria have existed in the literature for several decades (e.g. Boessneck 1969; Cornevin and Lesbre 1891; Hildebrand 1955; Kratochvíl 1969), but they tend to rely on the skill, experience and attitude of the analyst and are, therefore, rather subjective. Thanks to a recently developed new methodology (Salvagno and Albarella 2017)—which combines biometrical and morphological approaches—a step towards solving the sheep and goat identification issue has been made. Such methodology, which is based on measurements, thus allowing taxonomic identifications to be based on more objective criteria, represents the ideal tool to use in order to start a re-assessment of the role of the goat in English medieval husbandry.

Given these premises, this paper intends to:

1. Test the extent to which the new methodology, designed on modern comparative material (Salvagno and Albarella 2017), can be effectively applied to archaeological material.
2. Present the results from the study of three sheep and goat medieval assemblages. These assemblages have the potential to:

   (a) Clarify if the scarcity of goat remains is due to an under-estimation of this species by zooarchaeologists, or is, indeed, genuine.

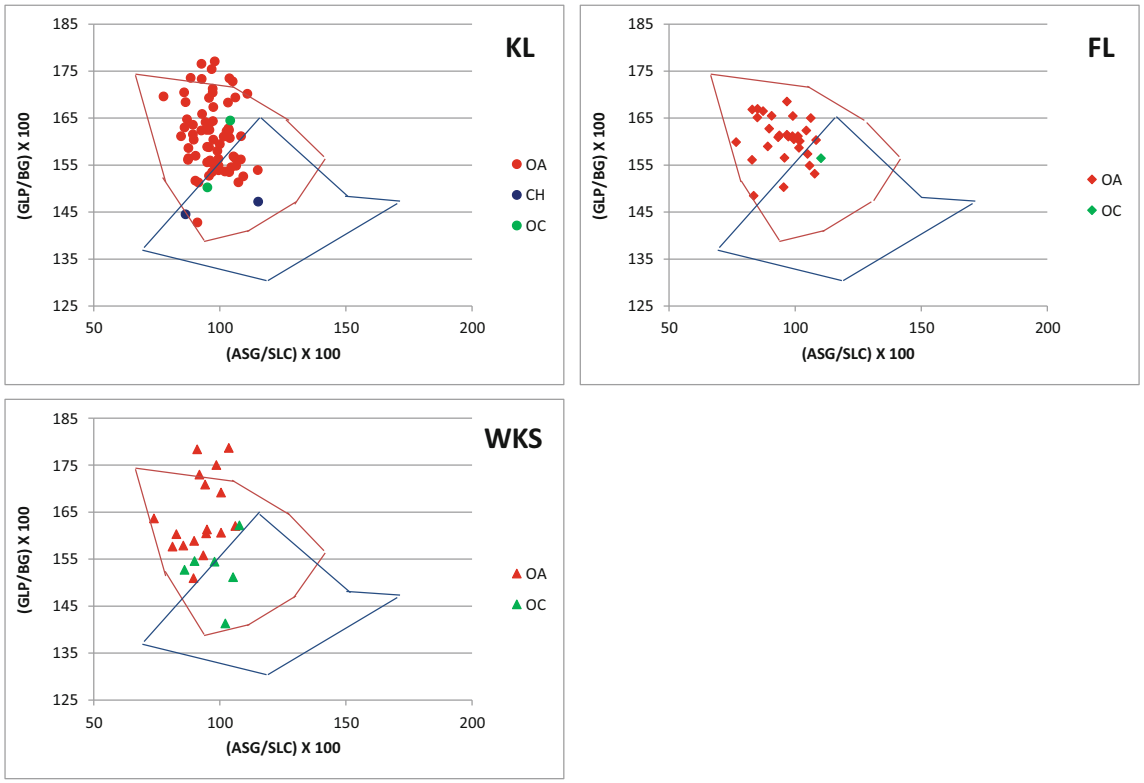

Fig. 4 Scapula: ratio between the shortest distance from the base of the spine to the edge of the glenoid cavity (ASG) and the smallest length of the *collum scapulae* (SLC) plotted against the ratio between the greatest length of the *processus articularis* (GLP) and the breadth of the glenoid cavity (BG). Symbols and lines as explained in Fig. 2

(b) Verify whether goats were mainly represented by horncores or if other anatomical elements were present.

3. Lay the basis for a more objective re-assessment of the role that the goat played in medieval English husbandry.

Materials and methods

Three medieval sheep and goat assemblages from King's Lynn (Norfolk), Flaxengate (Lincoln) and Woolmonger/Kingswell Street (Northampton) were selected as the most suitable and were re-analysed for the purpose of this study (Fig. 1).

King's Lynn (KL) (1050–1800 AD) Situated in the county of Norfolk in the east of England, this port site is located on an important area of convergence of roads, rivers and sea routes. From the thirteenth century onwards, it reached its peak as a centre of trade, maintaining contacts with France, the Low Countries and Scandinavia along with a lively inland commerce (Parker 1971). The archaeological investigations, carried out between 1963 and 1970, revealed a long time span of occupation which goes from the Late Saxon (c. 1050) to the post-medieval period (c. 1800) (Clarke and Carter 1977). The animal bone assemblage (Noddle 1976, 1977) is unusual because of the reported goat abundance. Noddle (Noddle 1977, p. 397) emphasises that "the considerable population of goats in King's Lynn is by no means unique"—a surprising statement in view of the evidence from other sites (Albarella 1999).

Flaxengate in Lincoln (FL) (late eleventh; late fourteen to middle sixteenth century AD) Located in the county of Lincolnshire, Lincoln was first occupied in the Iron Age, then by the Romans, and became a nucleated village in the ninth century. After the Norman Conquest (1066 AD), the city became one of the largest urban centres in the East Midlands (Jones 2003). The excavations (1945–1948 and 1972–1976) revealed a chronology ranging from the Late Saxon period (c. 870/80–900) to the post-medieval period (late seventeenth/early eighteenth to nineteenth century) (O'Connor 1982). The analysis of the animal bones, originally carried out by O'Connor (1982), revealed a complete absence of goat remains. Only contexts representatives of the medieval and early post-medieval periods (from the eleventh to early–middle sixteenth century) were selected.

Woolmonger/Kingswell Street in Northampton (WKS) (1000–1550 AD) This site is located in central-eastern England and has always played an important strategic role. Its

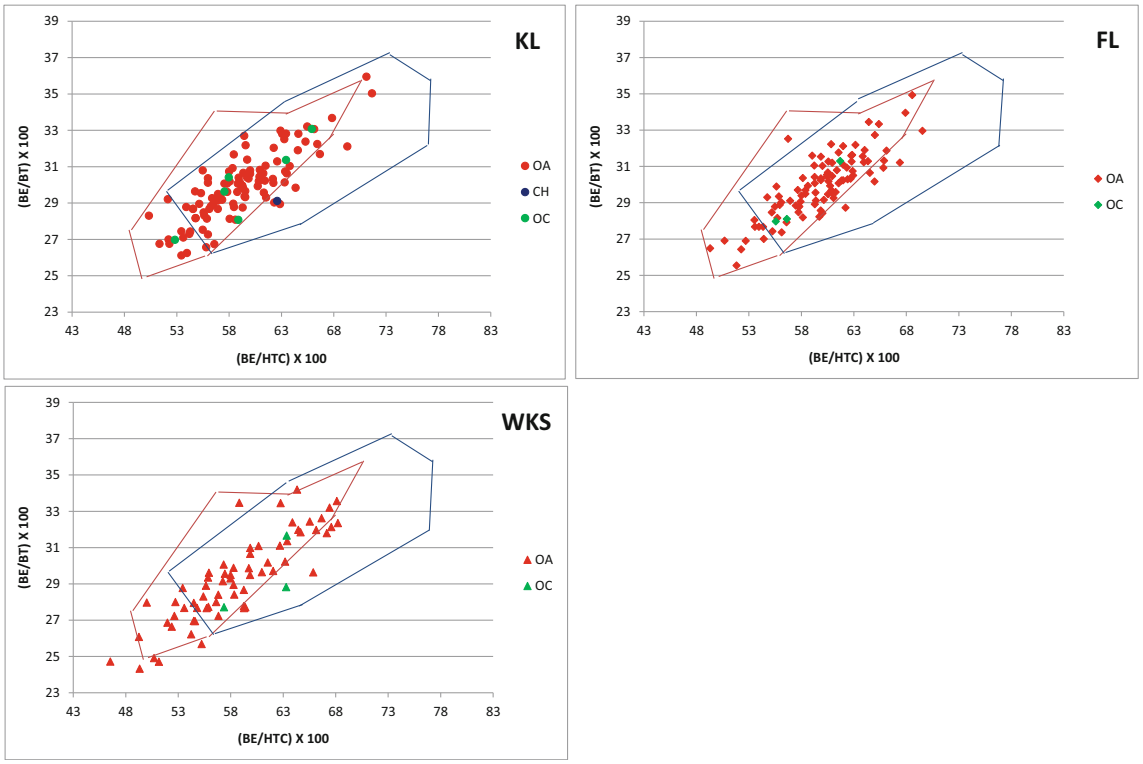

Fig. 5 Humerus: ratio between the breadth of the *capitulum* (BE) and the minimum diameter of the trochlea constriction (HTC) plotted against the ratio between the breadth of the *capitulum* (BE) and the medio-lateral breadth of the trochlea (BT). Symbols and lines as explained in Fig. 2

history goes as far back as the Iron Age. It then became a Roman settlement and then probably an Anglo-Saxon centre. Further growth of the town occurred in the following period (Brown 2008; Williams 1979). Northampton reached its peak in the second half of the twelfth century, when it is reported as the sixth most prosperous town in the kingdom (Brown 2008; Williams 1979). The decline began in the thirteenth century and became evident by the fourteenth century. The archaeological investigations (1972–1974; 1981–1987; 1994 and 2005) revealed a chronology which spans from the Late Saxon (AD 1000–1100) to the late medieval/early post-medieval period (AD 1400–1550). Armitage (1998–1999, 2008), who initially studied the animal bones, published the results in the form of very concise reports where all caprine remains are reported as sheep, with no goat or sheep/goat categories mentioned.

More specifically, these sites were selected because:

- In the case of KL, the results of the zooarchaeological analysis represent an anomaly, which called for verification.
- The other two sites are also urban, but located inland and in different regions from KL; thus, they represent different geographic scenarios, which are worth comparing.
- All three assemblages provided substantial bone material of reasonably refined chronologies, for which the status of the goat had not been fully clarified given the cursory nature of the methodological explanation concerning the approach to sheep/goat distinction.

All the animal bone assemblages included in this study are publicly deposited and accessible by other researchers. Permission to study the material was given by the institutions mentioned below, through a loan for research agreement. The animal bone material from King's Lynn is currently held at the Lynn Museum storage at Gressenhall Farm and Workhouse Museum in Norfolk. The assemblage from Flaxengate is currently stored at The Collection: Art and Archaeology in Lincolnshire in Lincoln, while the assemblage from Woolmonger/Kingswell Street is stored at the Northampton Museum and Art Gallery in Northampton.

As the main aim of this study is to re-examine these medieval sheep/goat assemblages in order to assess with a more objective methodology the presence of goat remains, the data for each individual site have been considered in toto, regardless of their chronology.

The methodology used is based on a combination of the traditional macro-morphological approach with a new morphometric approach. First, identification to species level was

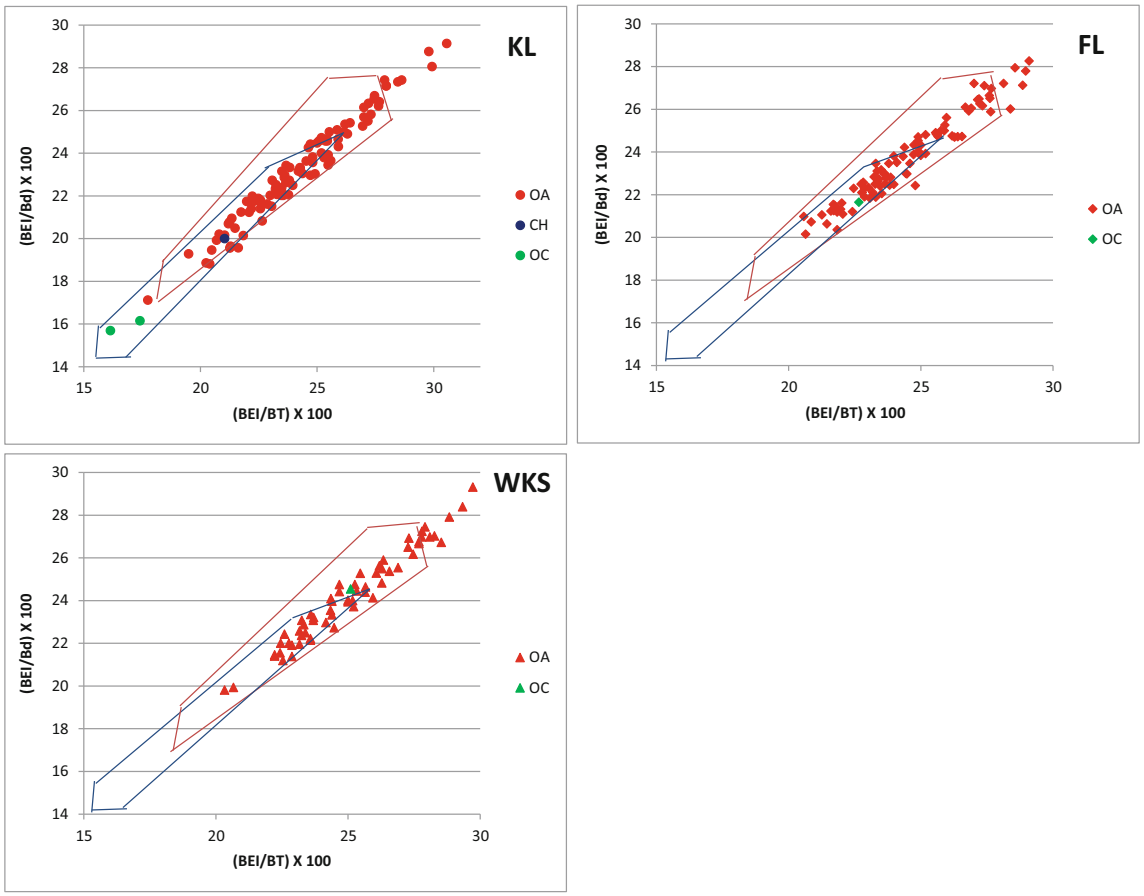

Fig. 6 Humerus: ratio between the breadth of the *epicondyle lateralis* (BEI) and the medio-lateral breadth of the trochlea (BT) plotted against the ratio between the breadth of the *epicondyle lateralis* (BEI) and the breadth of the distal end (Bd). Symbols and lines as explained in Fig. 2

undertaken using selected morphological traits from previous literature on the topic (Supplementary material 1). The categories used for the morphological identification were as follows:

- Sheep—classified as such if more than 50% of the morphological traits pointed towards sheep
- Goat—classified as such if more than 50% of the morphological traits pointed towards goat
- Sheep/goat—classified as such if only a minority of traits could be attributed to one of the two species

The morphometric approach has been developed by the authors (Salvagno and Albarella 2017), and it is based on the use of biometrical indices (BI) and linear discriminant analysis (LDA) in order to describe metrically the morphology of selected bones. Measurements, approximated to the tenth of a millimetre, were taken whenever possible with digital callipers.

The analysis was carried out in this order:

- A quantification according to body parts, so that the number of morphologically identified specimens and body parts represented at each archaeological site could be better evaluated
- A shape analysis through the use of BI in order to verify whether the morphological identification could be confirmed by biometry
- LDA in order to:

– Gain further insight into the possible presence of goats in the samples
– Verify whether the identifications carried out through the use of the morphological traits could be confirmed or rejected by the LDA
– See if some of the sheep/goat specimens (i.e. those which could not be attributed to one of the two species because of the lack of strong morphological diagnostic traits) could be attributed on the basis of a larger set of measurements than used for BI

LDA or direct option (Tabachnick and Fidell 2007, p. 395) was preferred to the stepwise method (Tabachnick and Fidell 2007, p. 396) because all the variables are included together at once during the analysis; with the stepwise method, they are inserted by the program which chooses, according to different

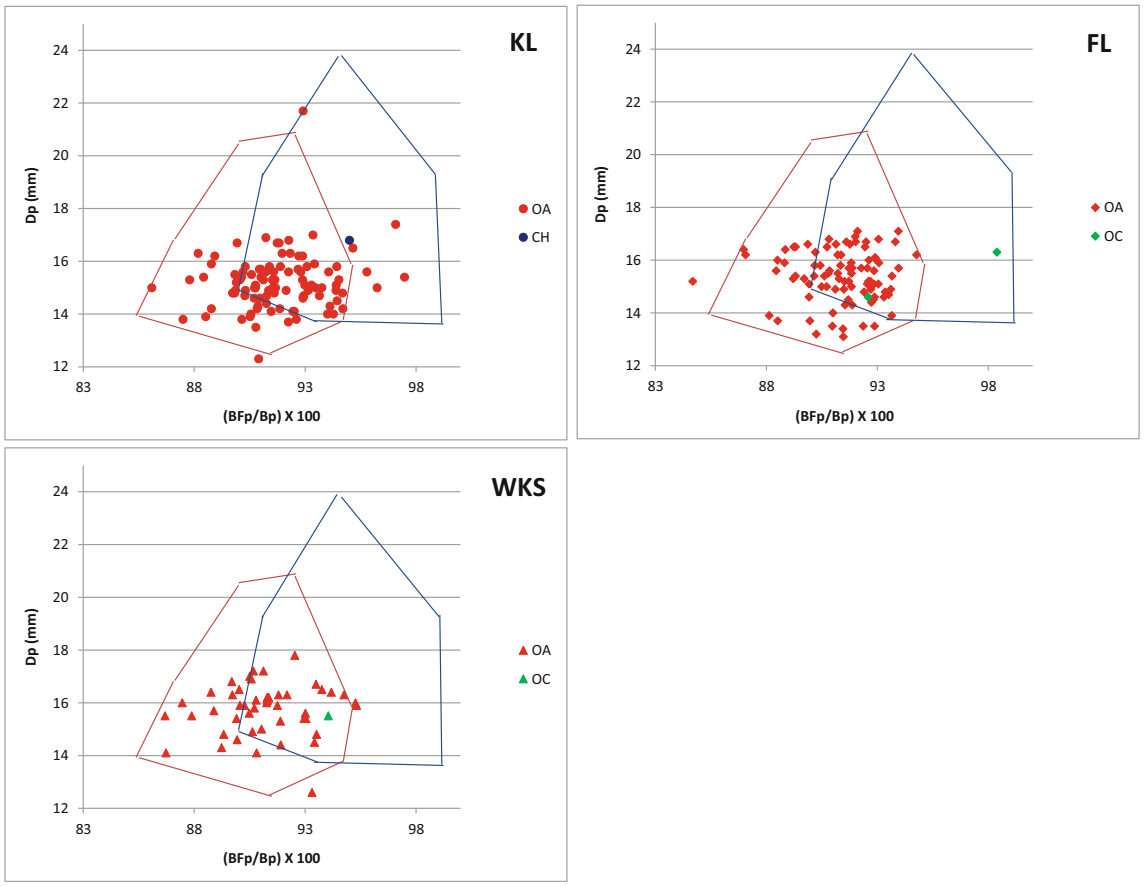

Fig. 7 Radius: ratio between the breadth of the facies *articularis proximalis* (BFp) and the greatest breadth of the proximal end (Bp) plotted against the depth of the proximal end (Dp). Symbols and lines as explained in Fig. 2

statistical criteria, which variables are the most effective (Tabachnick and Fidell 2007, pp. 395–396). The problem with this kind of approach is that the order of entry of the variables may be dependent on differences in the relationship among predictors that are irrelevant, so that they do not reflect population differences (Tabachnick and Fidell 2007, p. 395). In addition, there is no control over the variable selection process. As the methodology used in this study has been designed for the analysis of archaeological material, there are some measurements that are chosen because they are more likely to be taken on fragmented specimens than others (i.e. GL is rarely taken, unless you have a complete bone). For these reasons, a 'manual' control of the variables has been preferred (LDA).

As the main aim of the study is to look at the morphology of the bones without taking into consideration size, which can sometimes cloud the results, a method of standardisation, following the protocol used by Davis (1983), was applied to the raw data. This method consists of expressing each measurement of each bone as a fraction of the whole (i.e. individual measurements were divided by the total for that bone and multiplied by 100; Davis 1983, p. 523). The same standardisation method has been applied to both the modern and archaeological data presented in this study. To have a framework of reference for the expected distribution patterns of both species, data from modern sheep and goat reference collections (Salvagno and Albarella 2017) have been used as a baseline for the biometrical analyses (BI and LDA). All the statistical analyses were conducted with SPSS statistics program.

Results

Quantification according to body parts

Table 1 shows the number of morphologically identified sheep and goat specimens for each archaeological assemblage. At all three sites, some goat remains have been identified, but sheep is far more numerous. While for the sheep all body parts are present, the goat is mainly represented by horncores, and post-cranial bones are rare. KL represents a very clear example of this pattern: horncores are the only anatomical elements in which goat outnumbers sheep. If the horncores are included in the count, the sheep:goat ratio at the sites are 11:1 at KL, 283:1 at FL and 51:1 at WKS. The sheep and goat ratio drastically changes if the horncores are excluded: 163:1 at KL, 819:0 at FL and 76:1 at

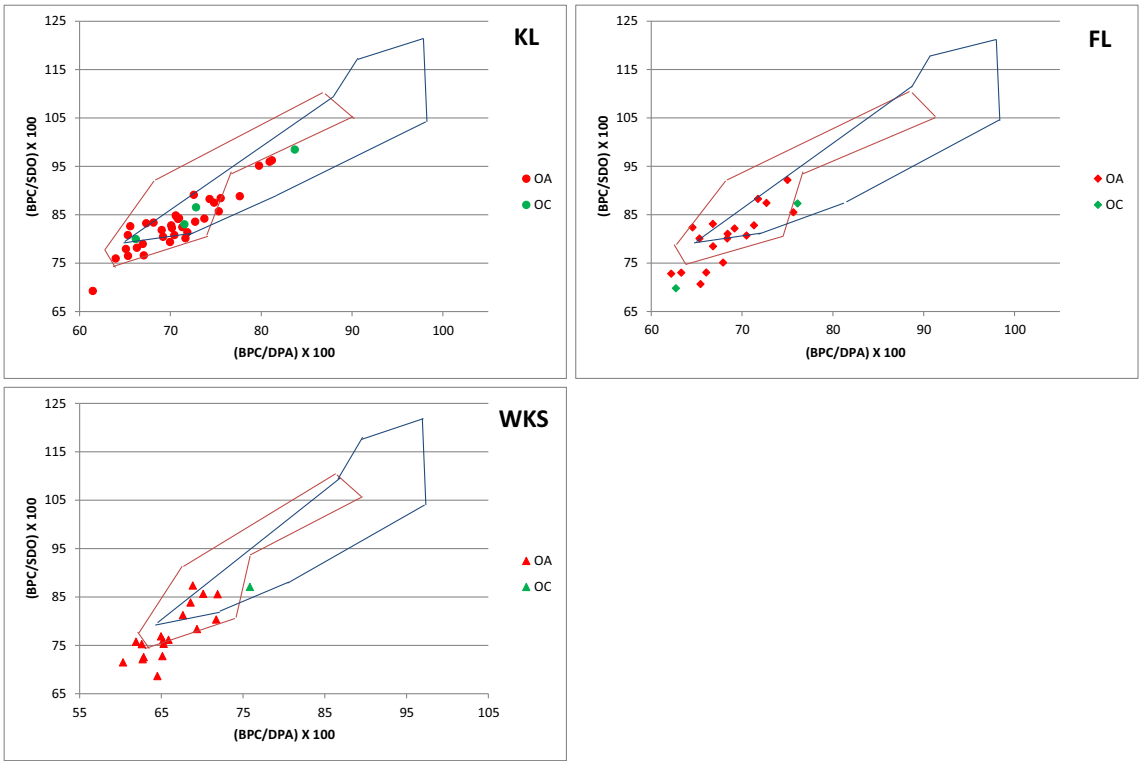

Fig. 8 Ulna: ratio between the breadth of the coronoid process (BPC) and the depth of the *processus anconaeus* (DPA) plotted against the breadth of the coronoid process (BPC) and the smallest depth of the olecranon (SDO). Symbols and lines as explained in Fig. 2

WKS. Clearly, horncores heavily influence the sheep:goat ratio. This preliminary morphological evidence therefore confirms the known patterns for sheep and goat during the medieval and early post-medieval periods: sheep remains are far more numerous than goat remains and, when the goat is present, it is mainly represented by horncores. The problem, however, remains that this evidence is based on trust—namely the correctness of our identifications, relying on rather subjective criteria.

Shape analysis: biometrical indices

Horncores

Figure 2 shows the combinations of measurements taken on the horncores for all three sites. On the horizontal axis, there is the ratio between E and F (length of the horncore = E; the length of its outer curvature = F), and on the vertical axis, the ratio between A and F (maximum diameter = A). At all sites, the separation between sheep and goat horncores is clearly visible with a minimum amount of overlap: archaeological sheep tend to plot among the modern sheep group, while the archaeological goat falls among modern goats. The fact that the E/F ratio is higher in goats while the A/F ratio is higher in sheep mirrors the differences in shape of this element between the two species (Clutton-Brock et al. 1990; Schmid 1972). No extreme outliers are present. However, a morphological identified sheep specimen (in KL) falls clearly among the archaeological and modern goat group: this could indeed represent a morphological misidentification. The specimens falling in the small area of overlap are not too far from the other archaeological specimens attributed to the same species and they are consistent with the distribution patterns of the modern material (polygons); thus, the morphological identification looks to be largely reliable. Overall, in the case of the horncores, biometrical data support morphological identifications.

Scapula

Figure 3 shows the ratios of measurements taken on the archaeological scapulae, which are meant to describe the difference in shape of the *processus articularis* in the two species. On the horizontal axis, there is the ratio between GLP (greatest length of the *processus articularis*) and LG (length of the glenoid cavity), while on the vertical axis, GLP/BG is plotted (BG being the breadth of the glenoid cavity).

The archaeological goats (despite their small number, only two from KL) have a lower score on the vertical axis, reflecting the more circular shape of the glenoid cavity in this species (Boessneck 1969; Prummel and Friesch 1986). One of the goat specimens falls in the area of overlap between the modern sheep and goat groups. The other goat specimen falls

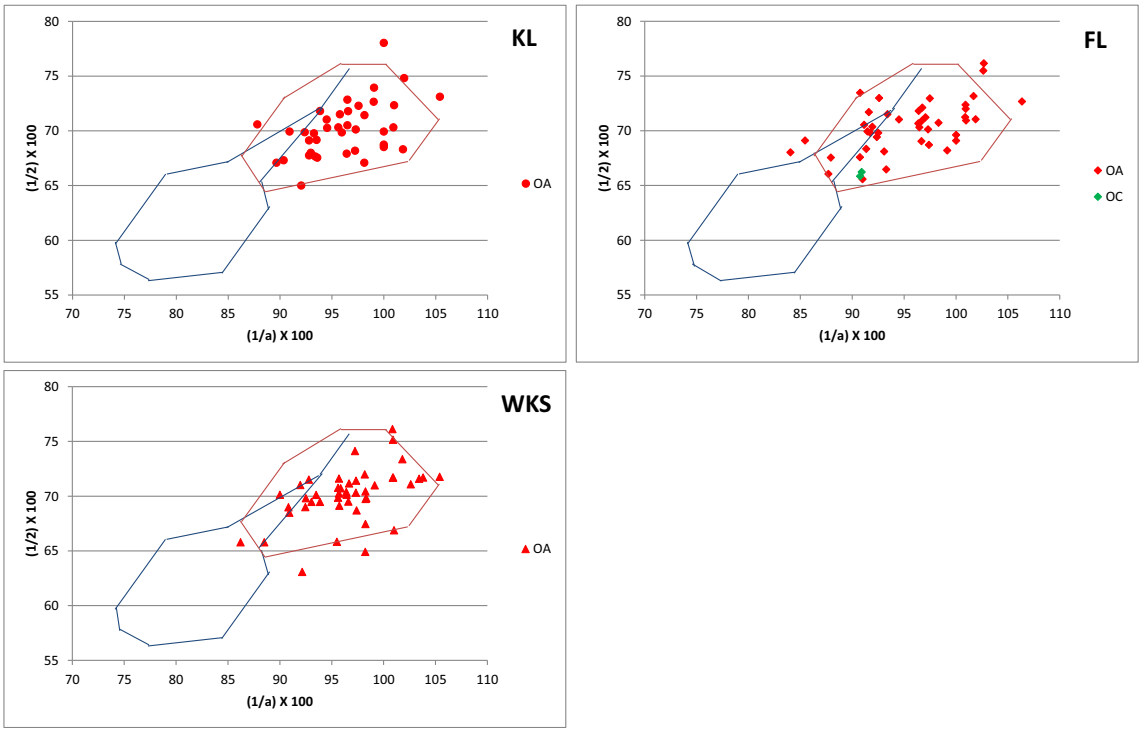

Fig. 9 Metacarpal: ratio between the diameter of the medial trochlea (1) and the width of the medial condyle (a) plotted against the ratio between the diameter of the medial trochlea (1) and the diameter of the *verticillus* of the medial condyle (2). The modern goat outlier (falling among the modern and archaeological sheep) is a pigmy goat, as such it might have a different morphology. Symbols and lines as explained in Fig. 2

outside the range of the modern goats but follows the same distribution pattern, showing very strong goat traits. The identification as goat of these two archaeological specimens is further confirmed by the fact that, when other measurements are used (Fig. 4), both specimens fall among the modern goat group or in the area of overlap between modern sheep and goats. All archaeological sheep fall either among the sheep modern group or in the area of overlap, supporting their identification. Some, despite following the same distribution pattern of the modern sheep group, fall outside the sheep polygon showing strong sheep traits.

A number of undefined sheep/goat specimens are present. At KL as well as at FL and WKS, the sheep/goat specimens largely fall either in the area of overlap between the modern sheep and goat groups, or in the area where the modern sheep gather. Since they seem to plot more towards the centre of the sheep distribution, they are likely to be sheep. The only exception is the *sheep/goat* specimen falling at the bottom of the plot at WKS (Fig. 3). This specimen is substantially distinct from the sheep archaeological specimens, and it seems to be more consistent with the goat pattern of distribution.

In Fig. 4, different ratios are presented: on the horizontal axis, there is the ratio between ASG (shortest distance from the base of the spine to the edge of the glenoid cavity) and SLC (smallest length of the *collum scapulae*), while on the vertical axis, GLP is divided by BG. These combinations should be able to describe the difference in the shape of the glenoid cavity and the *collum scapulae* between the two species. On the graph, the thinner, more slender *collum scapulae* of the goat demonstrates a greater distance between the glenoid cavity and the base of the spine (lower GLP/BG scores and higher ASG/SLC), while for sheep, the distance between the glenoid cavity and the base of the spine is shorter and the *collum scapulae* is thicker and stouter (Boessneck 1969).

The only archaeological goats identified are from KL, and as Fig. 4 shows, their morphological identification is consistent with the biometric values. Archaeological sheep at all three sites largely fall in the area of the graph with their modern counterparts. Since they follow the distribution of the modern sheep, their morphological identification should not be questioned. A few archaeological sheep specimens at KL and WKS fall outside the modern sheep group showing strong sheep traits.

Unidentified sheep/goat specimens at all three sites fall either in the modern sheep group or in the area of overlap. With the exception of the WKS specimen mentioned above, these specimens are likely to be sheep rather than goats as they plot more towards the centre of the sheep distribution. Their weakly expressed morphological characteristics—which have led to their identification as sheep/goat—are mirrored by the biometrical data.

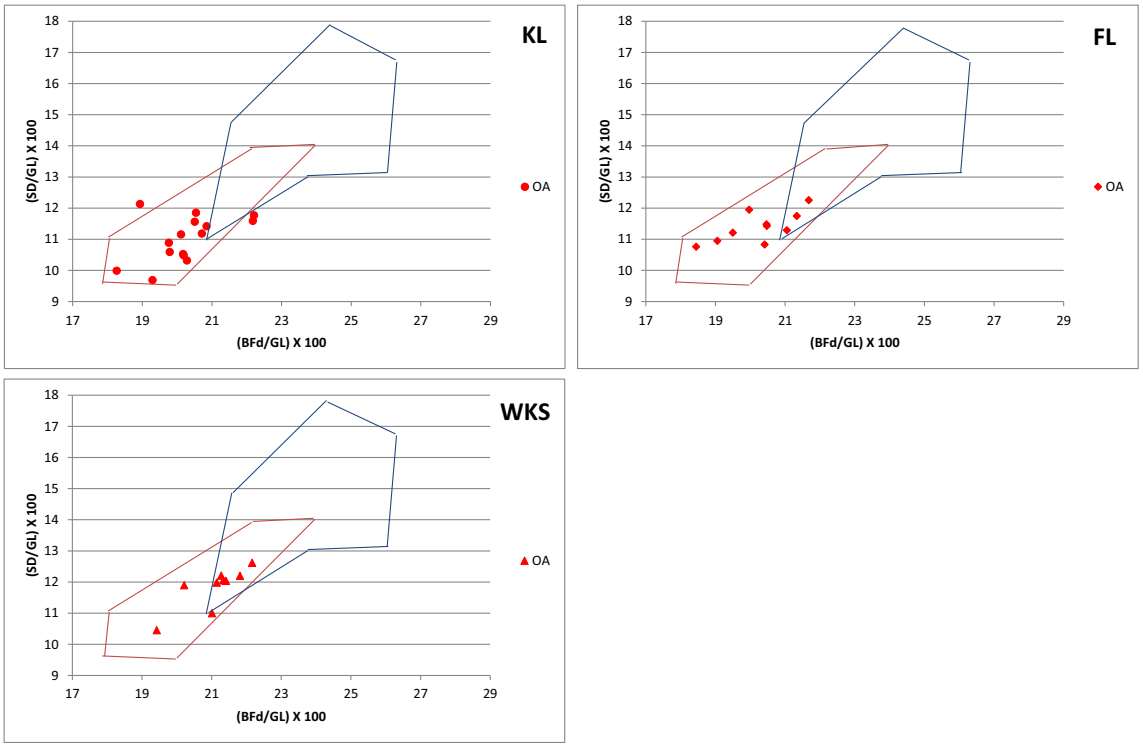

Fig. 10 Metacarpal: ratio between the greatest breadth of the distal end (BFd) and the greatest length (GL) plotted against the ratio between the smallest width of the shaft (SD) and the greatest length (GL). Symbols and lines as explained in Fig. 2

Humerus

Figure 5 compares BE/HTC (BE = breadth of the *capitulum*; HTC = minimum diameter of the trochlea constriction) and BE/BT (BT = medio-lateral breadth of the trochlea) ratios, which describe the differences in the distal trochlea of the humerus. Goats have an overall more medio-laterally elongated trochlea than sheep (Boessneck 1969), resulting in higher scores for both indices. Only one goat distal humerus has been found at KL, and this specimen is borderline between the goat and the sheep modern groups; as such, its identification is retained. The archaeological sheep all fall either in the area of overlap of the modern groups or among the modern sheep; as such, they are consistent with their morphological identifications. Some sheep specimens at WKS show strong sheep traits, as they still follow the modern sheep distribution but plot away from the core of the modern cluster (see lower part of the distribution).

Several sheep/goat specimens are present at the three sites, and they mostly fall in the area of overlap between the two modern groups. As the amount of overlap is significant—preventing us from clearly identifying the centres of distribution for the two species—biometry in this case cannot assist in assigning them to species level. The only exception is one of the sheep/goat specimens at KL as it clearly plots among the modern sheep, and as such, it is more likely to be from a sheep.

Figure 6 shows BEI/BT plotted against BEI/Bd (BEl = breadth of the *epicondyle lateralis*; Bd = breadth of the distal end). This combination describes the different shapes in the *epicondyle lateralis* in the two species (Boessneck 1969; Helmer and Rocheteau 1994; Prummel and Friesch 1986). The only identified goat at KL plots in the area of overlap, which is not inconsistent with its morphological identification. The sheep at all sites either occupy the area of overlap of the two modern samples or fall among the modern sheep group. At all sites, some sheep specimens present strong sheep traits, plotting outside the sheep cluster (upper part of the distribution).

One sheep/goat specimen from FL falls in the area of overlap and another from WKS just outside it, in the modern sheep group. However, since the overlap is significant and centres of distributions are hard to identify, the identification of both remains uncertain. Two sheep/goat specimens at KL fall very clearly among the modern goat group, but considering the distribution pattern of the archaeological sample, and the fact that these two specimens fall among the sheep in Fig. 5, the evidence is not strong enough to justify a re-attribution.

Radius

Figure 7 shows the ratio between BFp/Bp (BFp = breadth of the facies *articularis proximalis*; Bp = greatest breadth of the proximal end) on the horizontal axis and Dp (depth of the

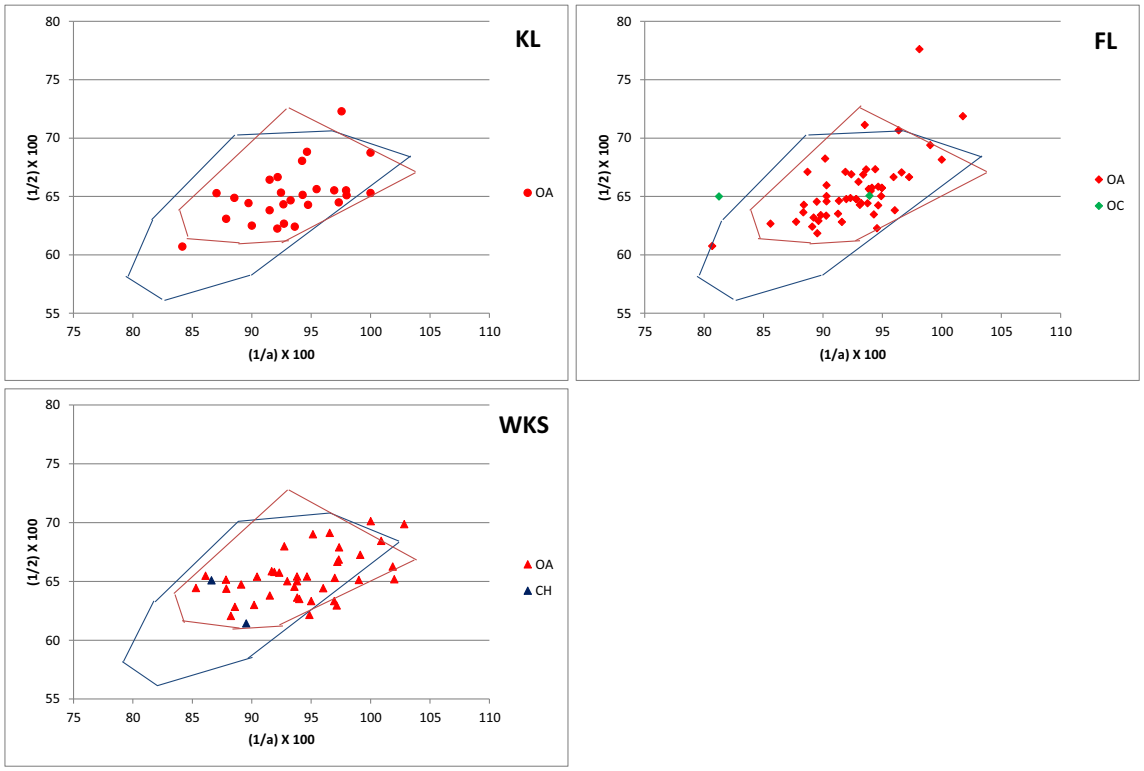

Fig. 11 Metatarsal: ratio between the diameter of the medial trochlea (1) and the width of the medial condyle (a) plotted against the ratio between the diameter of the medial trochlea (1) and the diameter of the *verticillus* of the medial condyle (2). Symbols and lines as explained in Fig. 2

proximal end) on the vertical axis. This combination describes the overall differences in the shape of the proximal articulation of the radius (Boessneck 1969; Prummel and Friesch 1986; Zeder and Lapham 2010).

Only one goat radius has been identified at KL and it falls indeed within the goat group. Most of the archaeological sheep gather in the area where only modern sheep plot or in the area of overlap. Nevertheless, some archaeological sheep at KL plot clearly among the modern goat group. This phenomenon was not observed on the modern material, and the inconsistency of distribution between modern and archaeological sample could be due to the fact that the proximal radius is known to change with age as, through time, it undergoes post-fusional growth (cf. Payne and Bull 1988 for pigs). In the modern sample, the age factor was controlled, while in the archaeological material, the same factor is unknown. As a consequence, different age classes—compared to the modern material—could potentially be present in the archaeological material, causing inconsistency. Thus, the use of these measurements to distinguish the two species in an archaeological assemblage needs to be taken with caution as the effectiveness of the BI may vary according to the population under study. Potentially, they can still be useful, as they were very successful in the separation of sheep and goats in the modern material, but they may not help in all cases, as shown for our three sites.

The sheep/goat specimens fall mainly in the area of overlap, so that they cannot be attributed to one of the two species. One sheep/goat specimen from FL, however, plots clearly among the goat modern group far from the archaeological sheep cluster; for this specimen, an identification as 'goat' appears to be reasonable, as it represents a clear outlier to the sheep cluster, but we must consider the caveat mentioned above.

Ulna

Figure 8 shows biometrical indices (BPC = breadth of the coronoid process; DPA = depth of the *processus anconaeus*; SDO = smallest depth of the olecranon) which describe the shape of the lateral coronoid process in the ulna; this is in fact more laterally elongated in goats than in sheep which is why goats have higher values in both ratios (Boessneck 1969; Prummel and Friesch 1986). No goat ulnae have been identified. Most of the archaeological sheep fall in the area of overlap or among the modern sheep group. This is potentially consistent with their morphological identifications. Several archaeological sheep specimens fall in the bottom left corner of the graph showing very strong sheep traits.

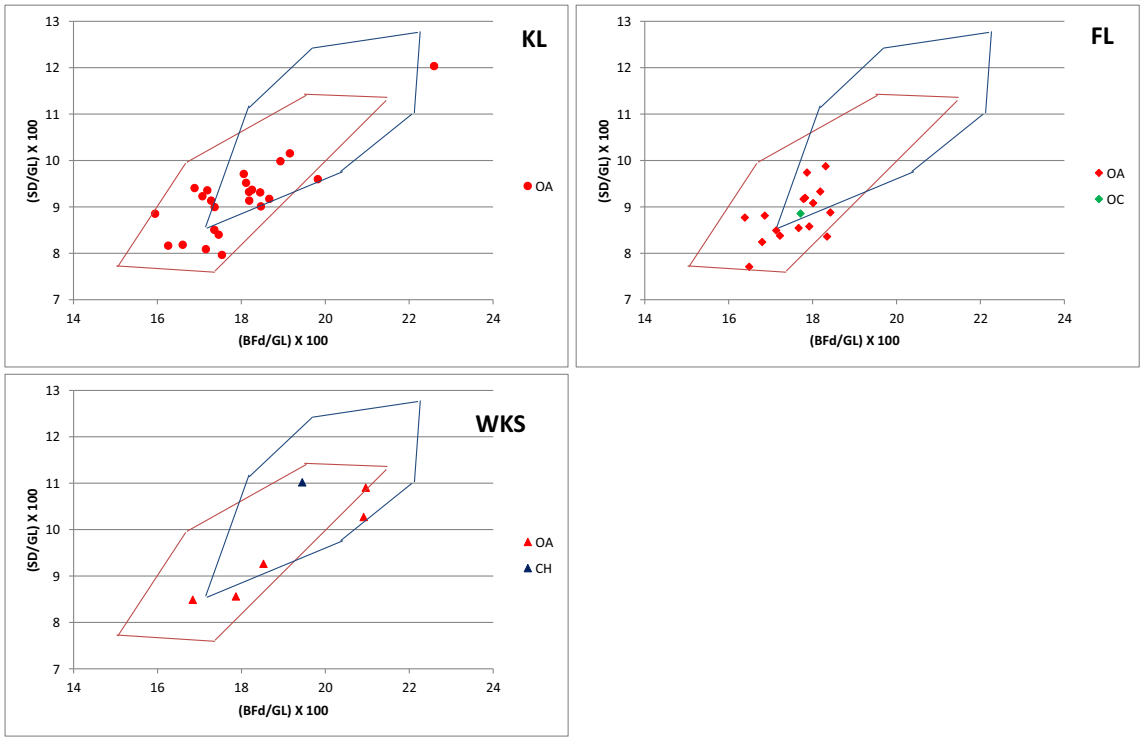

Fig. 12 Metatarsal: ratio between the greatest breadth of the distal end (BFd) and the greatest length (GL) plotted against the ratio between the smallest width of the shaft (SD) and the greatest length (GL). Symbols and lines as explained in Fig. 2

If the sheep/goat specimens are considered, it can be seen that some fall in the area of overlap between the two modern groups; thus, biometry cannot determine their identification even though they seem closer to the sheep centre of distribution than the goat centre. Several other sheep/goat specimens fall clearly among the sheep group or even outside it, showing very strong sheep traits (see FL).

Metapodials

Figure 9 presents the ratios taken on the distal articulation of the metacarpals. On the horizontal axis, there is the ratio between measurement 1 (1 = diameter of the medial trochlea) and a (a = width of the medial condyle), while on the vertical axis, there is a ratio between measurements 1 and 2 (2 = verticillus of the medial condyle). These combinations describe the morphological difference between the peripheral part of the trochlear condyles which is larger in sheep than goat (Boessneck 1969; Zeder and Lapham 2010). No goat archaeological metacarpals have been identified. Most of the archaeological sheep fall in the area occupied by the modern sheep with only a few borderline specimens. These archaeological sheep (at FL and WKS) fall very close to the modern sheep cluster and seem to be consistent with the sheep distribution pattern.

Two morphologically unidentified sheep/goat specimens from FL fall among the modern sheep cluster and seem to gather around the modern sheep centre of distribution; thus, they are likely to be sheep.

Figure 10 shows a different combination of measurements: BFd and GL (BFd = greatest breadth of the distal end; GL = greatest length) on the horizontal axis and SD (SD = smallest width of the shaft) and GL on the vertical. These indices describe the overall aspect of the bone which is slender in sheep and stouter in goat (Boessneck 1969). No archaeological goat metacarpals have been found. All the archaeological sheep, identified as such on the basis of their morphological features, fall among the modern sheep cluster or in the area of overlap between the two modern groups. As a consequence, their identification seems to be sound.

The same combination of measurements used for the metacarpals were adopted for the metatarsals. Figure 11 describes, as Fig. 9 does for the metacarpals, the morphological differences between the peripheral part of the trochlear condyles (Boessneck 1969; Helmer and Rocheteau 1994). There is much more overlap between the modern groups, indicating that the metatarsals are less effective than the metacarpals for separating between sheep and goat, as already suggested by Payne (1969). Only two goat metatarsals are present and both come from WKS. Both specimens fall in the area of overlap, and therefore, there is no reason to question their identifications. At all sites, most of the archaeological sheep fall in the modern sheep cluster, confirming their identification. A few archaeological sheep are borderline (at both KL and FL): they fall among the modern goat cluster but not far from the sheep group; for these specimens, further verification is required. Other archaeological

sheep from FL show very marked sheep traits as they fall outside the modern sheep group but follow the same pattern.

Two unidentified sheep/goat specimens are present at FL: one falls in the area of overlap and the other outside both modern groups. In this case, biometry cannot assist in their identifications.

Figure 12 (BFd and GL plotted against SD and GL) describes the overall difference in shape of the metatarsal (Boessneck 1969). Only one archaeological goat has been morphologically identified, from WKS; it plots in the area of overlap between the two modern groups and is therefore potentially consistent with the original identification. At all three sites, the archaeological sheep mostly fall in the area where the modern sheep are or in the area of overlap, consistently with their morphological identifications. At KL, a specimen identified as sheep plots as an outlier, showing pronounced goat characters. However, in Fig. 11, the specimen does not appear as an outlier. Given the inconsistency of the evidence, it is safer to regard that specimen of uncertain attribution.

Only one sheep/goat specimen is present (at FL); this specimen plots in the area of overlap, but since it stands very close to the archaeological (and modern) sheep centre of distribution, it is likely to be a sheep.

Tibia

Figure 13 shows the ratios taken on the distal articulation of the tibia (Bd = breadth of distal end; Dda = depth of the medial side; Ddb = depth of the lateral side) which are supposed to describe the overall shape of the distal end of this bone (trapezium-like shape in sheep and rectangular-like shape in goats) (Kratochvíl 1969). Only one archaeological goat has been identified at WKS: this specimen falls in the area of overlap between the two modern groups and there is thus no reason to question its identification. At all sites, the archaeological sheep fall among the modern sheep or in the area of overlap. A few archaeological sheep fall among the modern goat group, but as they are not too far from the archaeological sheep cluster and they seem to follow the sheep centre of distribution, the evidence is not strong enough to re-consider their identification. However, identification must be questioned for two sheep specimens—one from KL and the other from WKS—that fall more distantly from the archaeological sheep cluster (low on the vertical axis).

Sheep/goat specimens are present at all three sites: most fall clearly among the modern sheep; thus, they are likely to belong to this species. Some are in the area of overlap, though they seem to be more consistent with the sheep distribution pattern. Two specimens from WKS, however, look dubious: they fall far from the modern sheep cluster and more towards the modern goat group. One even falls outside the goat cluster, showing very marked goat traits. For these specimens, identification must be reconsidered.

Astragalus

Figure 14 shows the ratio between H (height of the central constriction) and Dl (greatest depth of the lateral

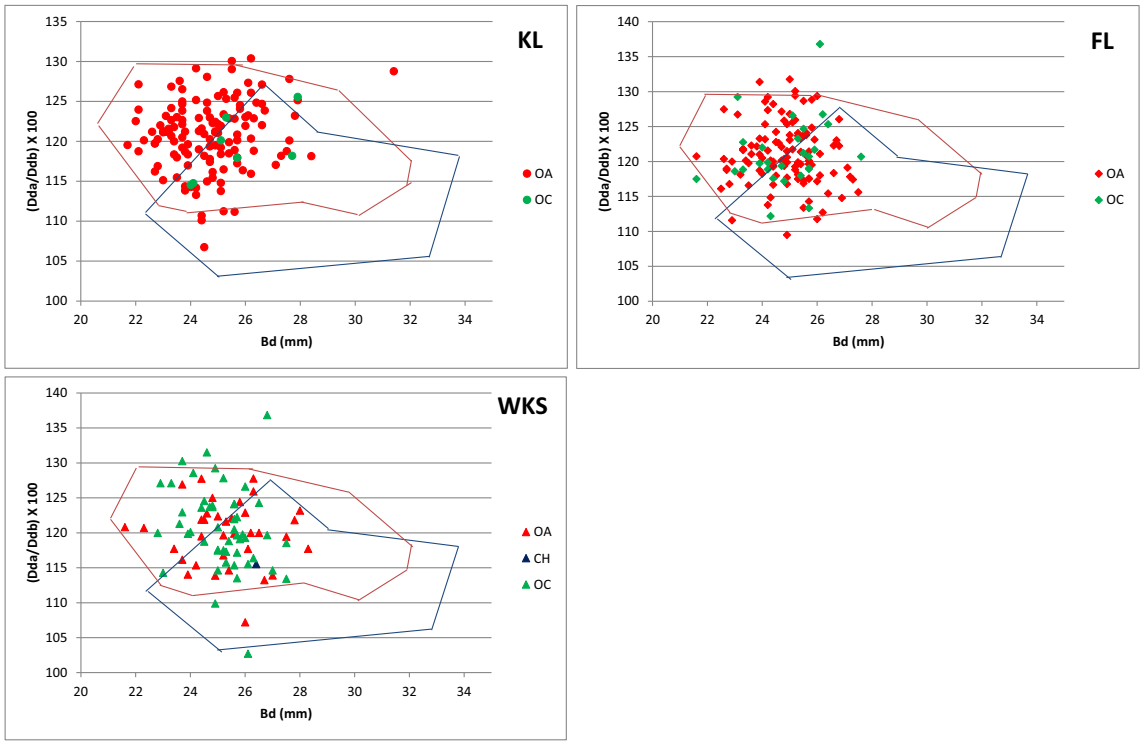

Fig. 13 Tibia: breadth of distal (Bd) end plotted against the ratio between the depth of medial (Dda) and lateral (Ddb) sides. Symbols and lines as explained in Fig. 2

half) on the horizontal axis and between Bd (breadth of the distal end) and GLl (greatest length of the lateral half) on the vertical axis for the astragalus. These combinations should be able to translate: (A) the depth of the sulcus at the middle of the trochlea which is usually deeper in sheep than in goat (Boessneck 1969); (B) the presence of an articular ridge which projects more in goat than in sheep (expressed by measurement Dl) (Boessneck 1969; Zeder and Lapham 2010); and (C) the ratio Bd/GLl also reflects the overall shape of the bone which is more robust in sheep than in goat (Boessneck 1969).

No archaeological goat astragali have been identified. Most of the archaeological sheep fall either among the modern sheep or in the area of overlap. There are a few archaeological sheep specimens that can be considered borderline (at KL and FL): they fall among the modern goats, but they are quite close to the other archaeological sheep; thus, the evidence is not strong enough for their morphological identification to be questioned. An archaeological sheep at KL falls well outside the modern sheep cluster showing strong sheep traits. The only sheep/goat specimens (FL) fall in the area of overlap, therefore remaining ambiguous.

Figure 15 presents the ratio between Bd and Dl on the horizontal axis and the ratio between Dl and GLl on the vertical axis. The separation between the two species is mainly determined by Dl/GLl. The higher Dl/GLl scores in sheep mirror the more robust shape (wider in relation to the height) of the bone of this species compared to the goat. No archaeological goats have been identified. Archaeological sheep all fall among the modern sheep or in the area of overlap, confirming their morphological identification. Two sheep specimens at KL and FL show very strong sheep traits.

Two sheep/goat specimens are present at FL: they both fall in the area of overlap; thus, their identification cannot be established. Nevertheless, it must be said that they seem more consistent with the sheep distribution pattern.

Calcaneum

Figure 16 shows measurements c (length of the articular facet of the *os malleolare*) and d (length taken from the articular facet of the *os malleolare* to the end of the articulation-free part of the process) plotted against ratio between c and the B (the breath of the articular facet of the *os malleolare*). These combinations mirror (A) the fact that the length of the articular facet for the *os malleolare* on the lateral process is greater than half of the entire process in sheep while in goat it is smaller (Boessneck 1969; Zeder and Lapham 2010); and (B) the difference between the

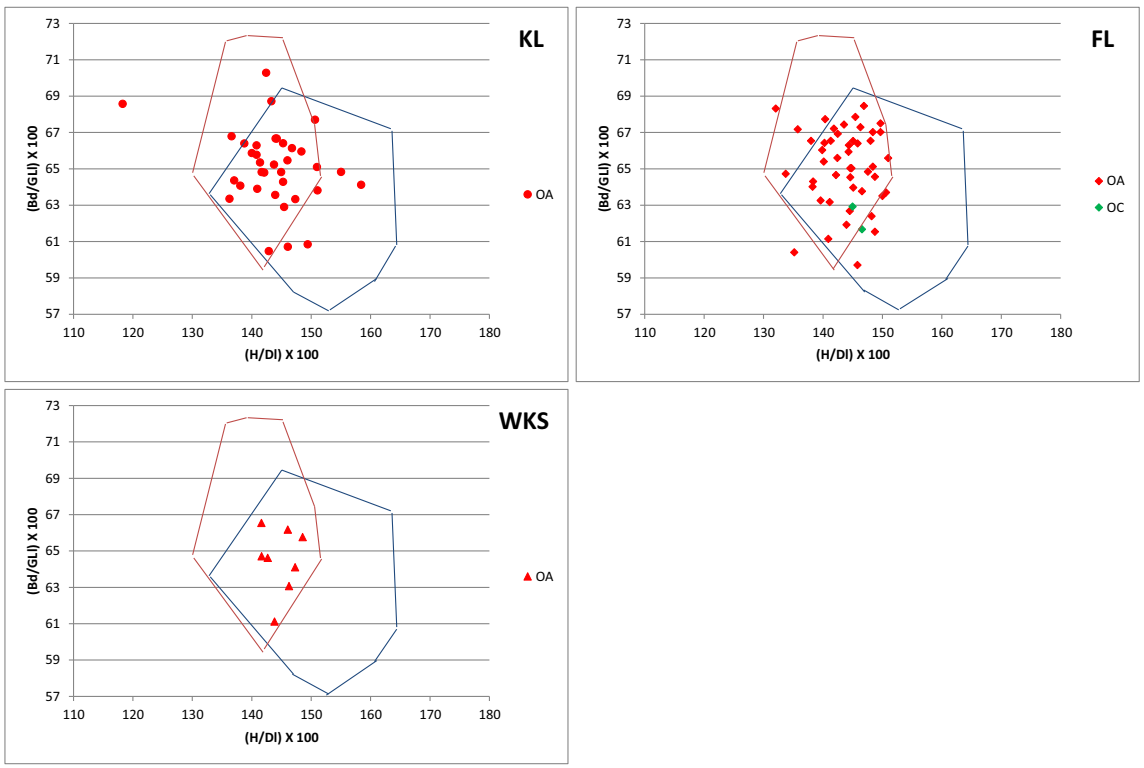

Fig. 14 Astragalus: ratio between the height of the central constriction (H) and the greatest depth of the lateral half (Dl) plotted against the ratio between the breadth of the distal end (Bd) and the greatest length of the lateral half (GLl). Symbols and lines as explained in Fig. 2

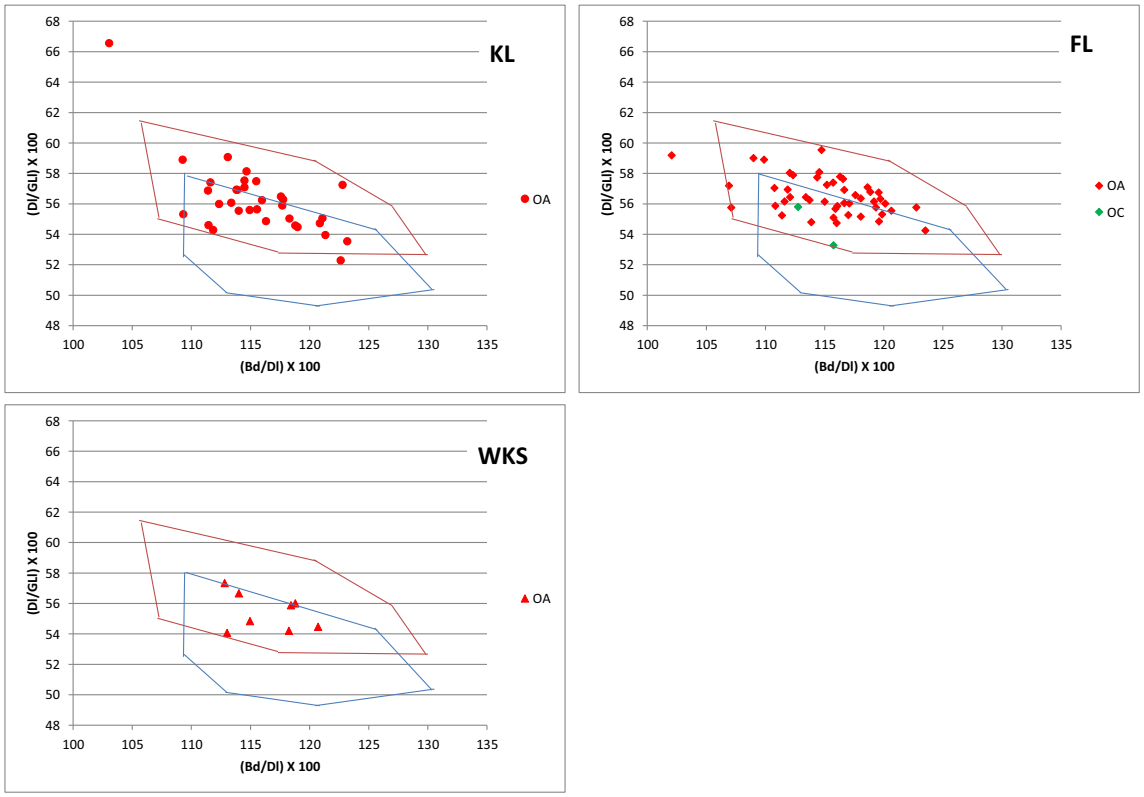

Fig. 15 Astragalus: ratio between the breadth of the distal end (Bd) and the greatest depth of the lateral half (Dl) and the ratio between the greatest depth of the lateral half (Dl) and the greatest length of the lateral half (GLl). Symbols and lines as explained in Fig. 2

articular facet of the *os malleolare* which in sheep is longer and narrower, whereas the same articular facet in goat is wider and shorter (Boessneck 1969; Zeder and Lapham 2010). Once again, no archaeological goat astragali have been identified. Most of the archaeological sheep fall among the modern sheep cluster or in the area of overlap, as such there is no ground to question their morphological identifications. At all sites, there are some archaeological sheep which follow the sheep pattern but plot outside the modern sheep cluster; these specimens have very strong sheep traits.

Very few specimens have been identified as sheep/goat, and they fall in the area of overlap between the two modern groups; as a consequence, biometry cannot help with the identification, even though they seem more consistent with the sheep pattern than the goat.

Figure 17 shows a different combination of measurements: DS (depth of the *substentaculum tali*) is plotted against *c* on the horizontal axis, while on the vertical axis, there is the ratio between c and d. The outcome is consistent with what shown in Fig. 16. All the archaeological sheep fall among the modern sheep or in the area of overlap, confirming their identification. One archaeological sheep at KL shows strong sheep traits, plotting outside the sheep group but following the same pattern.

The few sheep/goat specimens fall in the area of overlap between the two modern species. They seem to be consistent with the sheep group, and as such, they are very likely to be sheep.

Results are confirmed also when using a different ratio (DS/c and c/B; Fig. 18): the archaeological sheep plot among the modern sheep cluster or in the area of overlap. Some specimens plot outside the sheep group showing strong sheep traits.

The sheep/goat specimens are very few and they mainly fall in the overlapping area. Nevertheless, they seem to be more consistent with the sheep distribution than the goat pattern.

Third phalanx

Figure 19 shows a combination of measurements (MBS and DLS) which mirrors the difference in the shape of the sole in the two species (Boessneck 1969). Despite the sample size being very small, the archaeological sheep convincingly follow the modern sheep pattern falling, either among the modern sheep group or in the area of overlap.

Linear discriminant analysis

LDA has been applied to the archaeological assemblages in order to have further insights into the distinction between sheep and goat and also to test if the same

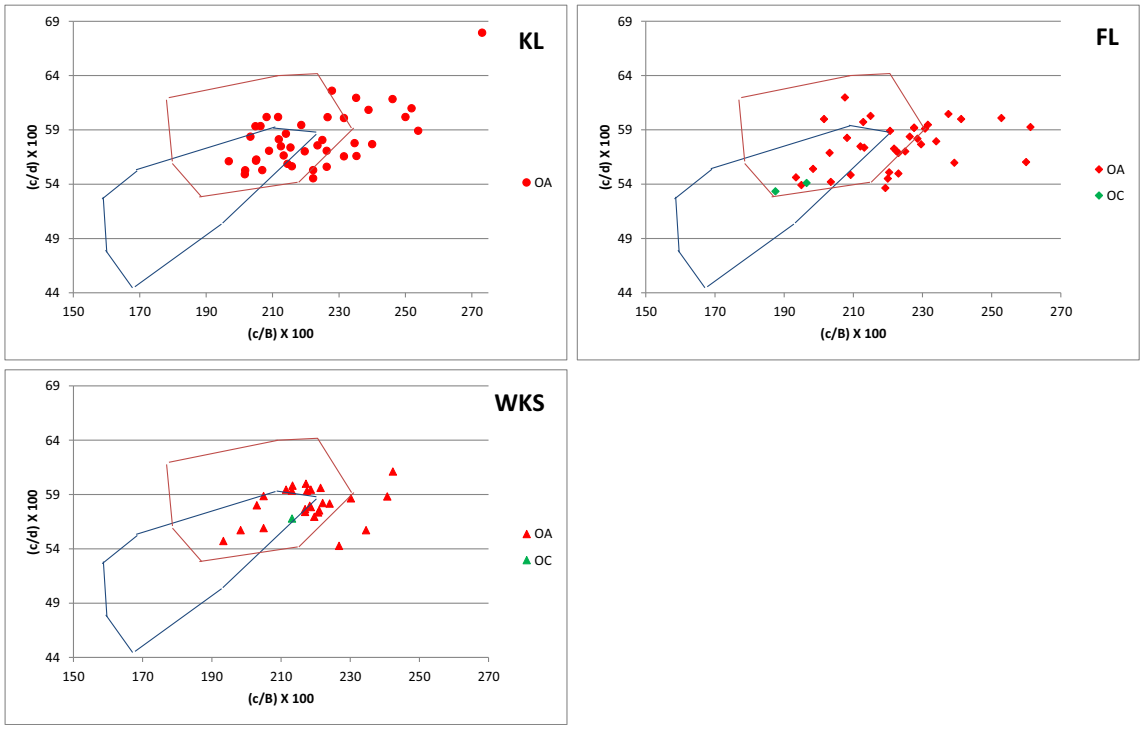

Fig. 16 Calcaneum: ratio between the length (c) and breadth (B) of the articular facet of the *os malleolare* plotted against the ratio between the length of the articular facet of the *os malleolare* (c) and the length taken from the articular facet of the *os malleolare* to the end of the articulation-free part of the process (d). Symbols and lines as explained in Fig. 2

successful outcome we had with the modern material (Salvagno and Albarella 2017) could be obtained on fragmented archaeological assemblages. In this instance, LDA is used as a predicting tool. The program attributes an individual score to each of the new archaeological cases. This score represents the distance of that individual specimen from the group centroid value (i.e. group means of the predictor variables; Field 2009, p. 620) calculated for each modern group. As a consequence, the program itself attributes to species level (prediction) the archaeological specimens on the basis of their individual scores; the group to which the new cases will be attributed is the one from which their distance is smallest (Burns and Burns 2008).

LDA, as it evaluates all metric variables at the same time, has the potential to support or contradict the identifications based on the morphological approach, and it represents an additional aid for attributing the unidentified specimens to species level.

Results for all three sites are presented on an element by element basis. The diagrams show, on the horizontal axis, the individual discriminant score attributed by the LDA to each archaeological specimen and, on the vertical axis, the species attributions assigned by the program. The only possible attributions were goat, identified by the number 1, and sheep identified by number 2 (vertical axis). The vertical lines on the graph represent the group centroids for each species.

Horncores

In Supplementary material 2, Table A shows the results when LDA was applied on the modern and the archaeological horncores. High consistency is present between morphological and biometrical identifications of the archaeological material (96% for KL, 100% for FL and 100% for WKS); the percentages of correct identification are very high, higher than the results obtained from the modern material for this same element (95%).

In regard to the modern material, of the 35 goat horncores originally present in the modern sample (all of known taxa), LDA has attributed 33 to goat and two to sheep. For the sheep modern group, which was originally composed of 28 sheep horncores, LDA have identified 27 horncores as belonging to sheep and one as belonging to goat. These results are very interesting as they indicate that LDA bears an intrinsic error. In fact, in the modern material, the percentage of correct re-attributions is not 100% (as it is for all the other elements, see Supplementary material 2 Tables A–Q) which, in other words, means that modern specimens, whose taxonomic origin is known, were occasionally misclassified. Consequently, it is likely that such bias has also affected the archaeological specimens. The nature of this error is strictly linked to the biological nature of the two species analysed and their variability: as they are closely related species, a certain degree of overlap

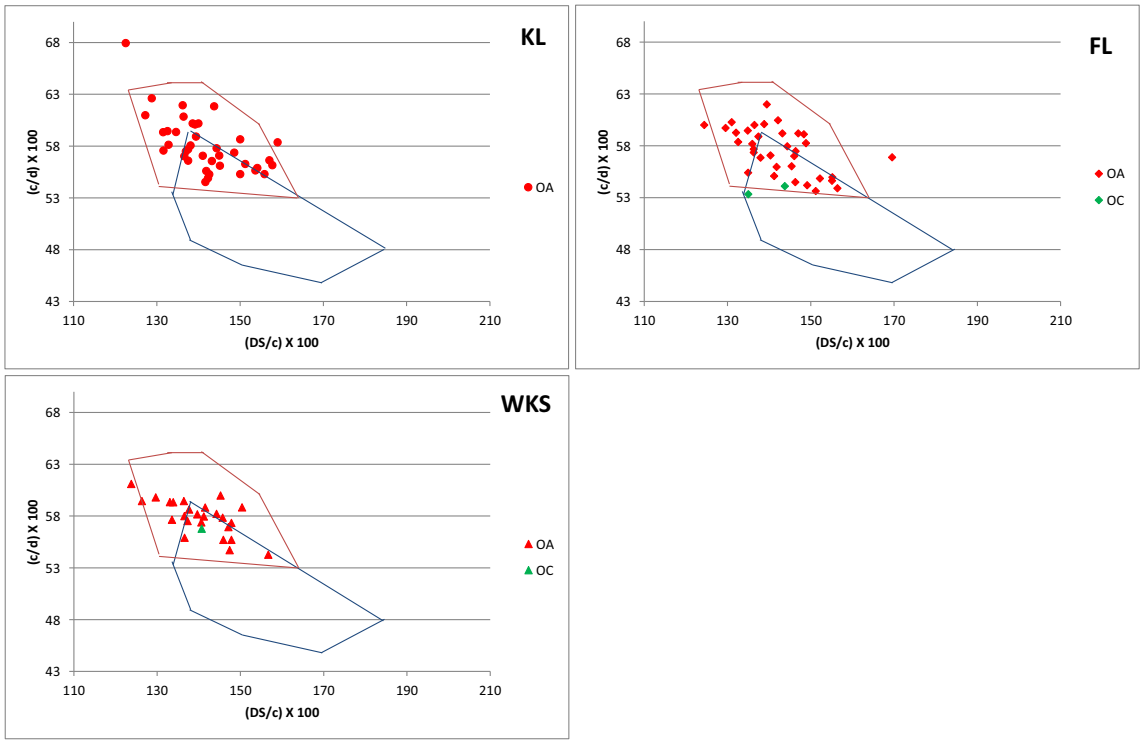

Fig. 17 Calcaneum: ratio between the greatest depth of the *substentaculum tali* (DS) and the length of the articular facet of the *os malleolare* (c) plotted against the ratio between the length of the articular facet of the *os malleolare* (c) and the length taken from the articular facet of the *os malleolare* to the end of the articulation-free part of the process (d). Symbols and lines as explained in Fig. 2

between the two will always exist. In addition, as LDA works following very rigid rules, all the new archaeological cases could be exclusively assigned to sheep or goat. These are the only two categories allowed by LDA, which does not have a sheep/goat category. With all specimens attributed to species, it is almost inevitable that some misidentifications will occur.

Despite these limitations, the use of LDA in combination with BI and morphological approach is still recommended. In fact, compared to BI, LDA has the advantage of being able to consider multiple measurements at the same time for the same element; more measurements included in the analysis means that a better description of the morphology of the bone can be achieved, and this would optimise, in some cases, the separation between the two groups. LDA also provides further insights on which are the most effective measurements to use for distinguishing between the two taxa. These considerations apply to all anatomical elements and will not be repeated for the other sections. If the archaeological data are taken into consideration (Supplementary material 2 Table A), it can be seen that, at KL, 29 horncores were morphologically identified as goat, but LDA attributed only 28 to this species and one to sheep, while one morphologically identified sheep has been attributed to the goat group. For the other two archaeological assemblages, morphological identifications were consistent with the LDA results.

Figure 20 shows visually the results presented by Supplementary material 2 Table A. In all graphs, most of the morphologically identified sheep and goat specimens tend to gather around the group centroid lines of the correct taxa. At KL, the archaeological goat re-classified as sheep by the LDA is approximately equidistant from the two centroid lines and is marginally an outlier in the sheep range, whereas the re-classified sheep plots well within the goat range and is slightly closer to the goat centroid (indicated by the red arrow). This very same specimen plots well within the goat area at KL in Fig. 2 (top graph); thus, the results from the BI are confirmed by the LDA.

Results are less satisfactory when, in order to increase sample size, some variables/measurements are left out of the analysis (S2 Table B). In fact, with the exclusion of measurements *E* and *F*, the degree of consistency between morphological and biometrical identification decreases (to 81% for the modern material, 85% for KL and 60% for WKS). The only exception to this pattern is FL where there is perfect agreement between morphological identification and biometrical analysis (100%), but the sample here is small. Clearly, the exclusion of these measurements makes the effectiveness of LDA on the horncores more questionable.

Figure 21 shows that more misidentified specimens are present when E and F are excluded. This result is not surprising as less information is available to the LDA.

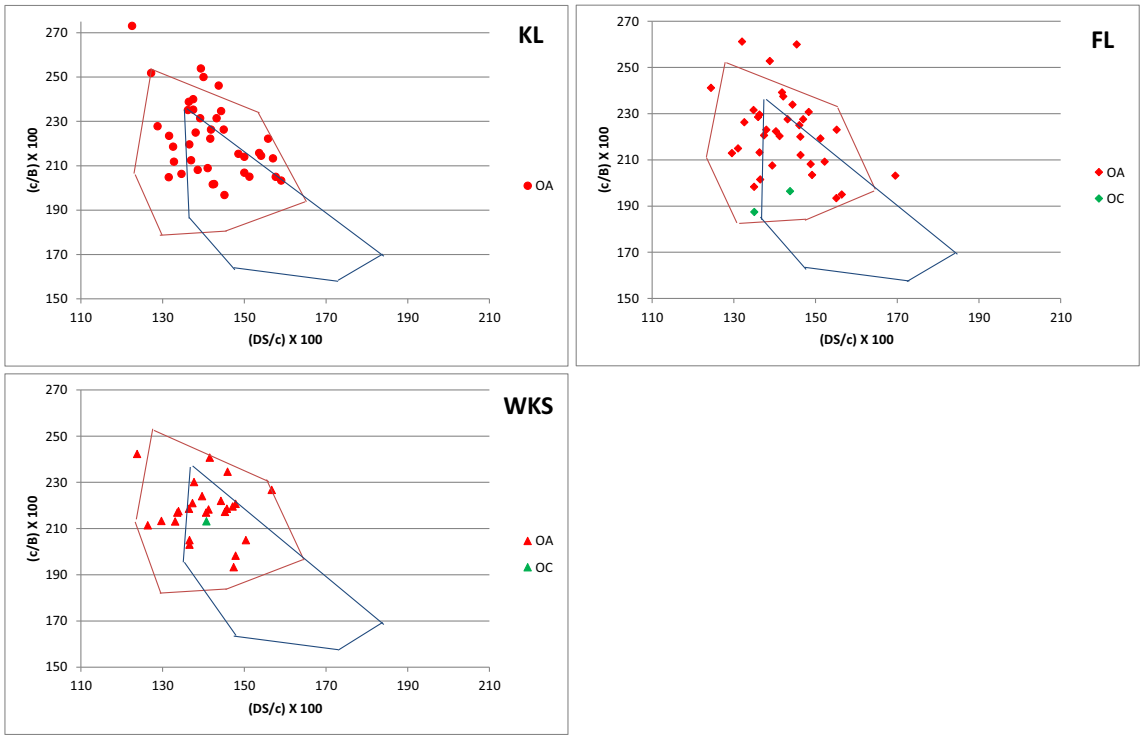

Fig. 18 Calcaneum: ratio between the greatest depth of the *substentaculum tali* (DS) and the length of the articular facet of the *os malleolare* (c) plotted against the ratio between the length (c) and the breadth (B) of the articular facet of the *os malleolare*. Symbols and lines as explained in Fig. 2

Scapula

In Supplementary material 2, Table C shows the results when LDA was applied on the measurements of the archaeological scapulae. For this element, the degree of consistency between morphological and biometrical identifications (94% for KL, 94% for FL and 100% for WKS) is very high, higher than the results provided by the modern material (86%). This difference in the rate of successful identification is likely to be due to the fact that the modern sample was more diversified—consisting of several different breeds while the archaeological populations may have been more homogeneous, therefore providing a better opportunity for a clear-cut distinction between the two species.

Figure 22 shows how the archaeological specimens relate to each other. At KL, one of the morphologically identified goats has been identified as such also by LDA, and it plots in between the two group centroid lines. Three sheep were re-attributed to goat by LDA. In the graph, they are equidistant from the two centroids, and as such, their re-classification cannot be relied on, especially considering the error that is inherent to the method. Conversely, the goat scapula re-attributed to sheep plots far away from the goat centroid, and in the midst of the sheep distribution—it may indeed represent mistaken identification, although this very same specimen does not appear suspicious in Figs. 3 and 4.

At FL, two sheep and a sheep/goat specimen were re-attributed to goat by LDA. One of the sheep specimens is

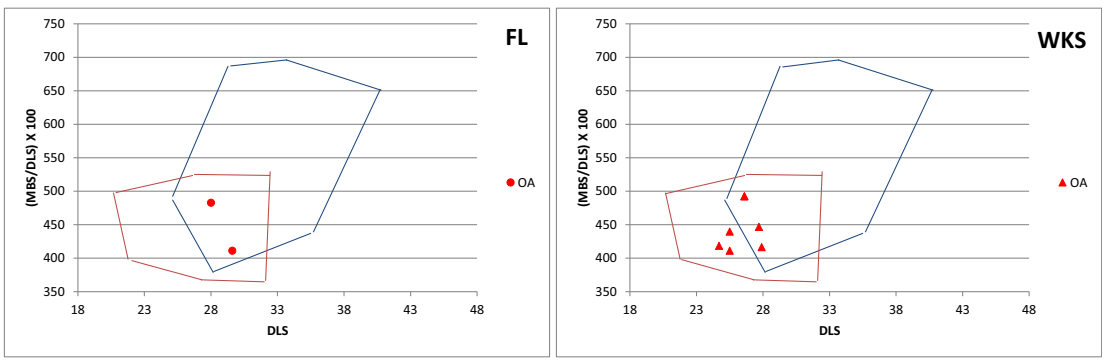

Fig. 19 Third phalanx: diagonal length of the sole (DLS) plotted against the ratio between the middle breadth (MBS) and the diagonal length of the sole (DLS). Symbols and lines as explained in Fig. 2

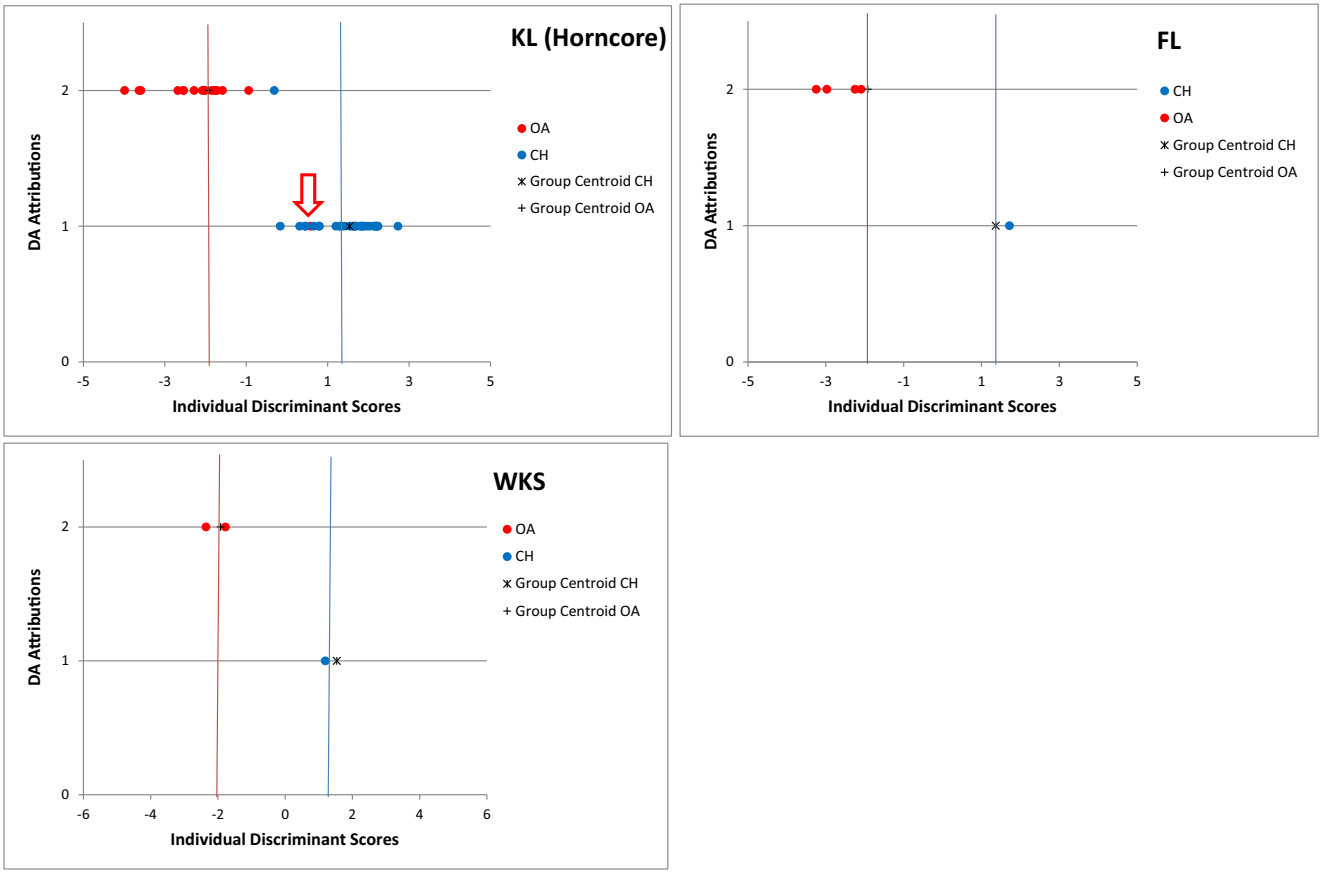

Fig. 20 Diagram of the LDA individual discriminant scores attributed to the archaeological material for the horncore. OA = *Ovis aries* (sheep), CH = *Capra hircus* (goat), KL = King's Lynn, FL = Flaxengate, WKS = Woolmonger/Kingswell Street

equidistant from the two centroids, and as such, its re-classification cannot be trusted. Conversely, the other sheep and the unidentified specimen fall very close to the goat group centroid line. Considering that the percentage of correct attributions of the modern material is lower than in the archaeological material, a re-classification of these specimens is doubtful. Of the two, however, the more likely goat is represented by the sheep/goat specimen which also plotted close to the goat range in Fig. 4.

At WKS, all the morphologically identified sheep gather around the group centroid of the sheep group. Most sheep/goat specimens also plot close to the sheep group centroid, while one coincides almost exactly with the goat centroid. Considering the separation between this latter specimen and the sheep group in Fig. 22 and that Fig. 3 clearly shows a sheep/goat specimen plotting far from the archaeological sheep, the LDA identifications are likely to be genuine.

Humerus

The percentage of consistent re-attributions for the archaeological humeri is 93% at KL and 100% at both FL and WKS. Clearly, inconsistencies in the attribution process between LDA and the morphological approach have occurred, but as the percentage of matching attributions is higher in the archaeological material than in the modern material (88%) (Supplementary material 2 Table D), all the re-classifications proposed by the LDA may potentially be due to the inherent error of the method.

The morphologically identified goat in KL falls beyond the goat group centroid line, confirming its identification. Most of the sheep specimens gather around the sheep centroid line. A few sheep and sheep/goat specimens were re-attributed to the goat by LDA. While some are equidistant from the two group centroids, others plot rather close to the goat centroid (Fig. 23) and these latter may indeed belong to goat, even though biometrical indices do not fully support this (Figs. 5 and 6). At FL, all archaeological sheep fall beyond the sheep group centroid, following a clear pattern. The only sheep/goat specimen also falls beyond the sheep group centroid line and is, undoubtedly, also a sheep. At WKS, all the morphologically and biometrically identified sheep gather around (and beyond) the sheep group centroid line, showing strong sheep characteristics.

Radius

The percentage of consistent re-classifications for the archaeological radii is, respectively, 79% at KL, 100% at FL and

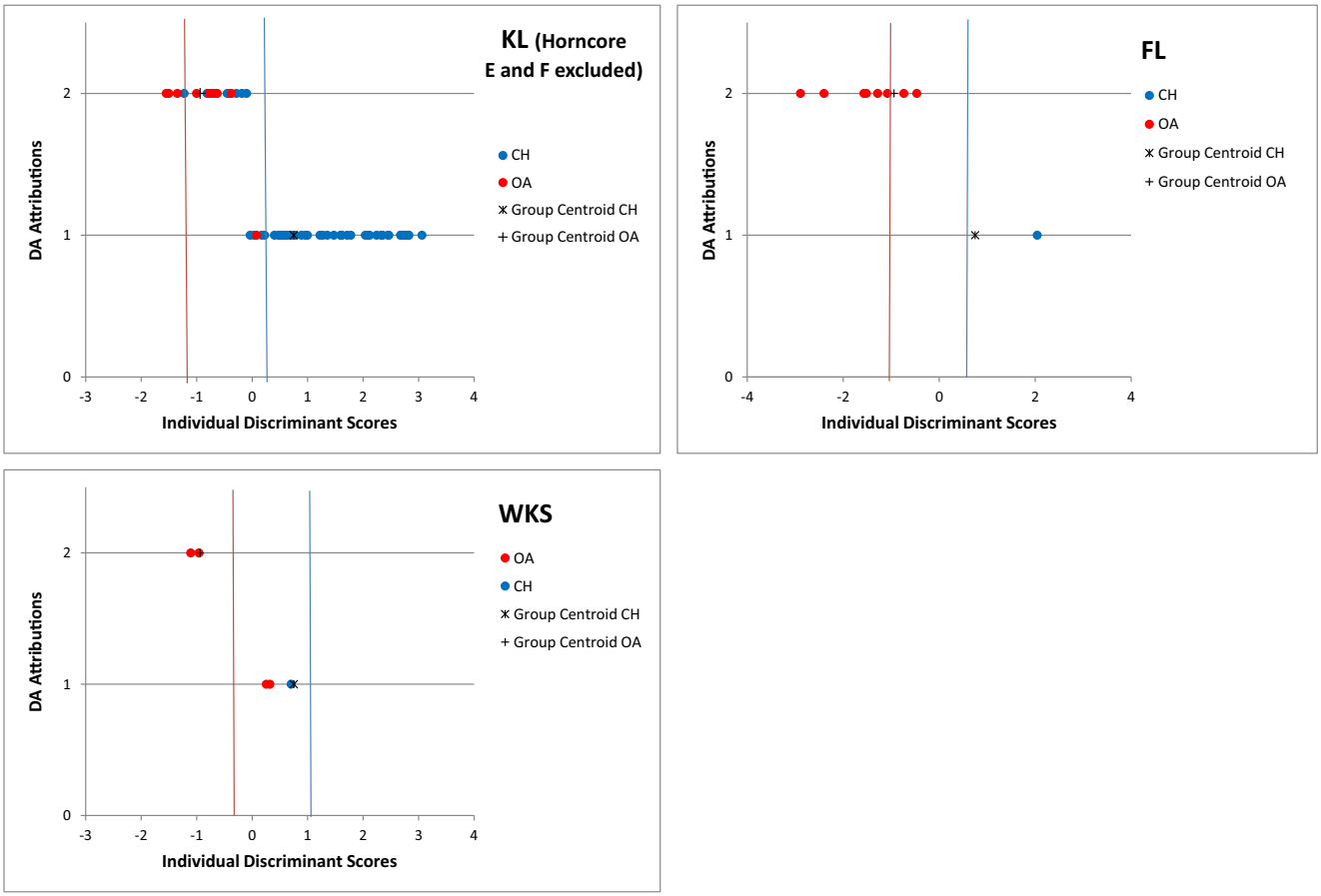

Fig. 21 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the horncore when variables *E* and *F* were excluded. Symbols are described in Fig. 20

90% at WKS. These percentages are, in two cases, lower than the results obtained from the modern material (93%; Supplementary material 2 Table E), which means that the identification error is higher than what one could expect from this application.

Figure 24 shows that, at KL, most of the archaeological sheep fall around or beyond the sheep centroid line. Four sheep specimens have been identified as goat by LDA. They fall in the area between the two group centroid lines. Since there are no archaeological sheep falling clearly on the goat group centroid or beyond that line, there is not very strong evidence to support the idea that these specimens are goats. The same pattern is visible if the scatterplots of the BI are considered (Fig. 7): there are borderline specimens and others which fall among the goat modern group but they are not far enough from the archaeological sheep centre of distribution to be considered misidentified.

At FL, there is perfect matching between the morphological and biometrical identifications: all the archaeological sheep fall beyond or very close to the sheep group centroid line. At WKS, one sheep specimen has been re-classified as goat by the LDA. It falls equidistantly from the two group centroid lines. If one considers that the analysis of the BI had not highlighted any clear inconsistency with the morphological identifications (Fig. 7) and that LDA bears an inherent error, the LDA re-classification cannot be relied on.

At all sites, when variables GL and SD are excluded from the LDA and the sample size increases, the percentage of correct re-attributions decreases, respectively, to 76% at KL, 92% at FL and 83% at WKS (Supplementary material 2 Table F). Clearly, the loss of information affects the diagnostic power of the LDA as the number of 'misattributed' specimens increase.

Figure 25 shows that a greater number of sheep specimens are regarded as misidentified by the LDA at all three sites when GL and SD are excluded from the analysis. At KL, the identification of a goat radius has been confirmed by LDA. On the other hand, several archaeological sheep fall in the area between the two group centroid lines, but a few others fall beyond the goat centroid line showing values that are more consistent with the goat group. These three specimens could indeed have been misclassified, but we must be careful, as the dropping of the measurements means that this analysis mainly relies on the proximal radius measurements. As discussed for the BIs, this articular end has an early fusing epiphysis and may be subject to substantial post-fusion increase, which may confuse morphometric patterns; thus, the use of LDA on this

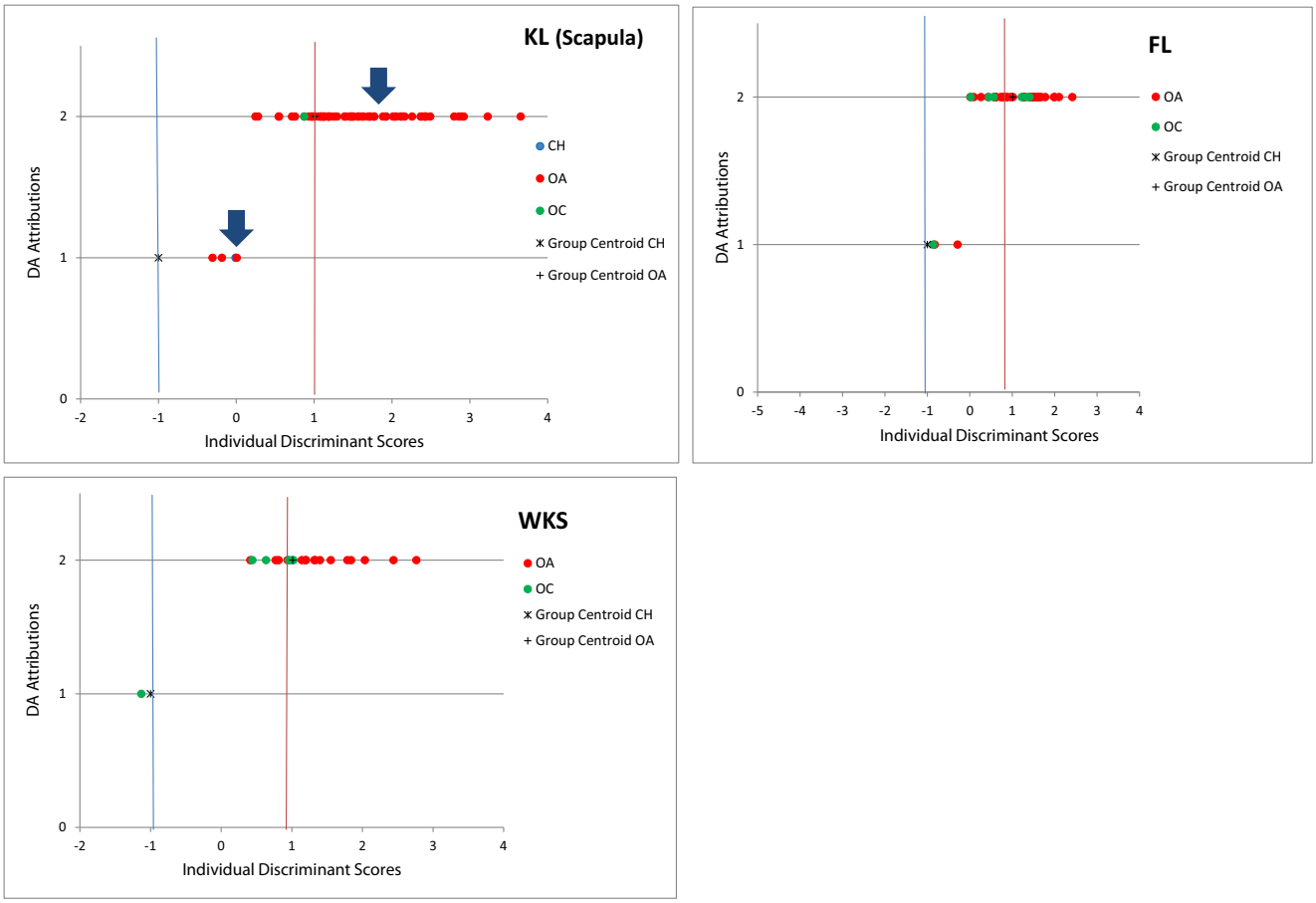

Fig. 22 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the scapula. Blue arrows indicate the position of the two archaeological goats. Symbols are described in Fig. 20

element, especially when GL and SD cannot be included, needs to be taken with caution. Similarly, at FL, the seven sheep attributed to goat by the LDA fall approximately in line with other archaeological and biometrically identified sheep; considering the bias the method itself bears, there is limited argument for their re-classification. One sheep/goat specimen is very consistent with the sheep group and can be considered as such, while the other unidentified specimen, which falls well beyond the goat group centroid line, may belong to a goat. This identification is confirmed by the BI (Fig. 7). Finally, at WKS, none of the re-attributed specimens falls beyond the goat group centroids but all fall in the area between the two group centroid lines, with some being equidistant from both lines (for example, the unidentified specimen). Considering the position of the specimens and the fact that no possible goats have been found with the BI analysis (Fig. 7), the specimens cannot be confidently re-classified as goats.

Ulna

For the ulna, the percentage of correct identifications (94% for KL and 100% at both FL and WKS) is higher than the results obtained from the modern material (93%; Supplementary material 2 Table G). This means that any re-classification (of which there is only one) may be due to the method's normal margin of error.

Figure 26 shows that, at KL, only one archaeological sheep has been re-identified as goat by the LDA. This specimen falls among the two group centroid lines and, as such, cannot be confidently considered to belong to a goat. The one sheep/goat specimen clearly plots with the sheep group.

At FL, all the morphologically identified sheep have been considered as such by the LDA, and they all fall very close or beyond the sheep group centroid. The unidentified specimen clearly follows the sheep pattern and, as such, has to be considered a sheep. The same situation is present at WKS: no re-classifications have occurred and all the sheep specimens fall very close to or beyond the sheep centroid group.

When the variables B and L are excluded from the LDA, the percentage of correct re-attributions is still high: 91% at KL and 100% at the other two sites (92% for the modern material; Supplementary material 2Table H). Consequently, the exclusion of B and L does not heavily influence the diagnostic power of LDA. With the exclusion of the above-mentioned variables, the disagreement between morphology and biometry increases slightly at KL. A few archaeological sheep fall in the area

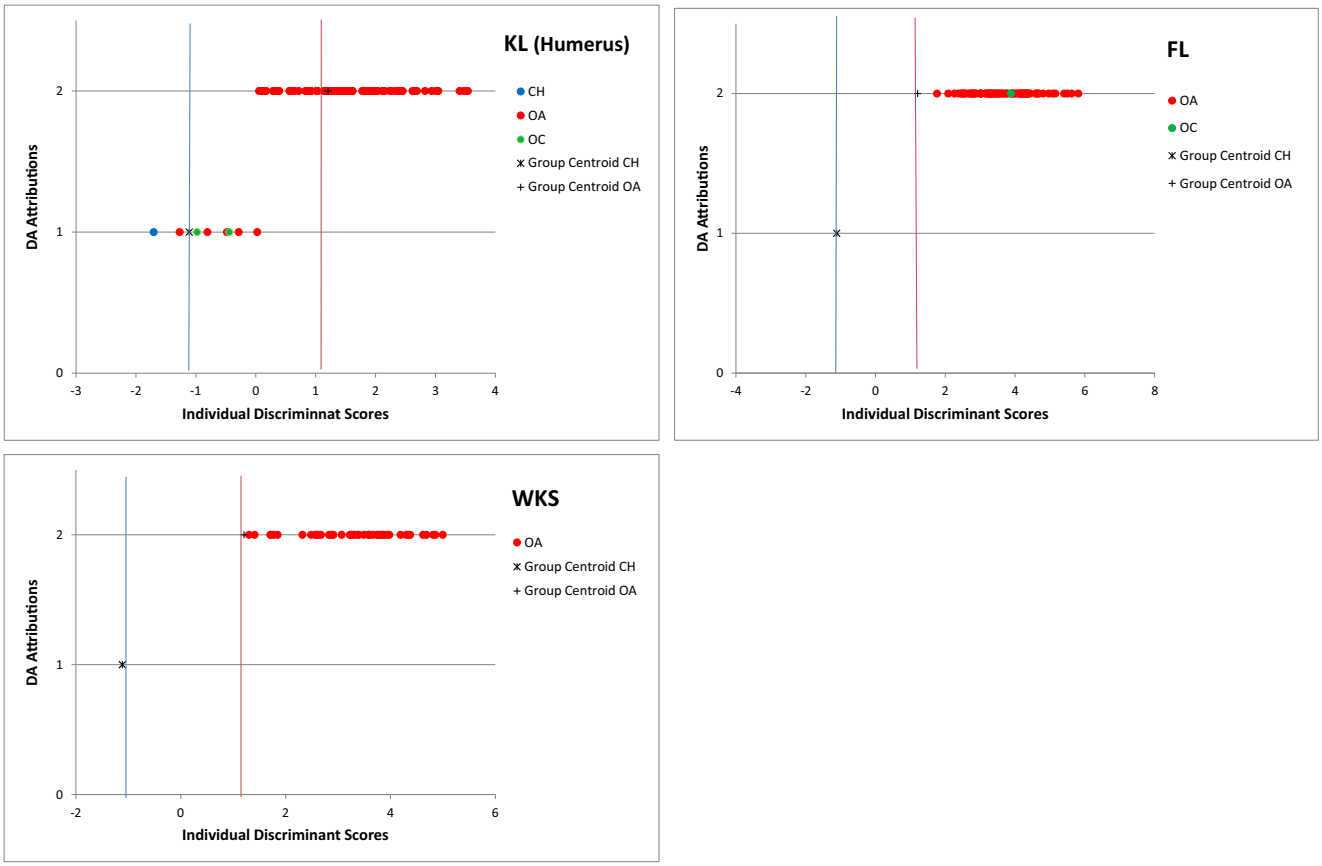

Fig. 23 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the humerus. Data are presented in this order: King's Lynn, Flaxengate and Woolmonger/Kingswell Street. Symbols are described in Fig. 20

between the two group centroids, but none of them plot on or beyond the goat group centroid (Fig. 27). The combined result is that the LDA re-classification cannot be relied on and the original morphological evaluation must stand. At FL, all the morphologically identified sheep gather around the sheep group centroid line. The two unidentified specimens by and large follow the same pattern, though the specimen plotting at the far left is more uncertain. The same output was obtained from the specimens from WKS: the degree of consistency between the morphological and biometrical identification stays stable. One morphologically unidentified specimen plots convincingly with the sheep group.

Metapodials

When all the measurements for the metacarpals were included in the analysis, a complete match was present between the morphological and LDA results at all sites (100%) (98% for the modern material; Supplementary material 2 Table J).

Figure 28 shows that, at all three sites, the morphologically identified sheep specimens fall close to the sheep group centroid, and some are indeed beyond the centroid line showing strong sheep traits.

When the variables GL and SD were excluded from the analysis, the value of correct re-attributions decreased slightly, respectively, to 94% at KL, 95% at FL and 98% at WKS (S2 Table K). Since the percentage of correct identifications of the modern material was slightly higher (97%), at least for two of the sites, it is worth looking at the position of these uncertain specimens on the diagram (Fig. 29).

At KL, the two sheep specimens which have been classified as goat by LDA fall in the area between the two group centroids, and therefore, there is insufficient evidence for the LDA re-classification to overrule the original morphological identification.

The number of misidentified cases has also increased at FL, where two of the 41 originally identified sheep were assigned to goat by the LDA. Considering that these specimens are approximately equidistant from both the group centroid lines, that the exclusion of some variables affects the diagnostic power of LDA, and that such 'misclassification' is not mirrored by the BI (Figs. 9 and 10), there is a limited argument for their re-classification. For the same reasons outlined above, the sheep specimen identified as goat by LDA at WKS cannot be re-classified.

The results for the metatarsals (all measurements included) are presented below (Supplementary material 2 Table L).

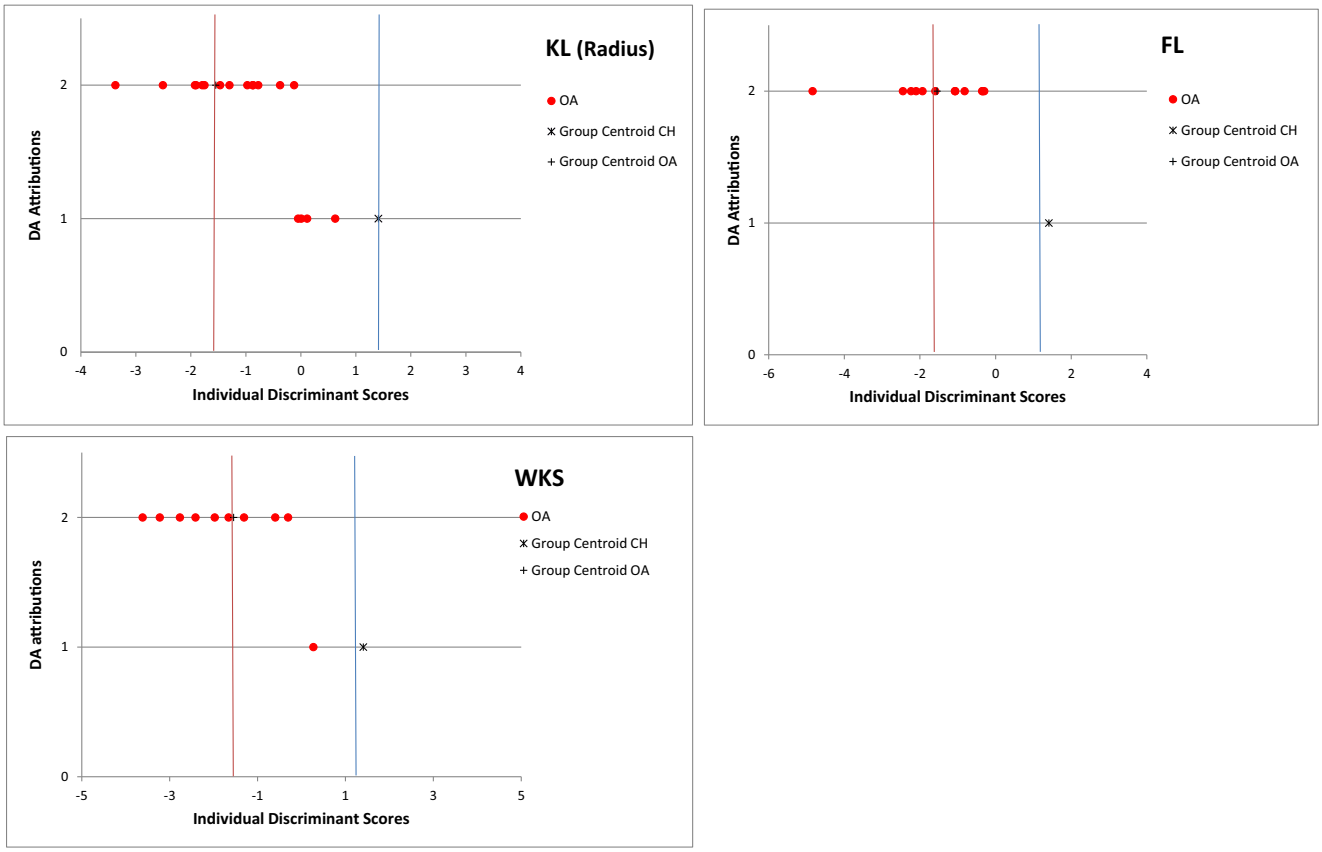

Fig. 24 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the radius. Symbols are described in Fig. 20

Apart from KL, for which the percentage of correct identifications is lower (85%) than the results from the modern material (93%), at the other archaeological sites, there is complete matching between morphological and LDA attributions.

In Fig. 30, it can be seen that, at KL, three of the 20 specimens morphologically attributed to sheep are re-classified as goat by the LDA. Of these, two plot between the two centroids and, therefore, cannot be confidently re-attributed to the goat, while another clearly plots in the goat area of the diagram and is, therefore, likely to have been misidentified at the morphological level. This assumption is also confirmed by the analysis of the biometric indices (Fig. 12). At FL and WKS, on the other hand, all the morphologically identified sheep fall beyond the sheep group centroid, confirming their attribution. The only morphologically identified goat present at WKS plots beyond the goat group centroid line, confirming its identification.

When the variables GL and SD were excluded from the analysis, the percentage of consistent attributions decreased at all sites (82% at KL, 84% at FL and 85% at WKS) (Supplementary material 2 Table M). Clearly, this exclusion had a considerable impact on the diagnostic power of the LDA. In all cases, these percentages are lower than the proportion of correct identifications as expected on the basis of the modern material (89%); therefore, the possibility of morphological misidentification of the archaeological material must be considered.

In Fig. 31, we can see that, at KL, most of the re-classified sheep fall in the area between the two group centroids and, although some lean more towards the goat centroid, the evidence is nevertheless insufficiently strong to be confident about a re-identification. The one specimen plotting on the right of the goat centroid is the same that plots as an outlier in Fig. 12, therefore confirming the validity of its re-identification as goat. At FL, a number of sheep re-identified as goat by the LDA fall, by and large, equidistantly from the two group centroid lines, and there is therefore limited argument for their misclassification, considering also the intrinsic bias the method has. Three sheep, re-classified as goat by the LDA, fall either very close or beyond the goat group centroid line; these may have been misidentified. Considering that this situation is not mirrored by the BI and that the loss of information caused by the exclusion of some variables heavily affects the LDA power, there is, however, limited evidence for their misclassification. The two unidentified specimens clearly plot within the sheep range. Finally, at WKS, the two morphologically identified goats plot close or beyond the goat centroid group line confirming their identification. Most of the re-classified sheep fall in the area between the two group centroids, and although some lean more towards the goat centroid, the evidence is insufficiently strong for a re-identification.

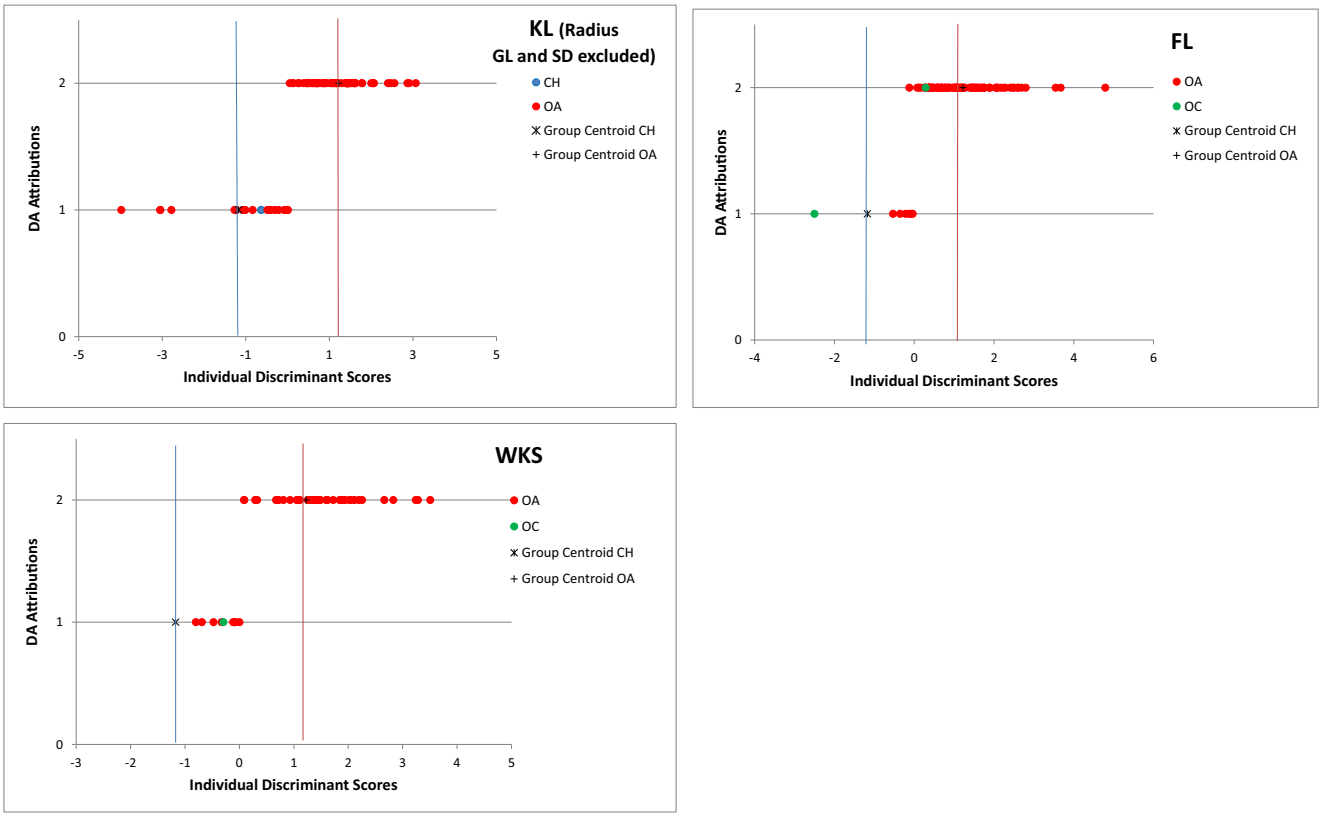

Fig. 25 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the radius when variables GL and SD were excluded. Symbols are described in Fig. 20

Tibia

For the tibia, the percentage of consistent attributions at KL (67%) is much lower than for the modern material (89%), while at WKS, there is a complete agreement between morphological and biometrical identifications (100%, Supplementary material 2 Table N), but this is not a meaningful proportion, due to the very small sample size. At FL, no complete tibiae were present to perform this analysis.

Figure 32 visually displays the results presented in Supplementary material 2 Table N. At KL, three out of four specimens (two morphologically identified sheep and one sheep/goat) plot around the sheep group centroid, while one morphologically identified sheep is definitely more in the goat area (as also previously seen in Fig. 13). Since both BI and LDA show consistency in the attribution of this specimen, its original morphological identification must be questioned. At WKS, on the other hand, both specimens have been identified as sheep from both morphological and LDA analysis.

When measurements GL and SD were dropped and the sample size increased, the degree of consistency at all sites is slightly higher (79% at KL, 82% at FL and 74% at WKS) than the one achieved on modern material (72%; Supplementary material 2 Table O), indicating that any re-classification may be a consequence of the method's inherent error.

Figure 33 displays the results presented by Supplementary material 2 Table O. The sheep outlier at KL is likely to be another goat (this specimen is different from the one in Fig. 32). At FL, some of the misidentified sheep fall equidistantly from the two group centroid lines (Fig. 33); as such, there is no strong evidence for them to be re-classified as goats. Although some specimens fall beyond the goat group centroid line, they demonstrate continuity with the other specimens and, considering the inherent error of the method, cannot be confidently re-classified. Such re-classification would also not be consistent with the results of the BI (Fig. 13). Concerning the morphologically unidentified specimens, apart from the one plotting at the far left—clearly in the sheep range—the others cannot be confidently identified due to the degree of error of the method and the area of the diagram where they plot. At WKS, the only morphologically identified goat has been identified as such by LDA as well and plots close to the goat centroid line (Fig. 33). Many of the specimens morphologically identified as sheep and re-identified as goats from the LDA are in fact in continuity with the sheep range and cannot be confidently regarded to be goats for the same reasons outlined above. The two outliers on the right (a sheep and a sheep/goat on the basis of their morphology) look genuinely different and may indeed represent goats. Such a small number of possibly re-classified specimens would be consistent with the evidence of the BI (Fig. 13). In Fig. 13, in fact, the sheep appears to be placed among the goats and the unidentified specimen falls on the lower edge of the modern goat group. Altogether, the evidence suggests that these two specimens are goats.

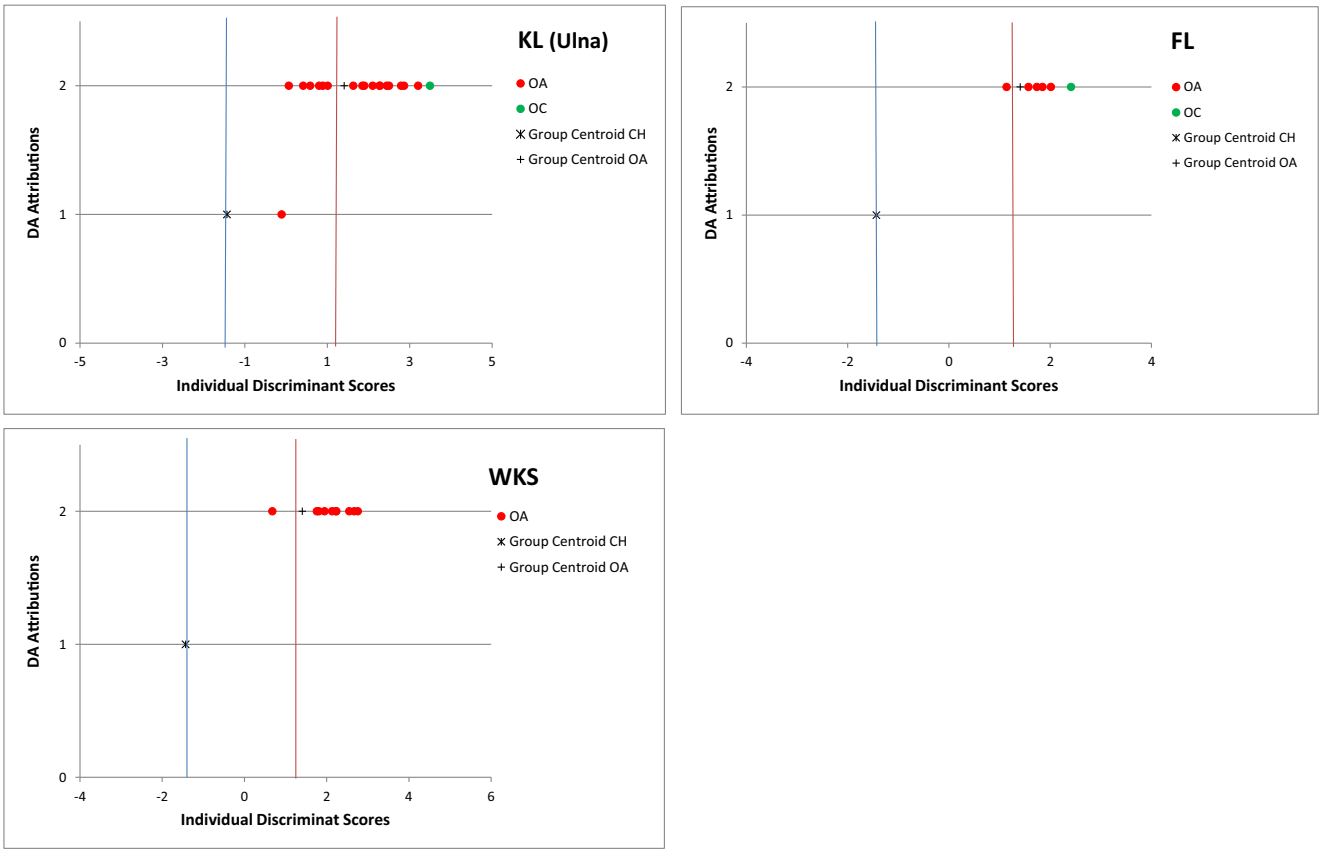

Fig. 26 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the ulna. Symbols are described in Fig. 20

Astragalus

The percentage of agreement between the morphological and biometrical identifications for the astragalus is 84% at KL, 90% at FL and 87% at WKS. These results are very similar to those obtained for the modern material (89%) (Supplementary material 2 Table P).

Figure 34 shows that some morphologically identified sheep at all sites have been re-classified as goat by LDA. They fall equidistantly between the two group centroid lines. Considering their position on the diagram, there is not enough evidence to question the original morphological identification as sheep: re-classification is, in fact, not supported by the BI analysis (Figs. 14 and 15).

The sheep falling on the goat group centroid lines at both KL and FL, on the other hand, may indeed be a goat, also considering the gap existing between this specimen and the rest of the distribution. However, its re-classification is not strongly supported by the BI (Figs. 14 and 15), and as such, these specimens must be regarded to be of uncertain identification. At WKS, all sheep specimens fall between the two group centroid lines or beyond the sheep group centroid lines. One specimen fell equidistantly from both lines, but considering that this is not mirrored by BI (Figs. 14 and 15), the evidence is not strong enough to justify a re-classification.

Calcaneum

Supplementary material 2 Table Q shows that the percentage of consistent re-attributions for this element is very high at all sites (97% at KL, 97% at FL and 100% at WKS). These percentages are higher than the results obtained from the modern material (95%).

Figure 35 shows that, at KL, the only sheep specimen that was re-classified as goat by the LDA plots between the two centroids and, therefore, cannot be confidently re-classified. This is also confirmed by the fact that there are no ambiguous specimens in Figs. 16 and 17. At FL, two specimens (a morphologically identified sheep and a sheep/goat), which have been identified as goat by the LDA, fall equidistantly from the two group centroid lines. Considering that the method bears an intrinsic bias, that these specimens fall equidistantly from the two group centroid lines and that no particularly problematic specimens have been found with the study of the BI (Figs. 16 and 17), there is little evidence for considering their re-classification. At WKS, all the morphologically identified sheep were re-classified as sheep by the LDA. One unidentified specimen plots very close to the sheep group centroid line, so it is likely to be a sheep.

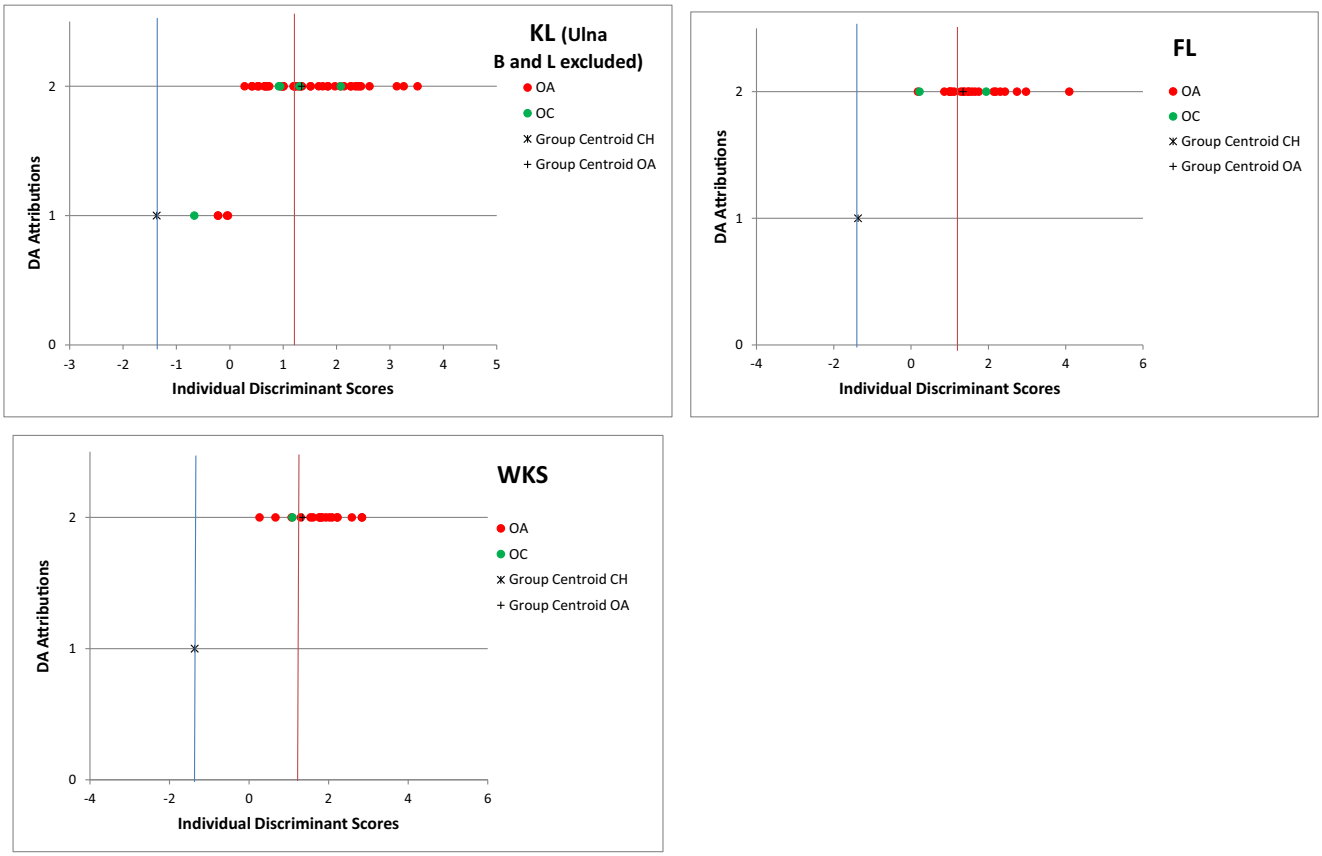

Fig. 27 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the ulna when variables B and L were excluded. Symbols are described in Fig. 20

Third phalanx

A problem of multicollinearity (i.e. a situation in which two or more variables are very closely linearly related) (Field 2009, p. 790) prevented the use of LDA on archaeological 3rd phalanges.

Discussion

Some considerations on the application of the new methodology on archaeological material

The application of the new methodology on three different medieval English sheep and goat assemblages has provided very promising results. The ratios have all succeeded in highlighting different distribution patterns for archaeological sheep and goat. In addition, the modern material sample used as a guideline for the identification of patterns in the archaeological material has generally shown to be a good fit. In other words, the archaeological sheep and goats tend to plot in the same areas as their modern counterparts with some outliers. A noticeable exception to this trend is the proximal radius, which has not provided particularly clear results. This, as has already been suggested, could be a consequence of the fact that the morphology of the proximal radius is very variable with age, and this may lead to confusion in taxonomic identifications.

The BI have proven to be extremely valuable as they can be used for supporting or questioning identifications made through the use of morphological criteria. An example of such potential is demonstrated by those (few) morphologically identified sheep that were biometrically re-classified as goats. BI can also assist in speciating the specimens that could not be identified morphologically, though this is only possible in a few cases. The most important feature of the BI is, however, the opportunity to provide transparency to the identification process and, therefore, opening it up for re-interpretation when required.

The application of the LDA as a tool to predict species identification has, for the first time, been applied on archaeological sheep and goat assemblages. Fairly high consistency has been noticed between the morphological approach, BI and LDA results. Almost all elements have provided high re-attribution rates, showing a high rate of agreement with the morphological identifications (Supplementary materials 2 and 3). As seen with the BI, the most problematic element in LDA analysis was the proximal radius; as such, the authors

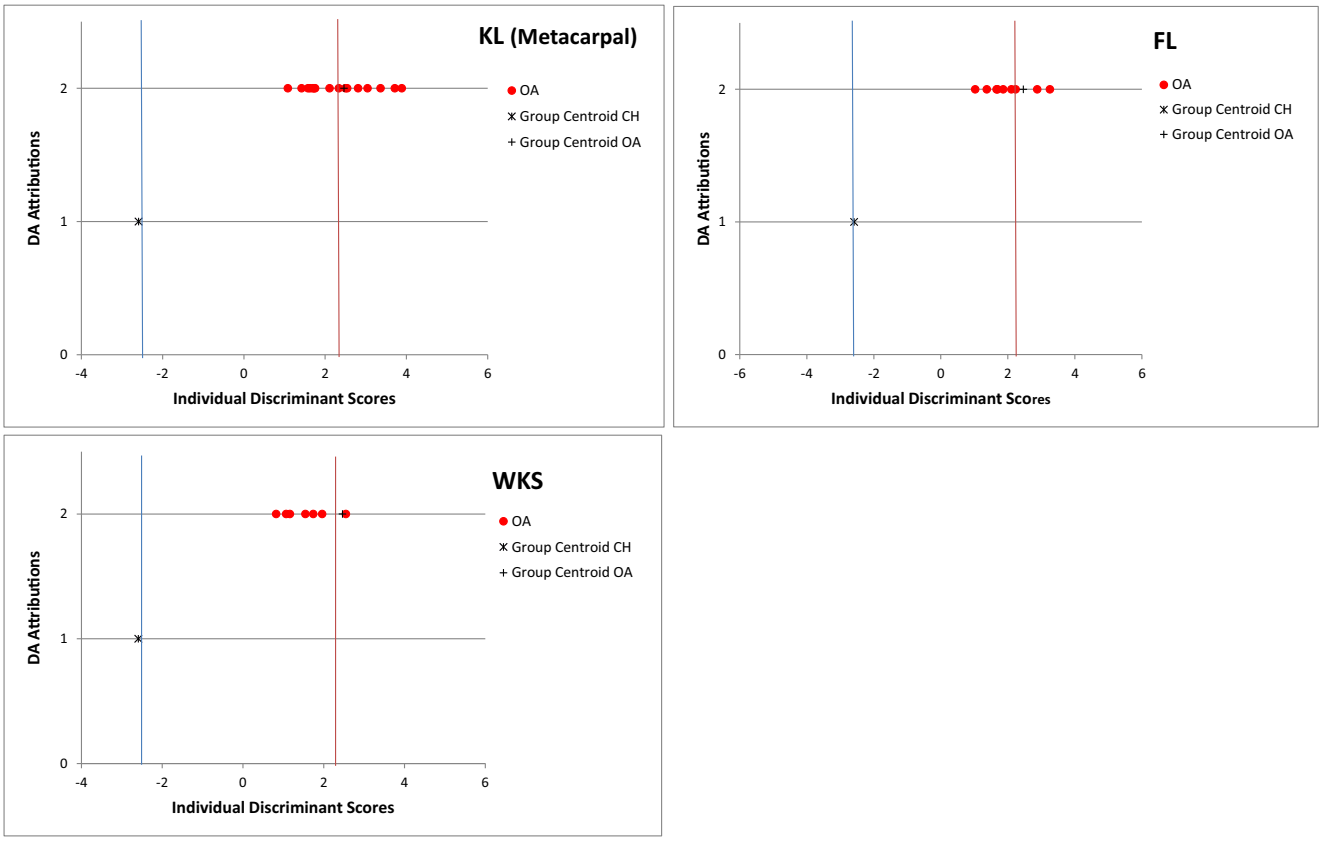

Fig. 28 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the metacarpal. Symbols are described in Fig. 20

recommend caution when interpreting data using this element, though its high rate of successful identification in the modern material suggests that this element may still be valuable. In some cases, the rate of identification success obtained with LDA was lower than what was expected on the basis of the analysis of the modern material. Despite its successful application, it is clear that LDA should not be used in isolation, as it has its own drawbacks. For example, sample size can clearly influence the results; thus, the smaller the sample, the less confident we can be about the reliability of the LDA attributions. In addition, the exclusion of some variables/measurements from the LDA, a likely scenario when dealing with fragmented archaeological material, may affect the results detrimentally, which means that the power of this method will be diminished. Finally, in evaluating the LDA results, it is essential to consider that the method bears, as previously explained, an intrinsic error, as LDA follows rigid rules (all specimens are assigned to one of the two categories, sheep or goat). With all specimens attributed to species, misidentifications are inevitable.

In using LDA as a predictive tool to interpret archaeological data, we strongly suggest following these rules to ensure a correct interpretation of the data:

1. When the percentage of correct re-attributions of the archaeological material is as high as, or higher, than the percentage provided by the modern material, the expectations of correct re-attributions are exceeded. As such, any identification error highlighted by the LDA may simply be a consequence of the inherent error of the method, though the identification of specimens that plot closer to the centroid of the other species must still be questioned.
2. When the modern material has provided a higher percentage of correct re-attributions compared to the archaeological, the misattributed specimens must be scrutinised closely as the probability of genuinely incorrect identifications is higher. A crosscheck between the different approaches is highly desirable, as this will allow the opportunity to make a more detailed and more reliable assessment of the actual relative frequency of sheep and goat.

This study has revealed that, if used appropriately, LDA has the potential to:

- Be a further means to support/question identifications assessed with the other two approaches

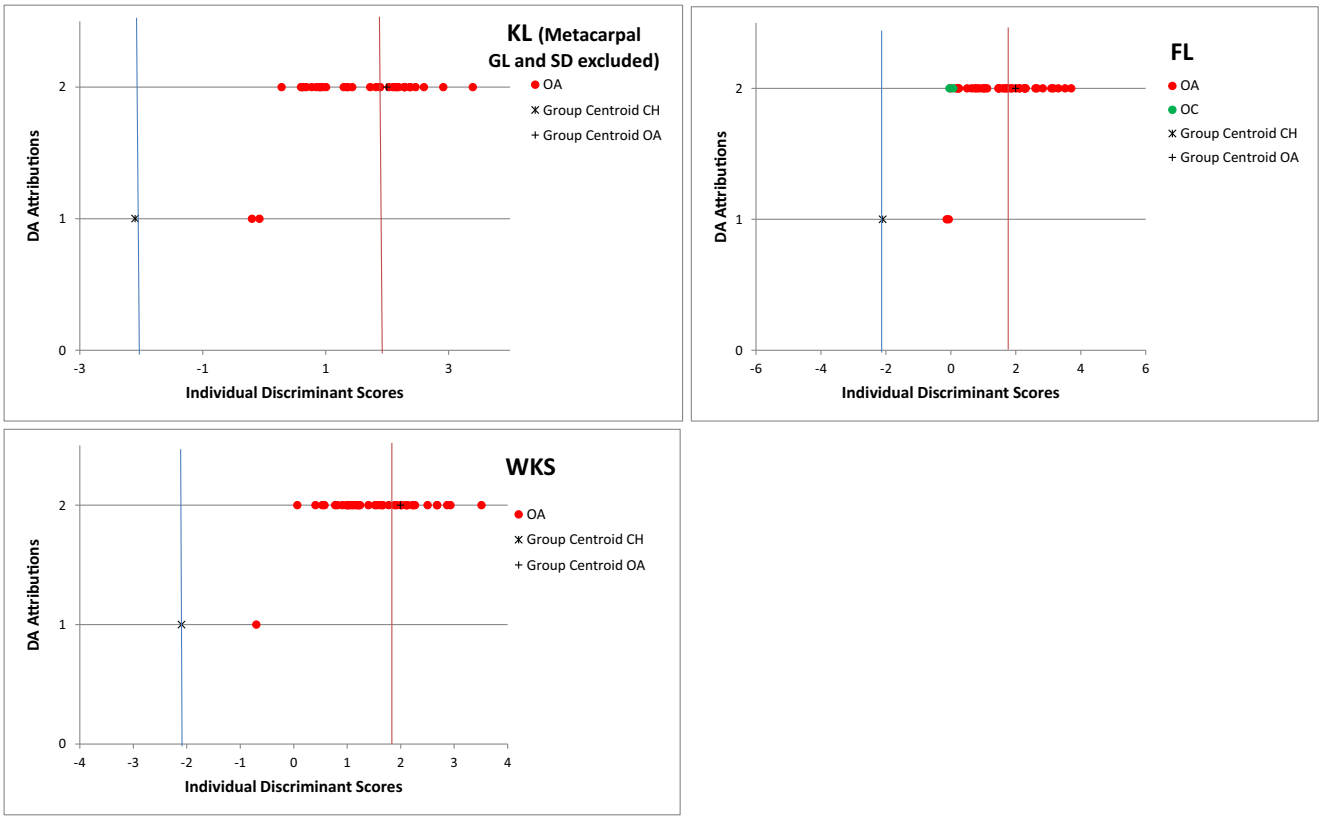

Fig. 29 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the metacarpal when variables GL and SD were excluded. Symbols are described in Fig. 20

- Assist in establishing the identity of the sheep/goat specimens
- Provide a visual representation of the distribution patterns of the caprine specimens from a given assemblage

It is important to remember that LDA will rely on a larger number of measurements than BI, all used simultaneously. This means that its power to describe the morphology of a bone biometrically is greater.

It is the combination of these techniques (morphological approach, BI and LDA) that can provide the best results and has the potential to increase the possibility of reliable identifications. However, if there is no time for a thorough analysis, even the application of only the BI approach in addition to the more traditional morphological approach will contribute to enhancing the identifications and making them openly subject to scrutiny.

A re-assessment of the role of the goat in medieval English husbandry and economy

The analysis of three English medieval goat and sheep assemblages with the use of the new methodological approach proposed in this paper has allowed the beginning of a re-assessment of the role that the goat played in the English economy and society of the time.

Overall, the results have confirmed what many researchers had observed in the past, namely that the goat was not abundant in medieval England (Albarella 1997, 1999, 2003; Albarella et al., unpublished; Clutton-Brock 1976; Dyer 2004; Grant 1988; Noddle 1994). Most of these previous works had, however, cautioned that only a morphological re-assessment of goat identifications could confirm this situation. The archaeological application of the new methodology does confirm the trend and suggests that the goat has *not* been under-estimated in medieval English animal bone assemblages.

In the archaeological record, this animal is mainly represented by horncores, while post-cranial bones are sporadic. In this regard, all three case studies have, by and large, shown and confirmed the pattern: goat horncores are more numerous than sheep horncores, but when post-cranial bones are considered, sheep by far outnumbers goat. This means that only very few goats, or parts of the goat carcass, were introduced/present at the sites to be butchered and consumed.

In the case of King's Lynn, the disproportion between goat horncores and post-cranial elements was particularly evident. The abundance of horncores, the fact that many were found in discrete accumulations (Noddle 1976, 1977), and the high

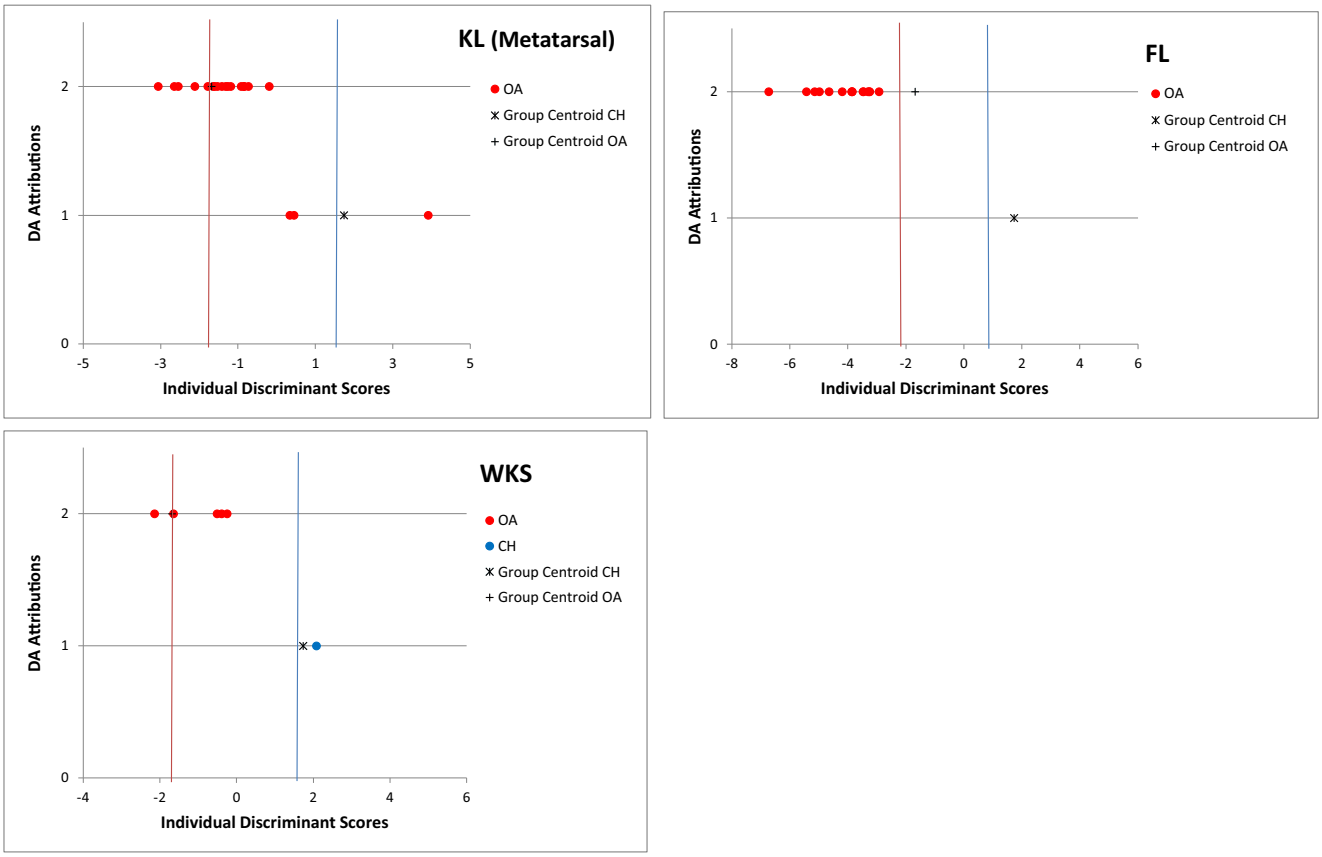

Fig. 30 Diagram of the individual discriminant scores attributed to archaeological material by LDA for the metatarsal. Symbols are described in Fig. 20

frequency of cut and chop-marks noted, suggests a specialised use for this material, beyond mere food consumption. Considering that, in the course of the Middle Ages, horn-working activities decreased while leather production increased notably (Albarella 2003), a tanning or a tawying process is the most likely cause of the accumulation of horncores. Horns were likely to be still attached to the skins when they arrived at the site (Serjeantson 1989). The skins were worked and processed into leather either at the site (even though in the case of King's Lynn there is no evidence of the existence of a tannery) or they may have been sent to another place to be worked. In this latter case, which implies a movement of highly perishable material from one site to another, it is likely that the horncores, still attached to the skins, were removed and left behind at the 'primary' place in order to make the goods more easily transferable and less prone to decay. In either of the two cases, the horns were the most likely waste material resulting from this process and were discarded or sold to horn-workers so that the keratinous sheath could be used as raw material.

The evidence that goat bones are rare at all sites regardless of geographical location or status leads us to the conclusion that a trade in goat skins may have existed with other countries as, otherwise, it is difficult to explain what happened to the many skeletons that belonged to the specimens whose horncores have frequently been found. This hypothesis fits well with the role that King's Lynn had as an important port and trade centre.

Following this hypothesis, we would expect to find a greater number of horncore deposits at coastal and port sites, i.e. import centres. The zooarchaeological evidence seems to confirm such reasoning. Beside King's Lynn, in fact, there are a number of coastal medieval sites in which accumulations of horncores have been found with very little evidence for goat post-cranials. Some examples for the eastern areas are the sites of Fishergate, York (tenth century to fourteenth century onwards) (O'Connor 1991), Norwich Castle (Albarella et al. 2009) and Coslany Street (tenth to fourteenth century) (Albarella 1997) in Norwich (Norfolk) and Ipswich (mid-seventh century to twelfth century) (Crabtree 1989) in Suffolk. In the south-western regions, only the sites of Exeter (Maltby 1979), Exe Bridge (Levitan 1987) in Devon, Bristol (fourteenth century) (Noddle 1975) and Hereford (eleventh century to sixteenth century) (Baxter, unpublished) provide the same pattern.

Considering the effort that such trade would have required, a question arises: what was the purpose behind such movements of goat skins? Several studies have demonstrated that

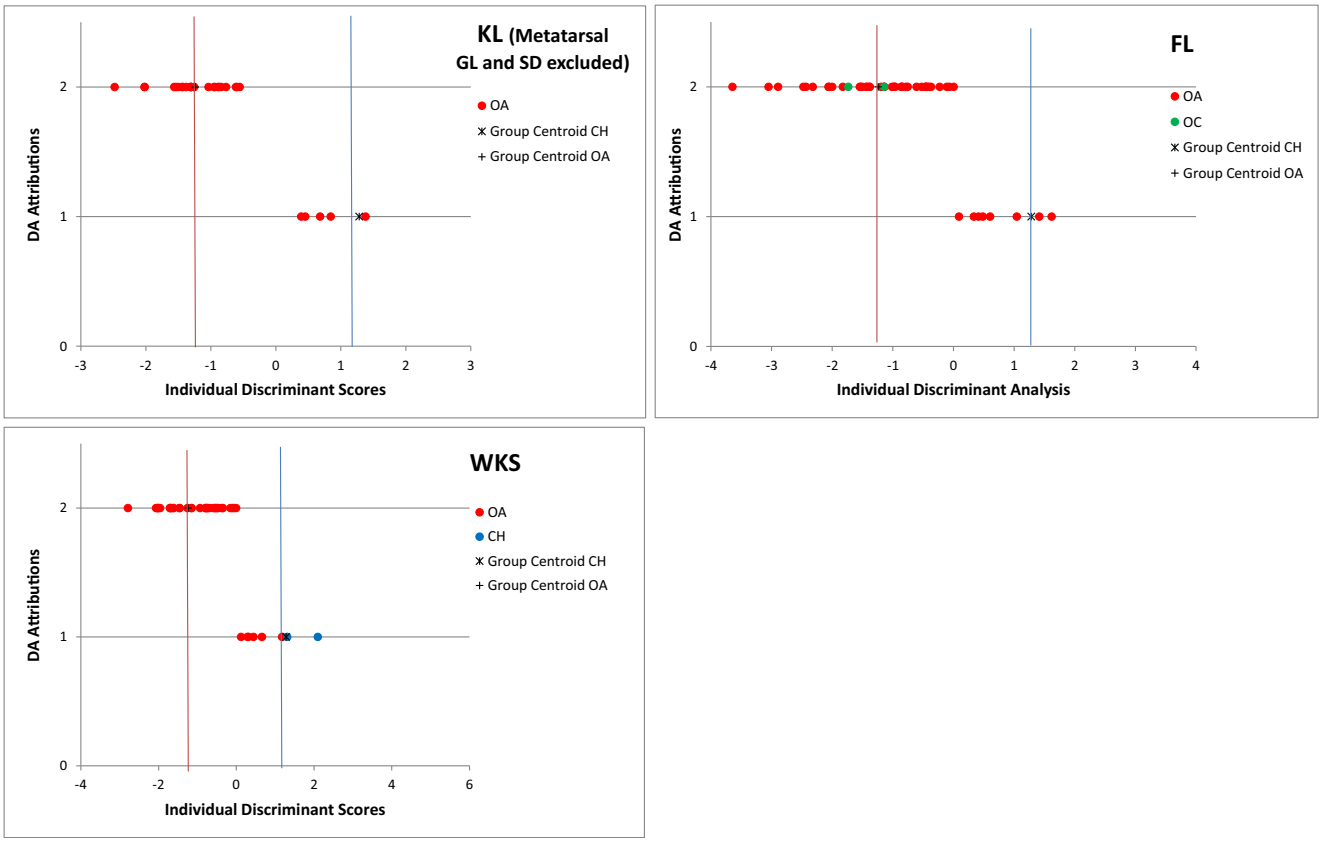

Fig. 31 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the metatarsal when variables GL and SD were excluded. Symbols are described in Fig. 20

goat skins have particular qualities (i.e. tenacity and strength) (Reed 1972; Salehi et al. 2013), which make them more suitable than sheep skins for the production of durable objects such as shoes, boots and garments. However, this reason seems not to be strong enough to justify a trade in goat skins, especially considering that the more readily available sheep skins would have represented a reasonable alternative. A recent study on parchment folios from European medieval pocket Bibles conducted by Fiddyment et al. (2015) opens a new perspective on the matter. The analysis, with the use of peptide fingerprints, has revealed that in England, during the twelfth and thirteenth centuries, parchment from sheep skins was mainly destined for the production of legal documents, while folios from goat skins were used for the manufacture of pocket Bibles. This evidence is intriguing and may point towards a specialised use of goat skins.

A similar situation to King's Lynn is common to other English medieval assemblages. Data from these sites are important to consider, as they indicate and confirm the existence of a pattern: in more industrialised centres, goat was used; with other animals, for some specific industrial activities. At sites like Harrison Street in Hereford (Hertfordshire, fifteenth

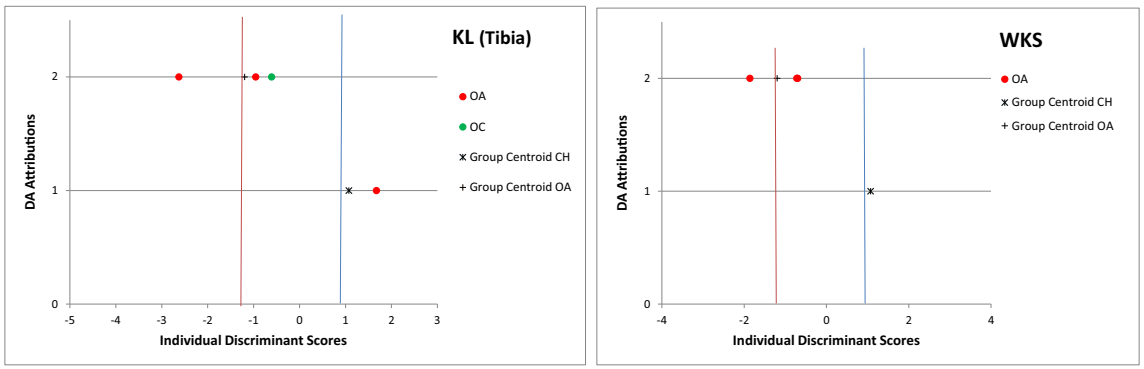

Fig. 32 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the tibia. No complete tibiae were recorded at FL. Symbols are described in Fig. 20

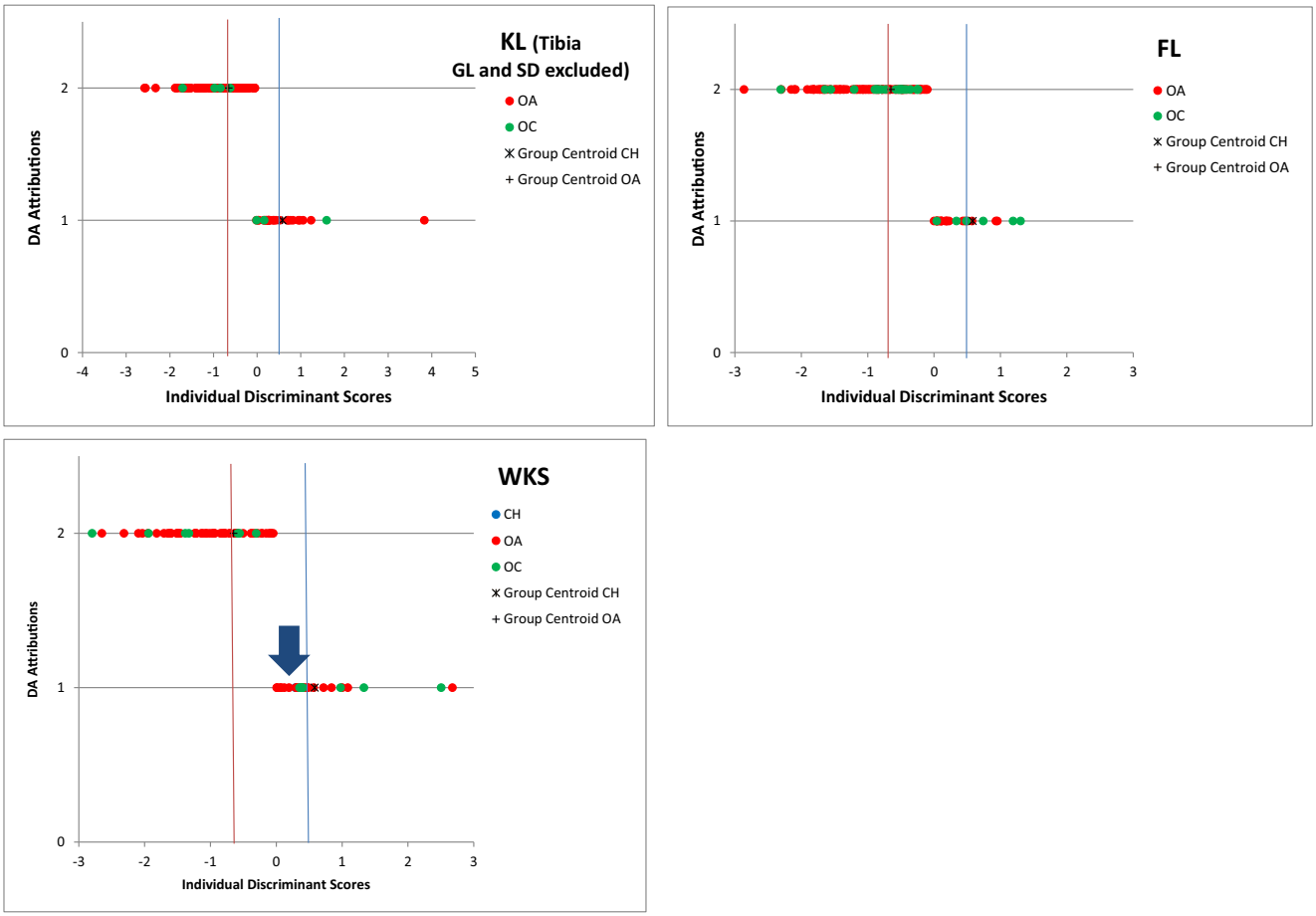

Fig. 33 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the tibia when variables GL and SD were excluded. Symbols are described in Fig. 20

century) (Baxter, unpublished), Skeldergate in York (eleventh to twelfth century) (O'Connor 1984), Hornpot Lane in York (fourteenth century) (Wenham 1965), Empire Cinema in Bedford (Bedfordshire, eleventh to twelfth century) (Grant 1983) and St Johns Street 29-39 in Bedford (Bedfordshire, eleventh to thirteenth century) (Grant 1979), accumulations of goat horncores (more rarely of footbones) in association with other archaeological (e.g. soaking pits, leather fragments, decomposed bark used for the tanning process) (Serjeantson 1989) and historical evidence have been found, suggesting a connection between goat and horn and leather industries.

Similar cases have also been recorded in other countries: at Haithabu in Germany (Reichstein and Tiessen 1974), as well as at the sites of Dordrecht and Dorestand and at s'-Hertogenbosch-Gertru (in the Netherlands) (Prummel 1978, 1982), where the impressive accumulation of goat horncores is coupled with an unusual abundance of goat post-cranial bones. This is a situation that is unknown in England and suggests that goats, as opposed to their mere skins or horns, must have been present at these Central European sites in substantial numbers.

The situation for the other two archaeological case studies analysed here, Flaxengate and Woolmonger/Kingswell Street, is rather different. Both sites are urban in nature, and at both, goat is mainly represented by horncores, but unlike King's Lynn, these appear in small numbers. The absence of any concentration of goat horncores and, as such, of strong evidence of a bias in favour of these elements, indicates the absence of any specific industry or trade associated with this species (or indeed others, as there is no evidence of the industrial use of sheep and cattle remains either). It is important to keep in mind that the fact that concentrations of goat horncores have not been found does not necessarily exclude the possibility that they existed. Nonetheless, the available evidence indicates that, at Flaxengate and Woolmonger/Kingswell Street, there is some consistency in the occurrence of goat horncores and post-cranial bones. This suggests the occasional, rather than intensive, use of this species, probably for household provision rather than industrial exploitation.

This particular scenario, according to which the goat is present in different numbers according to different exploitation patterns, was identified by Noddle (1994, p. 120), who mentioned that "there are a number of towns where only a few goat bones

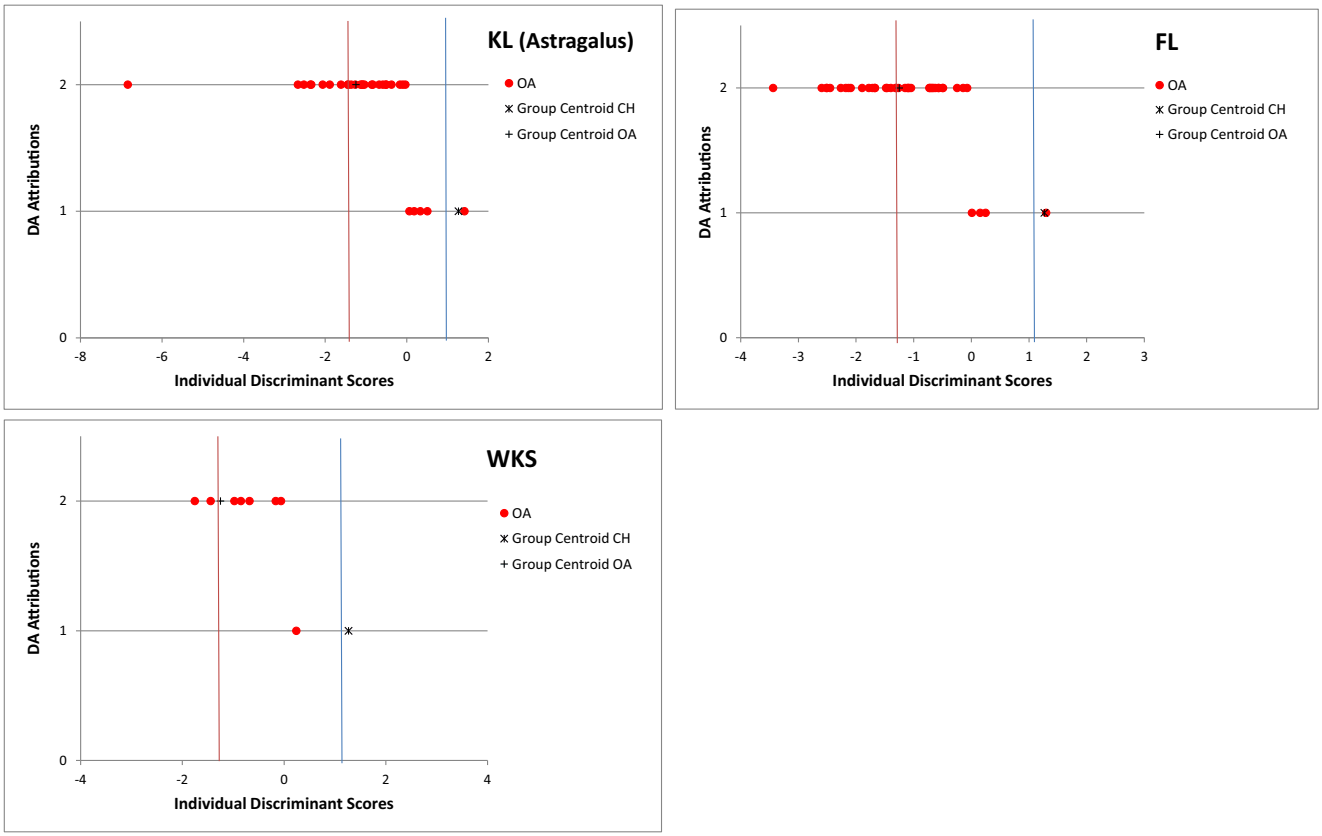

Fig. 34 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the astragalus. Symbols are described in Fig. 20

have been found and others where it has been plentiful". The illustrated archaeological examples described in this study indeed point towards a diversified picture for the medieval English goat, though the 'plentiful' scenario identified by Noddle does not apply to King's Lynn or any other site in England. It is likely that Noddle was misled by the horncore abundance which, as we have seen, does not necessarily imply the occurrence of animals.

In urbanised and industrially specialised centres, where accumulations of goat horncores have been found, the goat appears to have been mainly used for its skin and horns, as at King's Lynn. These site types, mainly located on the east coast, are likely to have been associated with a trade in goat skins with southern Europe, where this species was more abundant. There are a number of historical resources confirming the existence of hide and skin trades. Though not affecting the east coast, there is documentary evidence attesting to the importation of skins from Ireland to towns in the west of England (Clarkson 1966). Similarly, goat skins seem to have been imported to the site of Gamlebyen in Norway (Reichstein and Tiessen 1974). It is therefore possible that a similar commerce existed between England and other European countries.

In rural sites and in urban sites outside industrialised areas, the goat may have represented an alternative, but rarely used, source of meat and dairy products, as attested at Flaxengate and Woolmonger Street/Kingswell Street. Interestingly, a higher presence of goats in hilly and wooded counties is indicated by both charters and toponymy (Noddle 1994). This pattern is also confirmed by the Domesday Book (Darby 1977). Consequently, the regions in which goats were likely to be more common were the uncultivated areas and those lands where other farm animals could not easily feed. Particularly from the thirteenth century, southern, eastern and midland England had a distinct market-oriented husbandry system in which the goat did not have a place (Noddle 1994).

Unfortunately, the scarcity of available archaeological data from rural and less urbanised sites prevents us from undertaking an in-depth study of this phenomenon. In particular, it is difficult to compare directly the archaeological data with those from written sources, such as the Domesday Book, which seems to indicate a higher occurrence of the goat in the English medieval countryside than is apparent from archaeological sites. Nevertheless, the scanty evidence available seems to suggest that the goat was rare at rural sites too. Among the few rural sites where goat remains have been recorded, it is worth mentioning the twelfth- to early thirteenth-century Boteler's Castle (Oversley, Warwickshire) (Pinter-Bellows 1997) and the

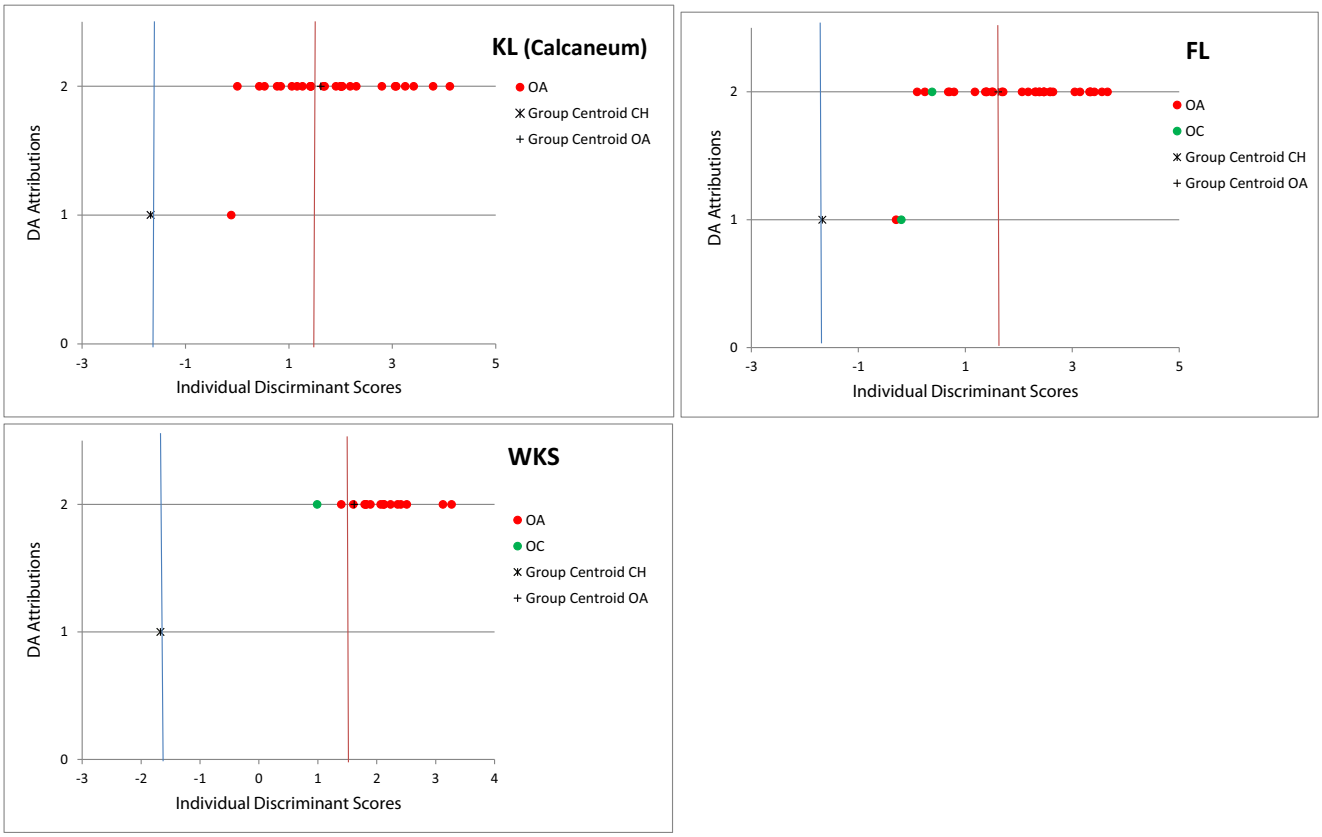

Fig. 35 Diagram of the individual discriminant scores attributed to the archaeological material by LDA for the calcaneum. Symbols are described in Fig. 20

twelfth-century site of Walton (Aylesbury, Buckinghamshire) (Noddle 1976). At both sites, the small number of goat bones unearthed and the absence of concentrations of goat horncores seem to confirm the idea that the goat was husbanded rather than used in industrial activities.

Further reviews of the status of the goat in medieval and post-medieval England, using a methodological approach that is detailed and transparent, such as the one proposed in this paper, will certainly be beneficial and will add detail to the overall pattern of goat exploitation. This paper, though inevitably limited to a small number of sites, has, however, already answered the one over-arching question that has troubled British zooarchaeologists in the last few decades. The rarity of the goat in the English medieval and post-medieval record is not an artefact of analytical bias, but a genuine phenomenon.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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