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The effect of dog scavenging on a modern cattle, pig and sheep bone assemblage

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ABSTRACT: Carnivores have long been known as important taphonomic agents that accumulate and destroy bones thus introducing biases in archaeological bone assemblages. This paper examines how scavenging by two domestic dogs affected the composition of a modern assemblage comprising limb bones of cattle, pig and sheep. The dogs did not inflict any serious damage to the cattle bones whilst the pig and sheep bones suffered very heavy attrition. The density of the bones was found to have mediated the destruction to a certain extent but other parameters appeared to be more critical. The size and maybe the shape of the bones seemed to be more important since some cattle bones that had similar density values to pig or sheep bones received little attrition whereas the bones of the two other species were destroyed. The nutritional value of the bones was also important. Not only did the dogs preferentially attack parts with soft tissue attached but they also left almost complete the acetabulum of the pigs pelvis despite its low density value. Differences in the jaw power and individual behaviour of the dogs influenced the manner of destruction to a minor degree. When the same skeletal element from the same species was offered to both dogs, the fragments that remained after each 'gnawing' session were very similar. The variety of factors involved makes it difficult to construct destruction models that may be generally applied. To estimate the scavenging bias introduced into the assemblage, species proportions and skeletal representation tables were calculated by a number of methods usually applied to archaeozoological data. All of them showed considerable discrepancies between the original assemblage (the bones given to the dogs) and the recovered assemblage following gnawing.

KEY WORDS: DOG GNAWING, BONE LOSS, SPECIES PROPORTIONS, ELEMENT REPRESENTATION

RESUMEN: Los carnívoros son reconocidos desde hace tiempo como importantes agentes tafonómicos en la acumulación y destrucción de huesos a través de la cual introducen sesgos en las muestras faunísticas de origen arqueológico. En este trabajo se analizan los efectos que, sobre la composición de una muestra de huesos apendiculares de vaca, cerdo y oveja, produce la actividad de carroñeo de dos perros domésticos. Estos animales no parecen haber causado gran destrozo en los huesos del vacuno pero sus efectos sobre los de los ungulados de menor tamaño han sido devastadores. La densidad de los huesos parece ser hasta cierto punto responsable de esta destrucción pero otros parámetros resultan ser más críticos. El tamaño y posiblemente la forma de los huesos son factores muy a tener en cuenta ya que ciertos huesos de vacuno de similar densidad a los del cerdo y de la oveja fueron apenas alterados en tanto que los huesos de estas dos últimas especies fueron destruidos. Igualmente importante resulta ser el valor nutritivo de los huesos. No solo se constata un ataque preferente de aquellas partes que poseen tejidos blandos adheridos sino que también los perros dejan prácticamente completos los acetábulos de las pelvis de cerdos a pesar de los bajos índices de densidad de éstas. Diferencias de comportamiento y de potencia del mordisco influencian el modo de destrucción en grado menor. Cuando el mismo elemento esquelético de la misma especie se ofrecía a ambos perros los fragmentos resultantes de cada sesión de roído fueron muy semejantes. La variedad de factores implicados dificulta la generación de modelos de destrucción que puedan ser aplicados de modo general. Para calibrar el sesgo que el carroñeo introduce en una muestra ósea se calcularon las proporciones y la representatividad esquelética de modo específico a través de una serie de métodos aplicados con frecuencia a los restos arqueozoológicos. Todas estas metodologías evidencian discrepancias considerables entre la muestra original (esto es los huesos proporcionados a los perros) y la muestra recuperada trás el ataque de éstos.

PALABRAS CLAVE: ROÍDO GENERADO POR PERROS, PÉRDIDA DE HUESOS, PROPORCIONES DE ESPECIES, FRECUENCIA DE ELEMENTOS ÓSEOS

INTRODUCTION

Carnivore behaviour has been investigated with the ambitious purpose of unravelling the superimposed signatures that various taphonomic factors and human actions leave in any bone assemblage. The destructive power of carnivores and the alterations they cause to bone assemblages have been discussed as early as the 19th century (Buckland, 1823). Studies of this phenomenon have culminated in a series of systematic observations on bone assemblages from caves, dens and lairs (Hughes, 1954; Sutcliffe, 1970; Kruuk, 1972; Klein, 1975; Bearder, 1977; Mills & Mills, 1977; Owens & Owens, 1978; Skinner *et al.*, 1980; Horwitz & Smith, 1988; Skinner & Aarde, 1991) as well as experiments set up to explain the role of carnivores as accumulators of bone assemblages, to establish the attrition patterns of skeletal elements and describe the gnaw marks that different predator species may leave on the bones.

The experimental settings varied in relation to predator – prey species from wild on wild (Brain, 1969a; Haynes, 1980; Richardson, 1980; Binford, 1981; Snyder & Klippel, 1986; Binford *et al.*, 1988) wild on domestic (Haynes, 1983; Stallibrass, 1986; Blumenshine, 1988; Marean & Spencer, 1991), domestic on wild (Binford, 1978; Payne & Munson, 1985; Morey & Klippel, 1991) and domestic on domestic (Brain, 1969b; Binford & Bertram, 1977; Kent, 1981; Payne & Munson, 1985; Greenfield, 1988; Stallibrass, 1990; Moran & O'Connor, 1992). In some experiments carnivores fed on complete carcasses whilst in others defleshed bones were offered to various predators. Despite the fact that similarities in attrition patterns were consistent, emphasising the preferential destruction of less strong bone elements and epiphyseal ends, a trend that was attributed to inherent properties of the bones such as their structural density, nutritional value and size (e.g. Sutcliffe, 1970; Binford, 1981; Brain, 1981; Haynes, 1983; Blumenshine, 1988; Horwitz & Smith, 1988; Marean *et al.*, 1992), the degree of damage varied and depended on a range of factors including the predator species, the prey species, the quantity of food available and competition between members of carnivore packs as well as competition with other predators. (Brain, 1969a; Haynes, 1983). Consequently, analogies drawn from one species to another, living in different habitats-conditions with dissimilar feeding habits may not always be satisfactory. For instance, wild animals may cause less damage on the bones than a dog because of the restrictions domestication has imposed upon it (Haynes, 1980). Furthermore, most experimental research dealt with a limited number of species often represented by a selection of elements and was rarely concerned with biases introduced to species abundance estimations. This experiment seeks to examine the degree of attrition domestic dogs will inflict to the long bones of the three main domestic species - cattle, sheep and pig - which dominate the European and Middle East assemblages from the Neolithic onwards and the distortion this attrition will cause to species proportions and element representation when the scavenged bones are treated as archaeozoological data.

METHODS AND MATERIALS

There are many variables to be taken into consideration when trying to define bone destruction caused by dogs since their behaviour may vary according to factors such as number of individuals, size and age, extent of hunger, free/restricted access to food, quantity of available food and management by humans. In this experiment, two dogs of different ages were given "kitchen waste", comprising pig, sheep and cattle bones, as their regular food. The dogs used to live and feed together and no competition was observed between them. Rita, a mongrel of English pointer mother and unknown father, was at the time of the experiment, one and a half years old. Lisa, a medium-sized Greek hound, was seven years old.

The bones were given to them unbroken with very small quantities of meat and other tissue adhering. Some of the bones were boiled, some roasted and a few were given raw. All the sheep and pig bones had their epiphyses unfused. Most of the cattle bones were unfused too. One set of phalanges had their proximal epiphyses fused and the scapula, distal humerus and proximal radius epiphyses were in the process of fusing.

The animals fed either on a cement floor or on hard garden soil with sparse vegetation. When they stopped eating and engaged in playing, the bones were carefully collected. This, at times, caused the dogs to come back and try to get the bones, probably an expression of competition with the person who was removing their food. The bone fragments were given to them for a second time but in every case they showed little interest, confined to very briefly chewing the bones and quickly abandoning them. The bone fragments were collected again and recorded following the diagnostic zones system proposed by Dobney & Rielly (1988). The number of complete bones given (WBG), the recovered identifiable fragments (IDF) and the unidentifiable bone fragments (UNIDF) are shown in Table 1. The sum of all bones recovered (R) is equal to IDF plus UNIDF. Bone loss, species proportions and skeletal element representation were calculated as follows:

	Pig			Cattle			Sheep		
Element	**WBG**	**UNIDF**	**IDF**	**WBG**	**UNIDF**	**IDF**	**WBG**	**UNIDF**	**IDF**
Scapula	4	3	2	1	0	1	1	0	0
Humerus	4	6	4	2	0	2	1	0	0
Radius	7	7	1	1	0	1	1	0	0
Ulna	7	1	3	1	0	1	1	0	0
Radius+Ulna	(7)	19	-	-	-	-	-	-	-
Carpals	56	0	0	6	0	6	6	0	0
Pelvis	8	3	6	1	0	1	1	0	0
Femur	4	7	3	1	0	1	1	0	0
Patella	5	0	0	1	0	1	1	0	0
Tibia	5	9	4	1	0	1	1	1	0
Fibula	5	0	1	-	-	-	-	-	-
Calcaneum	5	0	2	1	0	1	1	0	0
Astragalus	5	0	0	1	0	1	1	0	0
Tarsals	5	0	1	-	-	-	3	0	0
Metacarpal	2	0	0	-	-	-	-	-	-
Metatarsal	2	0	0	-	-	-	-	-	-
Abaxial	4	0	0	-	-	-	-	-	
1st phalanx	4	0	0	3	0	2	-	-	-
2nd phalanx	4	0	0	2	0	1	-	-	-
3rd phalanx	4	0	0	2	0	2	-	-	-
Sesamoid	-	-	-	1	0	0	-	-	-
Skull	-	-	-	-	-	-	1	0	0
Mandible	-	-	-	-	-	-	2	0	1
Maxilla	-	-	-	-	-	-	2	0	0
Max. Molar	-	-	-	-	-	-	4	1	4
Milk inc./can.	-	-	-	-	-	-	8	0	4
Mand. Molar	-	-	-	-	-	-	4	7	0
Mand. d4	-	-	-	-	-	-	2	0	2
other milk teeth	-	-	-	-	-	-	8	0	6
Total	**140**	**55**	**27**	**27**	**0**	**22**	**50**	**10**	**17**

TABLE 1

Number of bones given to dogs and bones recovered. WBG = whole bones given to dogs, UNIDF = unidentifiable fragments, IDF = identifiable fragments, r-u = radius and ulna; fragments of radius or ulna that could not be assigned to element.

Bone loss: To estimate the amount of bone loss for each species separately, the given assemblage (all the bones given) and the recovered assemblage (only identified fragments) were quantified by: NISP – all bones and bone fragments; MNI - the most numerous bone (the highest sum either on epiphyses, shafts or teeth) divided by two; EO (epiphyses only) - all the epiphyses, the astragalus, the articular surfaces of ulna and calcaneum, mandible fragments with at least one tooth and the distal epiphyses of the phalanges were counted; DZ (diagnostic zones) – for the given assemblage, each bone was counted once. For the recovered assemblage, the most abundant zone was counted for each element. A zone was included in the calculation only when 50% or more of that zone was present. This criterion was always applied when the diagnostic zone system was used. Tarsals, save for astragalus and calcaneum, carpals, sesamoid, teeth, maxillae, skull, fibula and patella were not included.

To estimate the loss of each element separately, the "percentage change" was calculated on MNEs by applying the formula suggested by Marean & Spencer (1991: 650); (number of bones given – number of bones recovered) / (number of bones given) x 100. The counting unit was again the best represented diagnostic zone.

Species proportions: The methodology was principally the same as for the calculation of bone loss with some minor differences. Because in this exercise the proportions of the three animals were to be compared, elements that do not exist in the skeletons of all the three species or are present in different numbers were eliminated. The carpals and tarsals, save for the astragalus and calcaneum, the pig fibula and metapodials II and V and the cattle sesamoid were eliminated. The frequency of pig metapodia III and IV was divided by two. The calculations were carried out twice, once including the sheep head elements and once excluding them.

Two indicators have been used to illustrate the change in species proportions. "%PD" (percentage difference) and the "%ME" (mistaken estimation). "%PD" is simply the difference between the given and found assemblage and is calculated thus: %PD = %WBG - %R. This figure shows how much a species percentage has increased or decreased after the gnawing experiment. It does not show the real frequency change of each species. The second estimator, the %ME is used to demonstrate this. It is calculated as: (%PD x 100)/ %WBG. For example the NISP for cattle is %WBG = 19 and the %R = 36 (Table 5). Obviously the cattle percentage has increased by %PD = 18. The percentage of the recovered assemblage (%R = 36), is almost double that of the given assemblage. This difference is shown by %ME = 94.

Skeletal representation: Because the number of different bone elements fed to the dogs differs, in order to estimate the skeletal representation in a way that would account for these differences relative to their representation in half carcasses, fragments of bones that retained at least one diagnostic zone, were converted into percentages by applying the following formula: (number of fragments recovered / number of bones given) x 100. These were called "modified numbers" and represent the survivorship of an element in relation to the number of the experimental feedings carried out for this particular element. They were then treated as if they were archaeozoological finds and survivorship calculated based on the best represented bone.

Skeletal representation was first calculated on proximal and distal ends of bones preserving part of the epiphyses or epiphyseal plate. For the ulna and calcaneum, the units of calculation were their articular surfaces. Mandibles were counted if at least one tooth was present. The distal epiphysis was counted for the first and second phalanges and the articular surface for the third phalange. Skeletal representation was then reconstructed, again using as counting units the most abundant diagnostic zone saved.

RESULTS AND DISCUSSION

The behaviour of the two dogs and the destruction they caused to the bones was very similar. Nevertheless, minor differences were noted concerning the size of the fragments left which were often larger when the bones were gnawed by the younger dog. The cooking method did not seem to affect the dogs' behaviour.

Gnaw marks were present on most of the fragments recovered. The surface of the pig bones were almost entirely covered with marks. The edges of the fragments were irregular and exhibited the type of damage that was described as pitting and flake scars by Stalibrass (1986) and Binford (1981). Tooth marks on cattle bones were concentrated on the epiphyses. The shafts had no gnaw marks. Grooves, similar to the ones described by Stalibrass (1986) and Binford's (1981) scoring marks, were occasionally noticed. The two sheep bone fragments recovered had no tooth marks.

Taking a closer look at the attrition of the bones of each species (Table 1), the cattle bones have apparently suffered the least loss. Similarly, cattle bones fed to sows by Greenfield (1988) displayed little damage. The only elements consumed by the dogs were the sesamoids and unfused phalanges. The epiphyses of the calcaneum and ulna epiphyses and the *tuber scapulae* were also eaten. One of the two humerii had its proximal epiphysis destroyed. The rest of the epiphyses showed markedly less damage, the attrition being limited to destruction of small pieces of bone matter. Other parts of the bones that are weaker or "manageable" for the dogs, were also attacked, for instance the blade and spine of the scapula, the edges of the pelvis and any protruding pieces. The majority of the bones were not seriously damaged and the surviving parts were all identifiable. It was apparent that the dogs were not able to chew intensively the cattle bones because they were too big for them to put in their mouths and crush them. The excellent survival rates of the cattle bones contrasts with Stalibrass's (1986) expectation that fox scavenging on sheep bones is equivalent to medium-sized dogs scavenging on small unimproved breeds of cattle. Despite the fact that the cattle bones used in the experiment were not from a small unimproved breed, the fact that the bones were derived from immature animals and the very slight damage caused, makes it unlikely that bones from even a smaller cattle breed would receive the type of destruction described by Stalibrass.

The pig bones were almost completely destroyed. Fragments, splinters and few mid-shaft tubes were mostly left, many of them hardly recognisable, if at all. The only epiphysis that survived well was the acetabulum of the pelvis, a result that contrasts with the findings of other researchers (Payne & Munson, 1985; Marean *et al.*, 1992) where the pelves suffered very heavy attrition. The neck of the scapula and the articulations of the calcaneum and ulna had relatively good rates of survival. The femur, tibia, radius and fibula were *crushed* and transformed into fragments, splinters and mid-shaft tubes. Only some of these fragments could be assigned to species. The carpals and tarsals, save for the calcaneum, were crushed and swallowed. The same, almost complete destruction, of pig bones was observed by Stalibrass (1990) and Greenfield (1988).

The lamb bones suffered even worse destruction. Nothing was left from the front and hind leg except for a splinter of tibia. The skull, maxillae and one of the mandibles were completely destroyed. One large fragment of the second mandible was saved, bearing most of the teeth. The corpus of the mandible was bitten off. Many loose teeth were consumed by the dogs but not all of them were recovered; the missing teeth were apparently swallowed and most probably could have been recovered in the dog's faeces. The total destruction of the lamb bones is most likely related to their very young age. Greenfield (1988) found that the bones of a young lamb were completely destroyed by pigs. In contrast, Payne & Munson (1985) described a lighter pattern of destruction for bones of adult goats fed to dogs, where jaws, teeth and early fusing bones had a relatively good rate of survival.

When bone loss was quantified (Table 2), it varied depending which method was used. Pig bone loss ranged from 50% to 89%, whilst a difference of 0% to 19% was found for cattle and 0% and 93% for sheep. The least loss was observed when MNI's were calculated: 0% for the cattle and sheep and 50% for the pig. Overall, the worst estimator was the "EO" method. The pig lost 89% and the sheep 93%. For the pig this is the highest loss observed. The cattle bone loss was only 9% but then cattle bones suffered very little destruction. The NISP method was also shown to be a very poor estimator when the attrition was heavy (pig 81%) and it also gave the worse result for the cattle (19%) but for the sheep it was probably a good method since the inclusion of teeth, elements that survived well, reduced the effect of destruction (66%). The DZ had the least loss for the pig bones (71%) average for the cattle (12%) and as low as the NISP counts for the sheep (93%).

The differences observed are obviously related to the definition of the calculation units and the different way destruction has affected them. The NISP, for example, worked well only for the sheep because many teeth were saved and these elements are decisive for estimating species whose bones have suffered very heavy destruction. Nevertheless, NISP counts gave a higher loss value for cat-

Species	Pig				Cattle				Sheep			
	G	R	L		G	R	L		G	R	L	
Methods	n	n	**n**	**%**	n	n	**n**	**%**	n	n	**n**	**%**
NISP	140	27	**113**	**81**	27	22	**5**	**19**	50	17	**33**	**66**
EO	97	11	**86**	**89**	22	20	**2**	**9**	15	1	**14**	**93**
MNI	4	2	**2**	**50**	1	1	**0**	**0**	1	1	**0**	**0**
DZ	69	20	**49**	**71**	17	15	**2**	**12**	15	1	**14**	**93**

TABLE 2
Loss of bones. G = bones given, R = bones recovered, L = bone loss.

tle despite the fact that the cattle bones were the least affected by gnawing, and gave almost as high a loss as the EO method for the pig whose epiphyses were almost completely consumed. The EO and the DZ had both the highest loss values for sheep but then hardly any bones survived from the sheep assemblage. When the EO method was used, the extent of bone loss in the cattle assemblage was lower than the DZ, despite the fact that more epiphyses were lost than diagnostic zones. This result is a function of the way counting was executed as only one zone was countable for each bone while for the EO both epiphyses of most elements were included. The MNI exaggerated the representation of sheep, equalling the frequency of this species with cattle despite the fact that only one sheep bone fragment was present compared to 22 fragments of cattle bone. The DZ method is not sensitive to epiphyseal loss neither does it exaggerate an isolated find. It is affected by the degree of fragmentation, since a large enough proportion of a zone must be saved in order to be counted.

The frequency of element completeness (Table 3) needs almost no discussion for sheep and cattle.

SPECIES	PIG			CATTLE			SHEEP		
METHOD	**MNE**	**MNE**	**Change**	**MNE**	**MNE**	**Change**	**MNE**	**MNE**	**Change**
ELEMENT	**Given**	**Retrieved**	**%**	**Given**	**Retrieved**	**%**	**Given**	**Retrieved**	**%**
Scapula	4	2	**50**	1	1	**0**	1	0	**100**
Humerus	4	2	**50**	2	2	**0**	1	0	**100**
Radius	7	1	**86**	1	1	**0**	1	0	**100**
Ulna	7	3	**57**	1	1	**0**	1	0	**100**
Pelvis	8	5	**38**	1	1	**0**	1	0	**100**
Femur	4	2	**50**	1	1	**0**	1	0	**100**
Tibia	5	3	**40**	1	1	**0**	1	0	**100**
Calcaneum	5	2	**60**	1	1	**0**	1	0	**100**
Astragalus	5	0	**100**	1	1	**0**	1	0	**100**
Metacarpal	2	0	**100**	-	-	-	-	-	-
Metatarsal	2	0	**100**	-	-	-	-	-	-
Metapodial II - V	4	0	**100**	-	-	-	-	-	-
1st phalanx	4	0	**100**	3	2	**33**	-	-	-
2nd phalanx	4	0	**100**	2	1	**50**	-	-	-
3rd phalanx	4	0	**100**	2	2	**0**	-	-	-
Mandible	-	-	-	-	-	-	2	1	**50**

TABLE 3
Loss of skeletal elements. MNE calculated on diagnostic zones.

Apart from the mandible (50%), all the sheep bones frequencies changed (100%). The frequency of cattle bones, on the other hand, did not change at all apart for the first phalanx (33%) and the second phalanx (50%). The pig element frequencies changed from 38% to 100%. The astragalus, phalanges and metapodia changed 100% which means that all the bones of the lower extremities were completely destroyed, save for the calcaneum (60% change). For the rest of the bones, the least affected was the pelvis (38%). The radius experienced the highest loss (86%) whilst the scapula, humerus, ulna, femur and tibia lost a 40% to 57% of their original proportion. It must be emphasised that these estimations are all based on shaft fragments. If element representation was counted on epiphyses, the loss would be much greater; only one scapula, one proximal radius and four pelvises retained parts of their epiphyses.

The species proportions

Species proportions fluctuated depending upon the method used to calculate them because of attributes inherent in the approach and counting unit used. These have been discussed in numerous papers (Lyman, 1994 and references therein) and also briefly discussed in the previous section in relation to the effect of scavenging. This exercise is meant to present the wrong estimation of species abundance as this relates to two factors; first, that destruction differs amongst species and secondly, that a change in the representation of one species unavoidably causes the proportion of the other species to change too.

The first and obvious discrepancy is that the ratio of the cattle was always overestimated whatever the calculation method whilst the sheep and pig are always underestimated (Tables 4 and 5). It is a delicate task to attempt generalisations about what may have happened in an ancient settlement and how, in turn, archaeozoological assemblages may have been shaped, but the fact that the cattle has such a high rate of survival at the expense of the other two species indicates that one should be very cautious when comparing the proportions of different species if there is evidence of attrition inflicted by carnivores (or other agents).

When the calculations excluded the cranial elements of the sheep (Table 4), the worst estimation was given by the EO method; a gross exaggeration of the representation of cattle, a complete absence of sheep and about half the original percentage of the pig. The diagnostic zones method failed to produce a good approximation of the original species proportions and this obviously stems from the different degree of fragmentation and attrition experienced by the different species; for example, many pig fragments remained unidentified or had

	NISP						EO					
Method	**G**		**R**		**PD**	**ME**	**G**		**R**		**PD**	**ME**
Species	**n**	**%**	**n**	**%**	**%**	**%**	**n**	**%**	**n**	**%**	**%**	**%**
Pig	68	71	27	61	**-9**	**-13**	83	70	11	38	**-32**	**-46**
Cattle	18	19	16	36	**+18**	**+94**	22	19	18	62	**+43**	**+233**
Sheep	10	10	1	2	**-8**	**-78**	13	11	0	0	**-11**	**-100**
Totals	96	100	44	100			118	100	29	100		

	MNI						DZ					
Method	**G**		**R**		**PD**	**ME**	**G**		**R**		**PD**	**ME**
Species	**n**	**%**	**n**	**%**	**%**	**%**	**n**	**%**	**n**	**%**	**%**	**%**
Pig	4	67	2	50	**-17**	**-25**	63	71	20	57	**-14**	**-68**
Cattle	1	17	1	25	**+8**	**+50**	17	19	15	43	**+24**	**+160**
Sheep	1	17	1	25	**+8**	**+50**	9	10	0	0	**-10**	**-100**
Totals	6	100	4	100			89	100	36	100		

TABLE 4
Species proportions before and after gnawing without sheep cranial elements. G = number of bones given, R = number of bones recovered, PD = % difference amongst the given and recovered assemblages, ME = % mistaken estimation of each species.

no diagnostic zone saved in large enough a proportion to be counted whilst the sheep bones were almost completely eliminated from the record due to heavy attrition. In contrast, the cattle bone suffered little breakage. Consequently most of the cattle bones were countable thus inflating its percentage and, in turn, reducing the proportions of the other two species. The method that gave the most balanced results were MNI counts but this is clearly a function of the logistics on which the MNI was calculated. As was the case for the estimation of bone loss, one sheep fragment was enough to provide a number equal to the original. Despite the fact that cattle were represented by many more bones, they too gave an MNI count of 1. Having accurately estimated the frequencies for cattle and sheep, it was not surprising that the under-representation of pig was minimal. Nevertheless, because of the small size of the cattle and sheep samples, a condition that always favours over-estimation of species represented by a few bones, it is probably too daring to argue that the MNI will give such good a prediction in a large sample. The NISP was not a bad estimator but the relatively good NISP result is clearly related to the high fragmentation of the pig bones. Apparently the same bone was counted several times thus bringing the pig proportion closer to the true one which in turn affected the other two species proportions in the same manner as discussed for the MNI. This obviously is far from satisfactory. Furthermore, both the cattle and sheep proportions were still wrongly estimated even if less than they were by other methods.

When the teeth and mandible of the sheep were included (Table 5) the underestimation of the sheep proportion was somewhat remedied. A real difference though was only noticed when the NISP was tabulated (ME only -13%). The reason for this result is the same as previously detailed for the pig; many teeth survived which when counted brought the sheep proportion closer to the real one, that is a coincidental rather than a real improvement. In fact, if criteria were established to avoid counting the same animal more than once, the NISP would not really have given such a good prediction.

Skeletal element representation

The pattern of skeletal element representation for cattle bones (Table 6), whether this is calculated on epiphyseal ends or diagnostic zones, corresponds with the frequencies found in a roughly complete carcass. The proximal humerus and the first and second phalanges are the only underrepresented bones. Clearly, when destruction is minimal, there is no substantial difference between the results of the two different methods of calculation.

	NISP						EO					
Method	G		R		PD	ME	G		R		PD	ME
Species	n	%	n	%	%	%	n	%	n	%	%	%
Pig	68	54	27	45	**-6**	**-17**	83	69	11	37	**-33**	**-47**
Cattle	18	14	16	27	**+13**	**+93**	22	18	18	60	**+42**	**+227**
Sheep	41	32	17	28	**-4**	**-13**	15	13	1	3	**-9**	**-73**
Totals	127	100	60	100			120	100	30	100		

	MNI						DZ					
Method	G		R		PD	ME	G		R		PD	ME
Species	n	%	n	%	%	%	n	%	n	%	%	%
Pig	4	67	2	50	**-17**	**-25**	63	69	20	55	**-14**	**-20**
Cattle	1	17	1	25	**+8**	**+50**	17	19	15	42	**+23**	**+123**
Sheep	1	17	1	25	**+8**	**+50**	11	12	1	3	**-9**	**-77**
Totals	6	100	4	100			91	100	36	100		

TABLE 5
Species proportions with sheep cranial elements. Abbreviations as in Table 4.

In contrast, the sheep skeletal representation (Table 6) cannot be reconstructed. One piece of mandible and one tibia fragment that were left would not have facilitated a precise interpretation.

The pig element frequencies, when calculated on epiphyses (Table 6, Figure 1), appear to present a "selection of specific cuts" with all elements which are often labelled as "butchery waste", missing (metapodia, carpals, most tarsals and phalanges); the hindleg is less well represented than the front leg, and from both the meat-rich parts are the commonest (pelvis, scapula, radius). The absence of humerus and tibia, particularly of the distal epiphyses is surprising since both are rather dense elements.

The employment of diagnostic zones to reconstruct skeletal element frequencies (Table 6, Figure 2) apparently improved the results bringing them closer to the original composition of the pig bone assemblage. Based on this method one may conclude that almost all the skeleton was present. No selection is implied despite the fact that some bones, such as the radius, are under-represented whereas others, for example the pelvis, are over-represented. The fact that the ulna is present in greater numbers than the radius would probably be interpreted as an indication that the radius was also there but somehow lost, perhaps because of preservation biases. A possible misinterpretation might be that since greater numbers of bones from the hind leg were found this portion of the carcass was preferentially consumed in the site. What hasn't been resolved is the absence of metapodial elements, a case which most certainly would have been interpreted as an indication of the marketing and circulation of dressed carcasses.

Correlation of the Gnawing Experiment Results with the Bulk Density Data

Spearman's rank order correlations were carried out to test whether or not the bone destruc-

Species		Sheep				Cattle				Pig			
	Method	EO		DZ		EO		DZ		EO		DZ	
Elements EO	**Elements DZ**	**mn**	**%**	**mn**	**%**	**mn**	**%**	**mn**	**%**	**mn**	**%**	**mn**	**%**
Scapula d	**Scapula**	0	0	**0**	**0**	100	100	**100**	**100**	25	42	**50**	**70**
Humerus p		0	0			50	50			0	0		
Humerus d	**Humerus**	0	0	**0**	**0**	100	100	**100**	**100**	0	0	**50**	**70**
Radius p		0	0			100	100			14	25		
Radius d	**Radius**	0	0	**0**	**0**	100	100	**100**	**100**	0	0	**14**	**20**
Ulna	**Ulna**	0	0	**0**	**0**	100	100	**100**	**100**	43	75	**43**	**61**
Metacarpal p	**Metacarpal**	-	-	-	-	-	-	-	-	0	0	**0**	**0**
Metacarpal d		-	-			-	-			0	0		
Pelvis	**Pelvis**	0	0	**0**	**0**	100	100	**100**	**100**	57	100	**71**	**100**
Femur p		0	0			100	100			0	0		
Femur d	**Femur**	0	0	**0**	**0**	100	100	**100**	**100**	0	0	**50**	**70**
Tibia p		0	0			100	100			0	0		
Tibia d	**Tibia**	0	0	**0**	**0**	100	100	**100**	**100**	0	0	**60**	**85**
Metatarsal p	**Metatarsal**	-	-	-	-	-	-	-	-	0	0	**0**	**0**
Metatarsal d		-	-			-	-			0	0		
Calcaneum	**Calcaneum**	0	0	**0**	**0**	100	100	**100**	**100**	40	70	**40**	**56**
Astragalus	**Astragalus**	0	0	**0**	**0**	100	100	**100**	**100**	0	0	**0**	**0**
1st phalanx	**1st phalanx**	-	-	-	-	67	67	**67**	**67**	0	0	**0**	**0**
2nd phalanx	**2nd phalanx**	-	-	-	-	50	50	**50**	**50**	0	0	**0**	**0**
3rd phalanx	**3rd phalanx**	-	-	-	-	100	100	**100**	**100**	0	0	**0**	**0**
Mandible	**Mandible**	50	100	**50**	**100**	-	-			--			

TABLE 6
Skeletal representation tables, mn = modified numbers = (Bones recovered * 100) / Bones given, DZ = diagnostic zones, EO = epiphysis only.

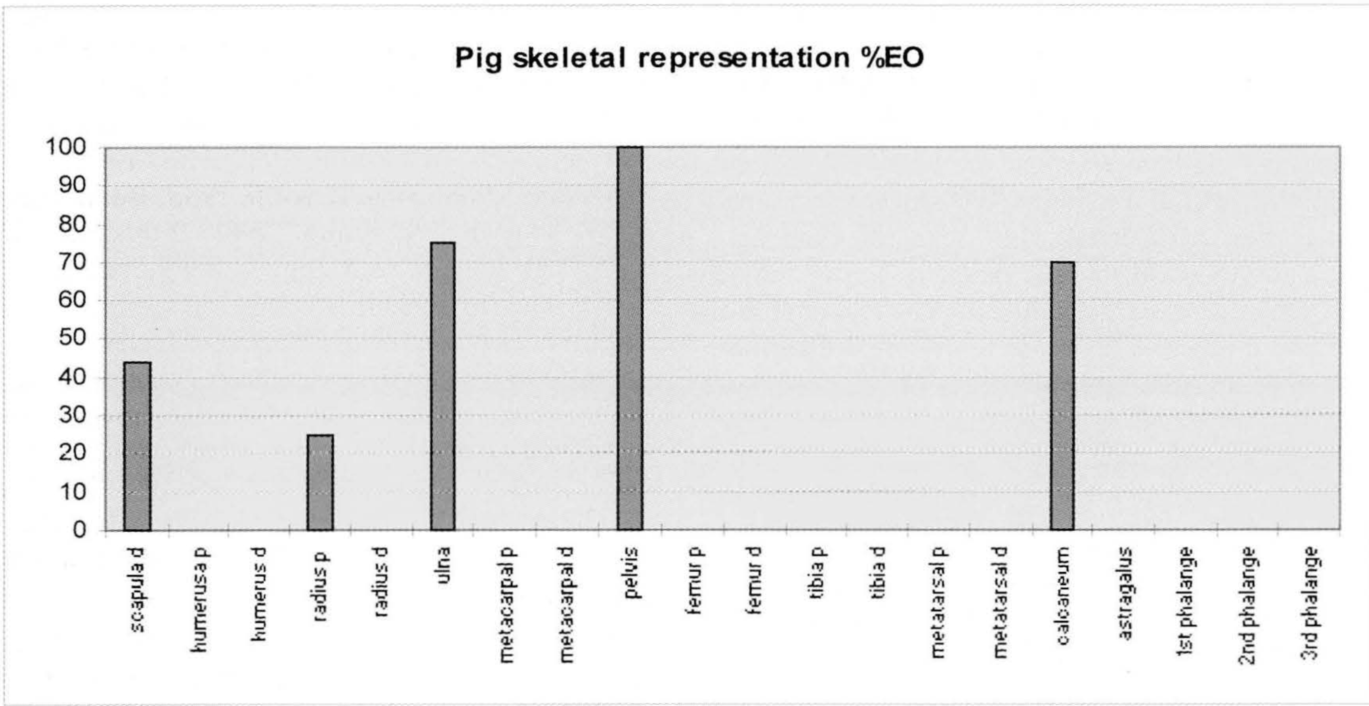

FIGURE 1
Pig skeletal element representation by epiphyses.

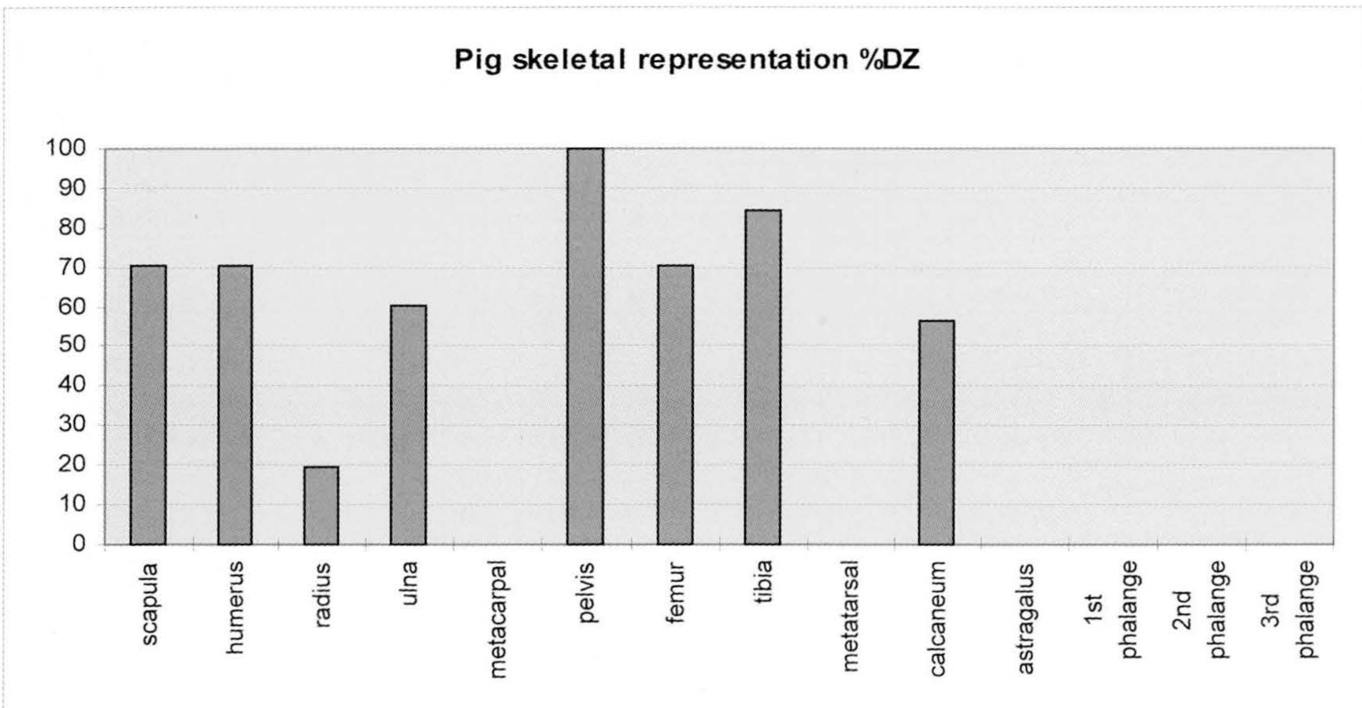

FIGURE 2
Pig skeletal element representation by diagnostic zones.

tion was mediated by their density. The bulk density values of cattle and pig bones (Ioannidou, 2003) were tested against the frequencies of the elements that remained after the experiment.

The cattle frequencies showed no correlation with the density data ($n = 48$, $r = .047$, $p<.751$) but a correlation was obtained for pig ($n = 61$, $r = .349$, $p<.006$).

Despite the fact that a correlation was attested to between the extent of destruction and pig bone density values, the relationship of density to destruction does not seem to be a straightforward one. It seemed that on certain occasions, density was of minimal importance whilst other factors such as the size and nutritional value of the bone were the determining parameters. Dogs often left undamaged bones whose density was low, possibly because they were not "attractive" or for some reason other than density, they were not capable of destroying them. One such example is the acetabulum of the pig pelvis. It survived well despite the fact that its density is only 0.16 whilst the distal shaft of the radius, which was consumed in all cases, has a density value of 0.32 (Ioannidou, 2003). Also, cattle bones that have a comparable density value to some of the pig bones were much less damaged. For instance, the distal shaft of the cattle radius that has a density value of 0.35 was almost undamaged. It appears that the size of the bones, which determined whether or not the dogs were able to hold them between their teeth comfortably enough to exercise all the power needed to crush them, was more crucial than density and, this accounts for the overall negligible destruction of the cattle bones. The nutrition value then should come second as the pig acetabulum survival indicates. Nevertheless, when comparing elements of the same species, differences in density values *appear* to correspond to the extent of destruction. However, this might be an artificial pattern. It is true that pig mid-shaft fragments survived better and these are the strongest parts of the bones but at the same time they are the ones that lack nutrition when crushed and all the marrow licked out. Nutrition seemed to largely determine destruction in Blumenshine's experiment (1988) where broken bones stripped of their marrow were little attrited. However, no differences were observed by Marean & Spencer (1991) and Marean *et al.* (1992).

CONCLUSIONS

Attrition inflicted by carnivores strongly affects the species proportion estimation, mortality profiles and the skeletal element representation, since it is unequal amongst species, possibly age groups and skeletal elements.

The skeletal representation frequencies calculated on epiphyseal portions are likely to be heavily biased and to poorly represent the original element composition given that these portions of the bones suffer the most severe attrition. Calculations on mid - shaft portions would give better estimations (Klein, 1975; Richardson, 1980; Hill, 1983; Blumenshine, 1988; Bunn & Kroll, 1988; Bunn *et al.*, 1988; Horwitz & Smith, 1988; Potts, 1988). Nevertheless, counting epiphyses may mean that one counts bones that have not been attacked by dogs. This sample then will not be affected by biases introduced into the assemblage because of carnivore gnawing. The point here is whether or not this sample is representative of the original. It probably reflects depositional events in the life of a settlement when a batch of rubbish was buried rapidly or under such conditions that did not permit access to carnivores.

When carnivore gnawing is extensive, species proportions are heavily biased towards larger species. As it was clearly found in this research, the original proportions of cattle were greatly inflated at the expense of pig and sheep. Calculation based on mid-shaft fragments, as was the case with DZ, did not relieve the problem sufficiently despite the fact that this was a good measure for tackling biases in skeletal representation. Jaws have often been found to dominate carnivore ravaged assemblages (Brain, 1967; Haynes, 1980, 1981; Skinner *et al.*, 1980; Binford, 1981; Stallibrass, 1986; Stiner, 1991). In this research too, the only identifiable sheep elements that survived were the teeth and a mandible fragment. Subsequently, species proportions calculated on teeth might provide a better approximation of the original assemblage, provided that one has already answered all other taphonomic problems related to the differential deposition and recovery of head elements.

Mortality profiles based on epiphyseal closure are unreliable in ravaged assemblages in view of the fact that most of the unfused epiphyses, of at least some species, may be completely destroyed.

Many researchers have argued that density is a major factor mediating bone attrition (e.g. Brain, 1967, 1976, 1981; Bonnischen, 1973; Binford & Berrtram, 1977; Kent, 1981; Andrews & Evans, 1983; Haynes, 1991). Despite the fact that in this experiment the pig density model correlated with the attrition caused by dog gnawing, the relationship might be incidental. Although there might be species whose bones may have such high a density that a domestic dog will not be able to crush them, in the case of the domestic species examined here, density did not appear to be the "driving force" determining destruction. This point has been extensively discussed by Lyman (1994 and references therein) and summarised thus: "a correlation between bone frequencies and bone structural density is a necessary condition for inferring a causal relationship between the two variables, but it is not a sufficient condition for such an inference" (Lyman, 1994: 253).

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