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Distinguishing Bearded Vulture Activities within Archaeological Contexts: Identification Guidelines

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ABSTRACT In Europe, the bearded vulture *Gypaetus barbatus* is currently an endangered species limited now to high mountain areas, but had a broader geographical distribution in the past. It breeds on ledges in limestone cliffs, in habitats similar to those also selected by prehistoric human groups. This species feeds mainly on bones of medium-sized ungulates that are processed before ingestion at bone-breaking sites or ossuaries; bone remains subsequently accumulate at their nesting places leading to potential mixing with human-derived or carnivore-derived assemblages. This fact could lead to incorrect palaeoeconomic interpretations that can be avoided if the taphonomic contribution of this bird of prey is correctly identified. Here, we present some key features to distinguish its presence in archaeo/palaeontological contexts. Bone surface alterations, breakage patterns and skeletal profiles are recorded. Several prehistoric, historic and modern assemblages accumulated by bearded vultures are studied. In addition, a new utility index based on bearded vulture dietary preferences that can be compared with skeletal element abundance in terms of %MAU (Minimal Animal Units) has been defined. Copyright © 2011 John Wiley & Sons, Ltd.

Key words: bearded vulture; bearded vulture bone utility index (BVBUI); digestion marks; taphonomy

Introduction

Taphonomic studies have allowed us to recognise the importance of predator preferences and behavioural traits and improved our understanding of the origin and post-depositional modifications of archaeological faunal assemblages (Lyman, 1994). However, there are still theoretical uncertainties that can decisively affect the accuracy of archaeozoological interpretations. Being strongly based on modern observations and/or current experiments (i.e., O'Connell *et al.*, 1988; Bartram & Marean, 1999; Domínguez-Rodrigo, 1999), the common attribution of bone alterations and even the very meaning of the taxonomic and anatomical representation of the assemblage (Marean *et al.*, 2004; Stiner,

2004; Marín-Arroyo, 2009a), is driven by the way taphonomic research is undertaken and the extent of the possible causes previously considered. In addition, as taphonomy is mainly focused on the study of the final results of biological or physico-chemical processes from which the original cause is inferred, it usually faces equifinality problems, in which several causes may provoke the same effect.

This is especially true in the case of the identification of the accumulating agent, particularly when it is only based on the observation of bone surface alterations. Necessary precautions must be taken then to avoid incorrect interpretations, or at least to widen the potential explanations (i.e. McPherron *et al.*, 2010 versus Domínguez-Rodrigo *et al.*, 2010). In order to do so, more studies are needed regarding the effects on faunal remains derived by the activities of the different accumulating agents that can be found at archaeological sites. Given this background, we present new observations

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on the activity of the bearded vulture *Gypaetus barbatus*, whose presence in archaeological sites can be easily overlooked, particularly when it appears combined with human consumption activities (see Robert & Vigne, 2002; Marín-Arroyo *et al.*, 2009).

The bearded vulture is the only avian vertebrate that feeds mainly on macro-mammalian bones (Brown, 1988; Brown & Plug, 1990; Thibault *et al.*, 1993; Margalida *et al.*, 2009a; Margalida, 2010). They collect bones from ungulate carcasses left by humans and carnivores or from natural deaths. Carcass elements are carried to the nest, which is generally located in a cavity or overhang in limestone cliffs (Brown, 1988; Margalida & Bertran, 2000). The surroundings of these sites were sometimes also occupied in the past by human groups. Fresh long bones are usually broken up before being brought to the nest. This is achieved by the bones or even complete carcasses being deliberately dropped from considerable heights onto rocky surfaces called 'bone-breaking sites' or ossuaries (Boudoint, 1976; Margalida & Bertran, 2001). This behaviour leads to fractures and impact notches that are very similar to those produced when lithic artefacts are used to extract bone marrow, and the two are easily confused. Bones are either promptly swallowed or stored within the nest for future consumption. Remains, which are regurgitated after consumption with other non-digested parts such as hair, horns and hooves show severe erosion from gastric acid attack (Robert & Vigne, 2002; Marín-Arroyo *et al.*, 2009).

Over time, with periodic human/*Gypaetus* use of a locality, accumulated bones left by each can become mixed and added to the archaeozoological assemblage without any clear distinction. Consequently, they can alter the taxonomic and anatomical composition of supposed human dietary assemblages and bias economic interpretations. To avoid this, the recognition of bearded vulture activities and the estimation of their impact on the fossil record are important. In spite of the fact that the relevance of this additional accumulating agent in studies of prehistory was previously studied at Gritulu cave, Corsica (Robert & Vigne, 2002) and El Mirón Cave, Spain (Marín-Arroyo *et al.*, 2009), there is still little awareness of the problem, and clear identification guidelines are lacking. Here, we identify key features (typical surface alterations, taxonomic compositions and skeletal profiles) that characterise *Gypaetus* contributions and enable them to be recognised in archaeozoological assemblages. We define a new utility index, based on anatomical representation and bearded vulture diet preferences that can be compared with skeletal element abundance in terms of % Minimal Animal Units (%MAU; Binford, 1984:50), to infer similarities in the same way as other human utility

indices such as the Modified General Utility Index of Binford (1978) or the Food Utility Index of Metcalfe & Jones (1988).

Material and methods

The bearded vulture

The bearded vulture is a long-lived and territorial cliff-nesting species weighing 5–6 kg, characterised by delayed maturity and a specialised diet based principally on bones (Brown, 1988; Margalida, 2010). Currently, two subspecies based on morphological features have been proposed (Hiraldo *et al.*, 1979): *G. b. barbatus* for all Eurasian and North African populations and *G. b. meridionalis* for the populations of Eastern and Southern Africa. Nowadays, the European bearded vulture population is limited to the Pyrenees (France and Spain), Corsica, Crete and the Alps (a total of 170 breeding territories, with an estimated 650 individuals). However, prior to 1950, it was common in mountainous areas throughout Europe (Hiraldo *et al.*, 1979).

Nests and ossuaries are utilised for food storage (Margalida & Bertran, 2001; Margalida 2008a, b). The opportunity for delayed consumption is a consequence of the nature of bones, which keep their nutrient properties long after the death of the animal (Brown, 1988; Houston & Copsey, 1994). Houston & Copsey (1994) estimated that bones maintain an edible condition 10 times longer than soft tissues, which represent an important advantage for bearded vultures with regard to the feeding behaviour of other scavengers. The accumulation of bones in their nesting sites can be a consequence of: (1) their storage for later consumption (Margalida & Bertran, 2001; Margalida, 2008b) (but finally abandoned); and (2) the partial digestion of parts, which are regurgitated afterwards in pellets (Margalida & Bertran, 1996; Robert & Vigne, 2002). Most of the long bone shafts are left in the field, and more fatty remains, including epiphyses, are brought to the nest (Margalida & Bertran, 2001; Robert & Vigne, 2002a; Margalida, 2008a; Marín-Arroyo *et al.*, 2009). Bone-breaking behaviour allows the species to break bones that, because of their length or width, cannot be swallowed whole (Figure 1), and also to dismember the different parts of a skeleton.

Nesting sites are located in sheltered areas, usually in caves, to avoid adverse weather (Margalida & Bertran, 2000; Hirzel *et al.*, 2004) as egg laying takes place in December–January (Margalida *et al.*, 2003). Caves are the main nest-site location selected; studies from the present-day Pyrenees (Heredia, 1991) show that they are used 50–70% of the time.

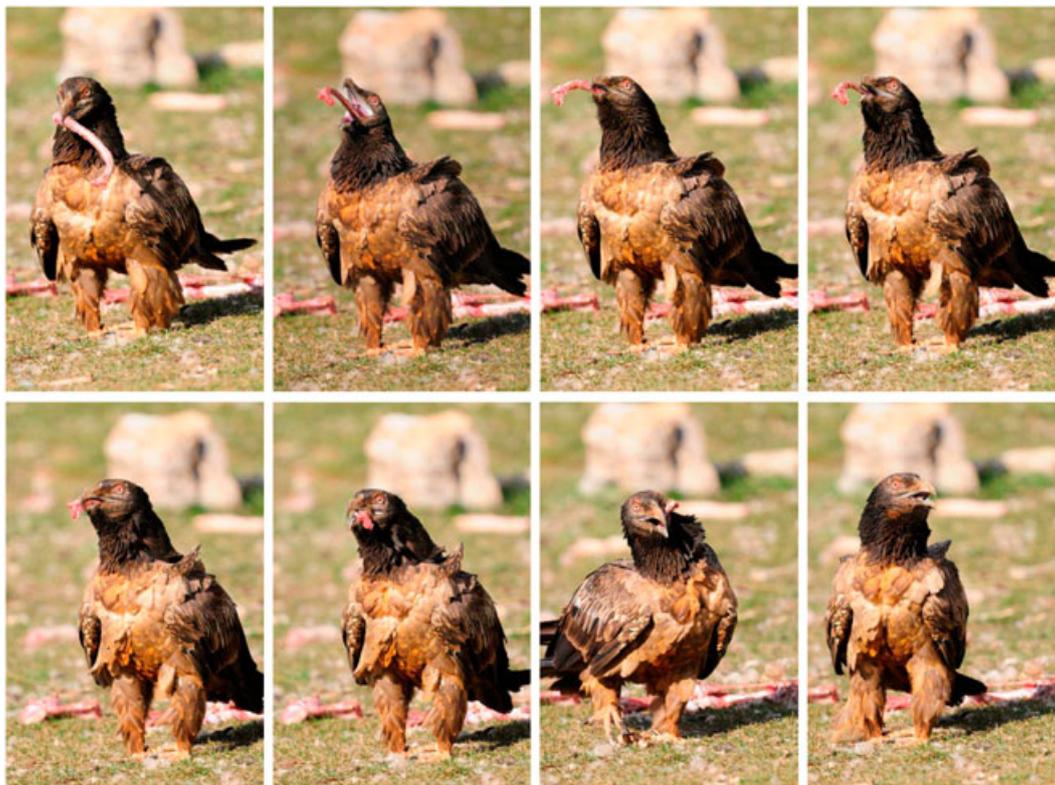


Figure 1. Sequence showing an immature bearded vulture swallowing a medium-size ungulate rib (Photo: Jordi Bas). This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Bone modifications

From a taphonomic point of view, bone surface alterations are undoubtedly one of the most distinctive features used in identifying accumulating agents, together with skeletal profiles and bone breakage patterns. In the case of bearded vultures, biochemical effects (i.e. digestion traces) are especially important because of their specialised feeding habits. The degree of digestion varies from one bone to another depending on the length of ingestion and the density of the bone (Figure 2). Robert & Vigne (2002) first proposed a coding system based on the intensity and location of the digestion marks on phalanges, which are the most common skeletal elements found in modern and prehistoric bearded vulture nests. Marín-Arroyo *et al.* (2009) added new categories not only for phalanges but also for other anatomical parts. The complete code list is presented in Table 1. However, intense digestion is not exclusive to this species. Some carnivores, such as hyaenas (Sutcliffe, 1970; Brain, 1981; Haynes, 1983), and wolves in extreme conditions (Binford, 1981; Esteban *et al.*, 2010), can act in a similar way, although they normally leave other types of alterations and evidence,

such as gnawing marks, presence of complete shafts and coprolites or lack of epiphyses (Cruz-Uribe, 1991), evidences, which are absent in bearded vulture accumulations.

The nature of bone breakage may also be an indicator of the origin of an assemblage. Unfortunately, in the case of bearded vultures, the process of breaking bones in ossuaries (see Boudoin, 1976; Margalida & Bertran, 2001) results in a pattern of long-bone breakage extremely similar to that produced during human marrow processing (see Figure 3 for examples of assemblages from bone-breaking sites). Therefore, confusion is likely when analysing this feature in archaeological contexts with mixed human and bearded vulture activities. In each case, fractures are usually made when bones still retain collagen (oblique fractures with smooth edges), and the type of percussion is similar, being made by natural or manufactured stones and with great dynamic impact. In order to find a distinctive attribute, following Bunn (1983) and Villa & Mahieu (1991), percentages of circumference categories and fracture types of limb bones in bearded vulture assemblages have been compared with data from other accumulating agents (Marean & Kim, 1998).



Figure 2. Examples of digested bones identified in bearded vulture assemblages. (a) Ovicaprid metacarpal digested and regurgitated (Code 4). (b) First and third phalanges (Codes 14, 35, 38 and 39). (c) Ovicaprid third phalanx still with the hoof attached (Code 38). This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

However, differences in breakage patterns do exist for other skeletal elements. Phalanges were regularly broken by Palaeolithic people for marrow extraction (Mateos, 2003) but are rarely fragmented within bearded vulture assemblages. *Gypaetus* readily swallows bones up to 30 cm long (usually metapodials in anatomical connection with phalanges) and, unlike people, does not need to break them in order to access their nutrients.

Prehistoric and modern assemblages

In order to investigate taxonomic and anatomical preferences in bearded vulture diet, we have collected several samples of prehistoric, historic and modern bone assemblages. In so doing, we aimed to avoid possible reservation and recovery bias as well as possible shifts in bearded vulture food selection through time.

Three modern assemblages (M1, M2 and M3 respectively) from nests occupied for only 1 year were recorded and collected in the Spanish Pyrenees by one of us (AM) during the summer of 2008. The remaining one (M4) is the assemblage recovered from 11 Corsican nests studied by Robert *et al.*, (2002). Historical data were obtained from three nests occupied by bearded vultures in southern (H1 and H2, respectively) and northern

(H3) Spain during 1940–1950 (Margalida *et al.*, 2009b: Table 1). In these cases, skeletal identification was made with the help of osteological reference collections (Sociedad de Ciencias Aranzadi, San Sebastián, Spain and our own collections). Distinctive morphological features together with bone surface condition and cortical thickness were noted.

We also assembled information from the Late Glacial EMD (P1) and LMD (P2) levels of Gritulu cave, a palaeontological site in northern Corsica (Robert & Vigne, 2002), and the late Pleistocene (P3) and early Holocene (P4) levels of El Mirón Cave, northern Spain (Marín-Arroyo *et al.*, 2009), the latter with radiocarbon dates ranging between $14\,850 \pm 60$ BP (GX-27114) and $10\,270 \pm 50$ BP (GX-24467) (Straus & González Morales, 2003). At El Mirón, where activity attributed to bearded vultures is mixed with that of humans, only fossils that displayed digestion traces similar to those produced by bearded vultures and lacking gnawing marks were used.

In order to avoid possible underestimation of small prey items (e.g., birds, leporids, carnivores and rodents) caused by preservation bias as a consequence of the fragility of their bones (Margalida *et al.*, 2005; Margalida *et al.*, 2007), only ungulate bones were used. To

Table 1. Codes relating to the bone modifications made by bearded vultures

CARPALS, TARSAL, EPIPHYSES AND SHAFTS	
1	Outer surface erosion
2	One side bone perforation (lack of narrow fragments)
3	Whole bone perforation (open marrow cavity)
4	Whole digestion (thinned edges)
5	Small fragment almost unidentifiable
1st PHALANX	
11	Signs of 'attack' invisible to the naked eye, only seen under binocular microscope
12	Porosity around both articular surfaces
13	Perforation under insertion tuberosities, mainly on dorsal-axial or palmar face (proximal part) or direct perforation on juvenile metaphysis in proximal articulation
14	Disappearance of proximal articulation surface; the distal end and a shaft fragment are left
15	Following stage 13, when perforation has caused phalanx fracture; only proximal articular part is left
16	Disappearance of distal articular surface; the proximal end and a shaft fragment with dissymmetry are left
17	Only the distal pulley is left
2nd PHALANX	
21	Signs of 'attack' invisible to the naked eye, only seen under binocular microscope
22	Porosity around both articular surfaces, more visible on the palmar face of distal articular surface sides
23	Marked porosity on proximal articular surface; perforation of axial or palmar face (sometimes close to dorsal edge at the end of distal articular surface)
24	Both articular surfaces are still connected; disappearance of the axial or palmar face of the shaft that narrows under proximal articular surface (axial face)
25	After breakage under proximal articular surface, this articulation disappears; only distal articular surface and a bit of dissymmetric shaft are left (more accentuated on abaxial face)
26	Only distal articulation is left
27	Dissymmetry accentuation and axial side of distal end (pulley) disappearance
28	Following stage, only proximal articulation is left
29	Proximal articulation plus asymmetric shaft
3rd PHALANX	
31	Signs of 'attack' invisible to the naked eye, only seen under binocular microscope
32	Porosity (dorsal edge) over or under the processus extensorius up to the palmar edge, only on axial face; Enlargement of vascular foramens on the same face
33	Juvenile phalanges attacked via proximal articular surface
34	Both articular surface are still connected. More perforation of compact bone on the dorsal edge than on axial face/or attack over palmar angle and proximal articular surface
35	After the breakage or dissolution of proximal articular surface, only the apex, a sole fragment are left (dissymmetry)
36	If porosity is also on the apex, it disappears and only the proximal articulation plus a shaft fragment are left
37	If it breaks, only the proximal articular surface plus a part of the abaxial face are left; the same applies if the 'attack' is simultaneous on the apex
38	Only the palmar side is left
39	Between stage 34 and stage 35
40	Only distal apex is left

establish whether differential taphonomic preservation of anatomical parts may have had effect on assemblage composition, we tested for any tendency that could be related to bone density, with no significant differences found in any of the cases (Mann-Kendall test $p > 0.05$ for all samples).

Finally, Tables 2 and 3 show the Number of Identified Specimens by species and anatomical part. The skull is not considered because of its low utility (Binford, 1981). Gritulu and Corsican nest anatomical values were derived from percentages of anatomical representation (PR) and the total minimum number of individuals values presented by Robert & Vigne (2002: Figure 2a and 2b) following the Dodson & Wexlar (1979) method of calculation.

The bearded vulture bone utility index

Given the known dietary preferences of bearded vultures in terms of anatomical choice (Brown & Plug, 1990; Margalida, 2008a; Margalida *et al.*, 2009a) and their behavioural ecology, a new index to measure the utility of each skeletal element for this species is defined. The Bearded Vulture Bone Utility Index (BVBUI) relies on three factors that can affect choice of bones chosen for consumption: (1) the total amount of within-bone nutrients in each element in terms of marrow and bone grease weight; (2) the quality of the fatty acids involved in terms of oleic acid percentage; and (3) the maximum dimension of the element.



Figure 3. Material from bone-breaking sites in the Spanish Pyrenees. Left: General view of the assemblage. B: Long bone with a percussion notch. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

As bearded vultures feed principally on bones (387 KJ from 100 g of bone on average, Brown, 1988) especially fatty bones (Margalida, 2008a), it is reasonable to consider that elements with more within-bone nutrients will be more attractive for consumption (*bulk strategy*), and that this feature is highly correlated with bone volume (Binford, 1978:32). However, this could mitigate against the ability of a bearded vulture to swallow a complete element. Although this species has a very flexible oesophagus, a maximum length of around 30 cm (see Figure 1) has been established for whole bone taken by adults (Brown, 1988). Longer bones have to be broken into several pieces before consumption, which involves dropping them over breaking sites and subsequent fragment collecting. In such cases, the energy expenditure related to food procurement increases, reducing the suitability of such elements for consumption. Bone dimension would then be inversely proportional to utility. On the other hand, the quality of the fatty acids contained in a bone can also affect its attractiveness. For any species, unsaturated fats are

of better quality because they are more easily digested, and their metabolic energy content is higher (Soede, 2006). Among the unsaturated acids, oleic acid is the most frequent and representative type in the bone tissue of ungulates, so a higher percentage of this acid will indicate greater digestibility and nutritional value, as has been shown in the diet of some birds (McWilliams *et al.*, 2002). Consequently, preference is given to the skeletal parts with a higher percentage of unsaturated acids (*a gourmet strategy*).

Following the previous precepts, we propose the estimation of BVBU as:

$$BVBU = \frac{\sqrt{\text{Weight of bone grease and marrow in gr} \times \text{Percentage of oleic acid in \%}}}{\text{Maximum dimension in cm}}$$

When comparing results with skeletal element abundance in terms of %MAU, BVBU must be standardised by dividing all values by the maximum value and multiplying by 100 and thus obtaining %BVBU.

Table 2. Taxonomic representation of modern, historic and prehistoric assemblages in terms of NISP

Taxa	Modern				Historic			Prehistoric			
	M1	M2	M3	M4	H1	H2	H3	P1	P2	P3	P4
<i>Bos</i> sp.	8	2		428	2						
<i>Equus</i> sp.			1	1	2	1					
<i>Cervus elaphus</i>			1					484	267	43	51
<i>Capra pyrenaica</i>										77	24
Ovis/Capra	82	159	23	319	10	12	18				
<i>Capreolus capreolus</i>	21	35	1							8	10
<i>Rupicapra pyrenaica</i>	4	34	5				10			31	19
<i>Sus</i> sp.		1		60	1						1
Subtotal	115	231	31	808	15	13	28	484	267	159	105
Total		1185				56				1015	

Table 3. Skeletal profiles of modern, historic and prehistoric assemblages in terms of NISP

Anatomical part	Modern				Historic			Prehistoric			
	M1	M2	M3	M4	H1	H2	H3	P1	P2	P3	P4
Mandible		2	5	12	1	1		1	1		
Atlas				3							
Axis				3							
Cervical v.	5	1		0		2	4				
Thoracic v.	9	5		53	1	1		17	8		1
Lumbar v.	1			0			6				
Ribs	8	5	3	22	1	1	9	22	10		
Sternum				0			1				
Scapula		3	9	88		1		3	1	2	
Humerus	2	1	1	18		1		1	3		1
Radio/ulna	8	1		34		1	1	3		3	
Metacarpal	42	18		45				8	2	29	1
Carpal	12	2		51	1	1			1	2	2
Pelvis + sacrum	2		2	0		1	2	1	2		
Femur				3			2	4	3	1	
Tibia	4	7		39		1	1	1	2	1	1
Tarsals	20	15		175		2		10	3	8	4
Metatarsal	5	5	1	36				5	2	2	4
1st phalanx	33	7		157	2			24	10	11	8
2nd phalanx	35	6		262				100	92	21	10
3rd phalanx	35	12	3	761	1			264	106	46	55
Total	221	90	24	1762	7	13	26	464	246	126	87

To calculate this index for ovicaprids and cervids, the most common ungulates in bearded vulture diet, we proceeded as follows:

- To calculate the amount of bone marrow, we used Binford's data (1978, Table 1) regarding the volume

Table 4. Bearded vulture bone utility index (BVBUI)

Skeletal part	BVBUI			% BVBUI
	Ovicaprids	Cervids	Mean	
Mandible	1.13	0.77	0.95	17.0
Atlas	0.90	1.06	0.98	17.6
Axis	1.44	0.78	1.11	19.9
Cervical v.	2.49	2.07	2.28	40.8
Thoracic v.	2.03	1.91	1.97	35.2
Lumbar v.	2.06	1.97	2.01	36.1
Ribs	1.33	1.49	1.41	25.2
Sternum	0.40	0.53	0.47	8.4
Scapula	0.84	0.75	0.79	14.2
Humerus	2.88	2.18	2.53	45.3
Radio/ulna	2.06	1.97	2.02	36.1
Metacarpal	2.65	2.12	2.39	42.8
Carpal	3.38	2.36	2.87	51.4
Pelvis+sacrum	1.31	1.25	1.28	22.9
Femur	2.71	2.28	2.49	44.7
Tibia	4.63	2.31	3.47	62.2
Tarsals	2.54	1.89	2.22	39.7
Metatarsal	2.63	2.84	2.73	48.9
1st phalanx	6.41	4.76	5.58	100.0
2nd phalanx	6.38	4.62	5.50	98.5
3rd phalanx	4.30	1.79	3.04	54.5

of the medullar cavity of sheep and reindeer. To transform volume into weight, we applied an average density for bone marrow of 0.72 g/ml, a value obtained by Emerson (1990, Table 5) in her bison study. We believe this provides a reasonable estimate that can be consistently applied.

- Regarding bone grease, Binford's (1978) study lacks quantitative data, although he extracted this product during his experiments to estimate oleic acid content. However, his research does provide values for dry weight of each bone after grease extraction that

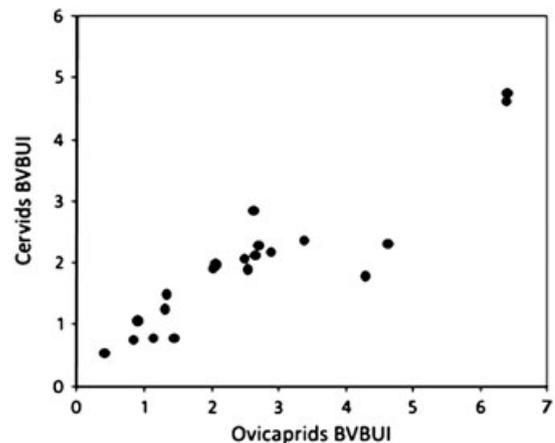


Figure 4. Relationship between ovicaprid and cervid BVBUI.

Table 5. Abundance of digestion traces in modern, prehistoric and historic assemblages in terms of NISP

Codes	Other bones (not phalanx)				Phalanx I				Phalanx II				Phalanx III						
	M	%	P/H	%	Codes	M	%	P/H	%	Codes	M	%	P/H	%	Codes	M	%	P/H	%
0	0	0	2	1.8	11	11	35.5	0	0.0	21	12	21.4	0	0.0	31	19	8.0	1	1.1
1	0	0	23	20.7	12	11	35.5	0	0.0	22	24	42.9	0	0.0	32	56	23.5	14	15.6
2	0	0	49	44.1	13	3	9.7	1	5.3	23	4	7.1	1	5.6	33	22	9.2	8	8.9
3	0	0	20	18.0	14	5	16.1	12	63.2	24	1	1.8	2	11.1	34	33	13.9	24	26.7
4	3	75	17	15.3	15	1	3.2	5	26.3	25	6	10.7	13	72.2	35	105	44.1	41	45.6
5	1	25	0	0.0	16	0	0.0	1	5.3	26	9	16.1	2	11.1	36	3	1.3	2	2.2
					17	0	0.0	1	5.3	27	1	1.8	5	27.8	37	0	0.0	9	10.0
										28	0	0.0	9	50.0	38	2	0.8	4	4.4
										29	0	0.0	1	5.6	39	2	0.8	16	17.8
															40	2	0.8	0	0.0

can be used here to derive bone grease weight. To do this, we used percentages of fat content per dry bone weight obtained by Emerson (1990, Table 5) for each skeletal element of bison, corrected by a factor of 3.75 following Brink's results (1997), who found an underestimation in Emerson's fat content for bison long bones caused by an inefficient extraction method (Brink fragmented bone more and also dissolved bone grease with chemical products instead of boiling). In the case of the mandible and because of a lack of data, we estimate grease content following Brink (1997, Figure 3) relationship between bone density and fat percentage using the Lam *et al.*, (1999) density values.

- To determine the quality of bone fat, Binford (1978, Table 1) provides figures for the percentages of oleic acid in bone grease and marrow of each skeletal element.
- Maximum dimensions of sheep and red deer and measurements of personal osteological collections

were obtained from ABMAP (2003), Mairrezkurrena & Altuna (1983).

Table 4 presents the resulting BVBU figures for ovicaprids and cervids. As shown in Figure 4, both sets of values are highly correlated ($r_p = 0.881$, $p < 0.001$) and can, therefore, be averaged to obtain a generalised index more suitable for comparison with mixed assemblages (Table 4).

Once this new index is derived, a statistical correlation between body part representation and the BVBU can be made to assess whether or not a particular bone accumulation is the result of bearded vulture consumption activities. Following Binford (1981), standardised %MAU can be used as a measure of skeletal abundance. On the other hand, Spearman's rank correlation index is proposed to determine whether there is a similarity or not between %MAU and %BVBU. This test is able to identify both linear and curvilinear relationships as it

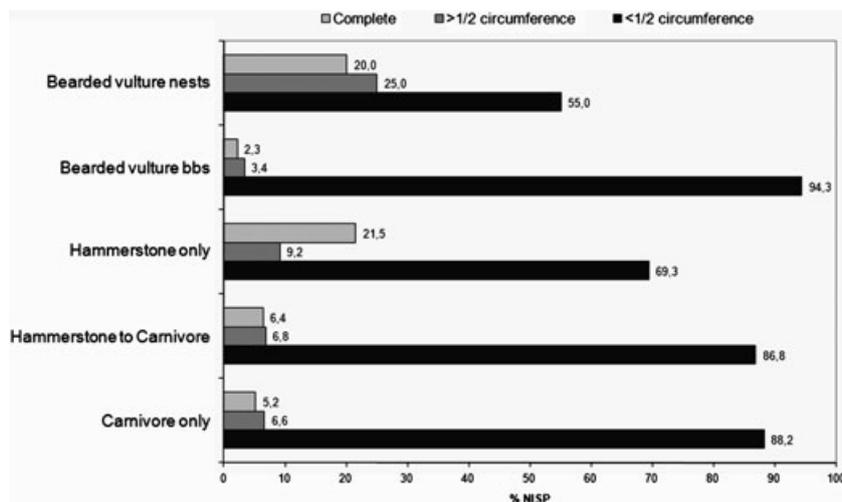


Figure 5. Percentage of shaft circumference of long bones found in bearded vulture nests and ossuaries, accumulations produced by humans, carnivores and carnivores after humans (data from the last three categories was obtained from Marean & Spencer 1991; Marean *et al.*, 1992, 2004).

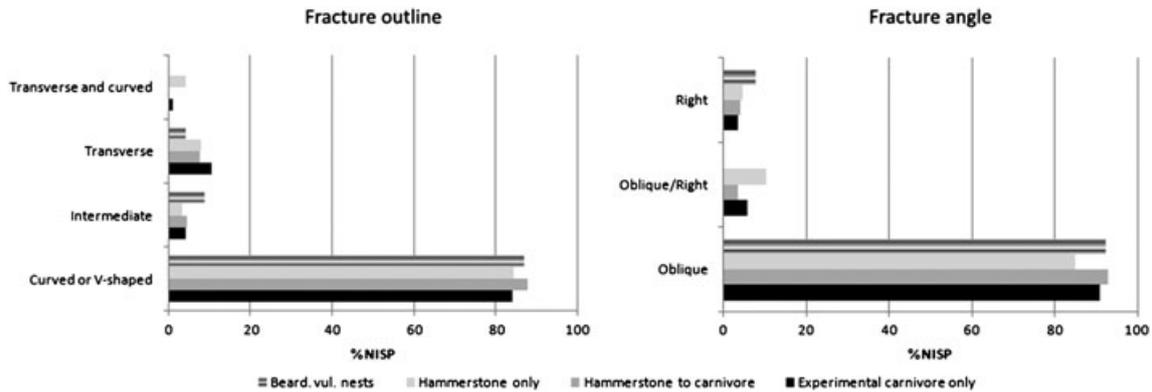


Figure 6. Comparison of fracture outline and angle between experimental carnivore only, hammerstone to carnivore, hammerstone only and Pyrenean bearded vulture nests (M1 and M2).

examines the degree of similarity from an ordinal point of view. However, to confidently accept a likely positive correlation is not enough, and a high degree of statistical significance is required. In this sense, Grayson (1989) fixed a threshold value of 0.05.

Results and discussion

Bone modifications

Although not exclusively related to bearded vulture activities, digestion traces are a key line of taphonomic evidence of its presence in archaeological sites above

all regarding phalanges and compact bones such as carpals and tarsals (usually still in anatomical connection when metapodials are chosen). Table 5 presents the abundance of each type of digestion trace listed by codes. Historic/prehistoric nests have been grouped together because of the low quantity of digested bones found in the former, whereas digested bones from modern nests are shown alone. In modern nests, phalanges, especially phalanx II and III, are the most common digested elements. However, in prehistoric nests, code 2 is the most representative usually found in carpals, tarsals and patellae.

Regarding long-bone breakage patterns, the custom of dropping them over rocky areas might lead to a representation of shaft circumferences similar to that produced

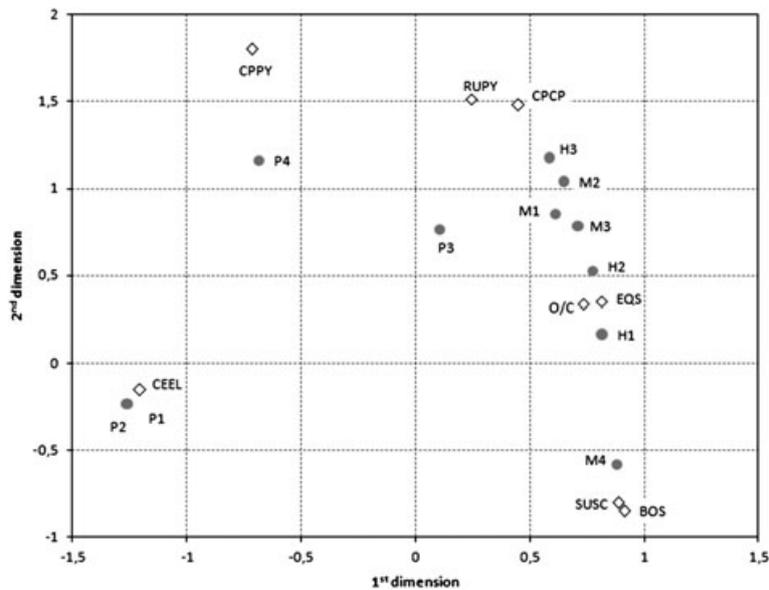


Figure 7. Correspondence analysis showing the evolution of the bearded vulture diet. RUPY: *Rupicapra pyrenaica*; CEEL: *Cervus elaphus*; SUSC: *Sus scrofa*; BOS: *Bos*; EQS: *Equus*; CPPY: *Capra pyrenaica*; CPCP: *Capreolus capreolus*. O/C: *Ovis/Capra*. Assemblages - P: Prehistoric, H: Historic, M: Modern.

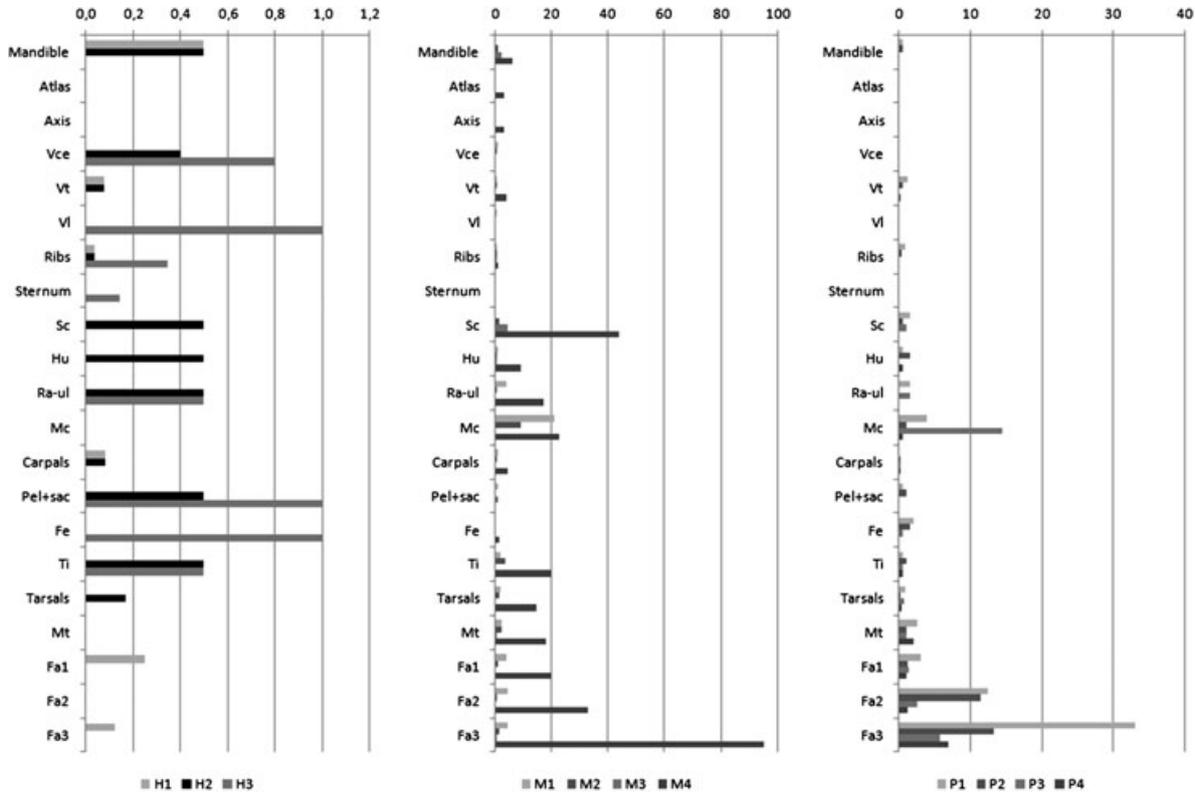


Figure 8. Skeletal profiles in terms of NISP in modern, prehistoric and historic assemblages.

by other agents such as humans and carnivores. The representation of circumference categories was measured in bearded vulture nests and ossuaries. Figure 5 shows its comparison with other bone assemblages accumulated by humans, carnivores and carnivores after humans.

We found significant differences in shaft circumference for bone accumulations made by bearded vultures in nests and assemblages resulting from human activities

Table 6. Results of the Spearman rank correlation between % BVBU and %MAU in historic (H), modern (M) and prehistoric (P) nests of bearded vultures and probability values

	<i>r</i>	<i>p</i>
H1	0.153	0.508
H2	-0.190	0.409
H3	-0.111	0.631
M1	0.763	0.0001
M2	0.426	0.054
M3	-0.247	0.280
M4	0.496	0.022
P1	0.487	0.025
P2	0.627	0.002
P3	0.578	0.006
P4	0.809	0.0001

($\chi^2 = 8.99$, $df = 2$, $p = 0.01$), carnivore activities ($\chi^2 = 26.28$, $df = 2$, $p < 0.001$) and carnivore scavenging after human consumption ($\chi^2 = 24.55$, $df = 2$, $p < 0.001$). Consequently, this test would allow us to distinguish assemblages accumulated by bearded vultures, which are characterised by a more even distribution of circumference types, that is a less fragmented pattern. At the same time, differences were observed between bearded vulture nests and ossuaries ($\chi^2 = 40.82$, $df = 2$, $p < 0.001$). In ossuaries, the bone breakage is higher than in nests with a higher amount of shafts with a less than half circumference, a fact that resembles evidence from humans and carnivores.

Regarding the type of fracture, Figure 6 shows a comparison of fracture outline and angle between modern bearded vulture nests and other types of bone assemblages. There are no significant differences between them (experimental carnivore only versus bearded vulture nest: $\chi^2 = 2.14$, $df = 2$, $p = 0.54$; hammerstone to carnivore versus bearded vulture nest: $\chi^2 = 1.28$, $df = 2$, $p = 0.73$; hammerstone only versus bearded vulture: $\chi^2 = 3.21$, $df = 2$, $p = 0.36$), and so, these features cannot be used to identify the presence of bearded vulture, with V-shaped outlines and oblique angles being the most abundant in each context.

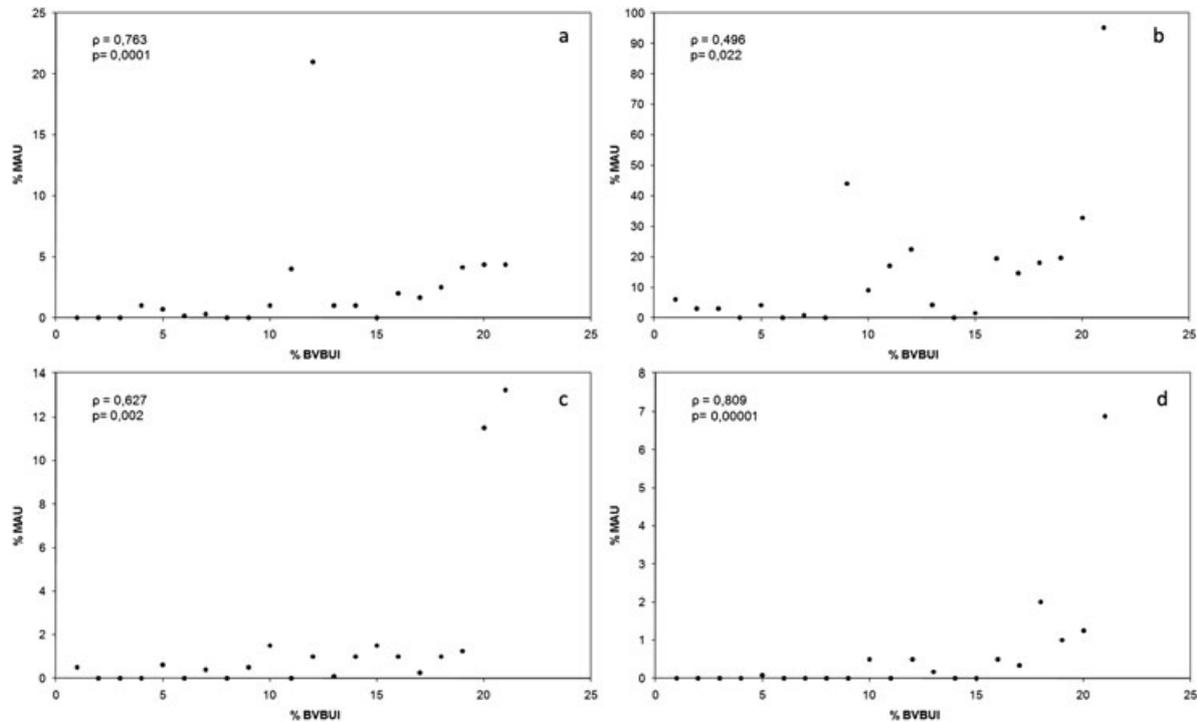


Figure 9. Examples of positive and significant correlations between skeletal profiles and %BVBUI in modern (M) and prehistoric (P) nests of bearded vulture. a M1 (Spanish Pyrenees nest), b M4 (Corsican nests), c P2 (Level LMD Gritulu cave), d P4 (Early Holocene El Mirón).

Taxonomic representation

In order to assess the evolution through time of bearded vulture diet and to identify their consumption preferences, a correspondence analysis has been made with Number of Identified Specimens data (Table 2). As Figure 7 shows, the diet of European bearded vultures from the Pleistocene to the present day is clearly linked to medium-size ungulate carcasses.

The taxonomic representation in each period of study is consistent with the availability of resources. Thus, during prehistoric times, depending on the habitat, red deer and Spanish ibex were the most abundant species in the diet of bearded vultures. These taxa were very common in the palaeoenvironment of El Mirón and Gritulu, being profusely consumed both by hunter-gatherer groups and carnivores, and thus providing a constant food source for bearded vulture scavenging (Marín-Arroyo, 2009b).

The switch to domestic ungulate consumption observed in historical and modern times towards ovicaprids reflects the reduction of wild ungulate populations because of hunting and the simultaneous expansion of livestock ranching throughout Europe (Margalida *et al.*, 2009b). In particular, there has been a decrease in deer consumption throughout recent historical time. However,

the size of the prey scavenged remains constant through time, which reflects the disadvantage of large bone consumption in terms of energetic and time expenditure. As a consequence, large-sized mammals, such as bovinds or equids, are scarcely represented in the bearded vulture palaeodiet. Only in Corsica and in modern times do bovinds have an important role in bearded vulture diet. However, the size of *Bos taurus* in Corsica, because of its island status, is relatively small (Vigne, 1988), thus requiring less effort for handling and carrying carcasses.

Anatomical representation

Regarding the anatomical preferences of bearded vultures, Figure 8 shows the skeletal profiles of the different assemblages analysed in this study. Feet and metapodials are overwhelmingly abundant in prehistoric and modern times, whereas the axial and upper limb elements are more evenly represented in historic ones. However, this fact can be affected by the recovery procedures applied in the latter assemblages, mostly focused on larger bones, and by the small size of the sample. In this sense, modern nests, as a result of the detailed analyses that were conducted on them, are more reliable for characterising bearded vulture choices.

In order to relate these anatomical preferences with nutritional values and to verify the use of the BVBUI defined earlier, correlations between %MAU and %BVBUI were made for each assemblage. We found (Table 6) that there is a significant similarity in all of the prehistoric assemblages and in three of the four modern ones (see examples of graphical correlation in Figure 9). As expected, historic anatomical representation differs from the choices derived from BVBUI. Remarkably, the M3 assemblage shows a negative but not significant correlation with the index. The small size of this sample and the abundance of scapulas are behind this result. Overall, however, when dealing with large and well-collected samples, BVBUI appears to be an objective way to distinguish whether a skeletal profile belongs to bearded vulture activities or not.

Conclusions

The identification of the bone accumulating agent in any archaeological site is crucial for avoiding incorrect palaeoeconomic interpretations. Taphonomic analyses, including the evaluation of taxonomic and anatomical part representation and the study of bone surface alterations, are normally used to elucidate this. Comparative taphonomic information is usually retrieved through actualistic studies conducted with controlled samples and environments. Here, we present results of a new index that characterises the presence/absence bearded vultures as taphonomic contributors in archaeological sites.

Bearded vultures are currently endangered birds of prey restricted to a few mountainous areas in Europe; however, their geographical range during the Pleistocene extended across mountainous regions throughout Europe. Notably, they use the same or similar shelters and caves as human groups in the past. The bone accumulations at breeding sites, which include regurgitated bone fragments (with hair and hooves) from pellets, leads to the formation of faunal deposits that could become mixed with non-contemporaneous human-derived or carnivore-derived assemblages. In addition, their habit of breaking long bones and whole carcasses by dropping them over rocky areas in order to produce smaller fragments that are easier to swallow, results in a breakage pattern that can be confused with human marrow processing. Consequently, bearded vulture bone accumulations can significantly affect archaeozoological deposits by altering their taxonomic and anatomical representation, and thus biasing our understanding of the site.

To avoid this, we have gathered and tested several distinctive features to help with the recognition of bearded vulture presence in archaeological contexts. They are the following:

- (1) Bearded vulture diet is mainly focused on medium-sized ungulates, as they are the most productive species in terms of energetic yield.
- (2) Digestive traces are the most remarkable feature regarding bone surface alterations. They are usually present on phalanges and small bones, such as carpals, tarsals and patellae, although they can also appear on metapodials and other long bones. The degree of decomposition of the cortical layer is fairly high as the gastric acids of this bird have an extremely low pH. This bone modification is rather different from the one produced by carnivores in the lack of gnawing marks and coprolites.
- (3) Long-bone breakage patterns can be statistically distinguished from those produced by humans or carnivores by comparing the abundance of circumference categories following Bunn (1983). In the case of bearded vulture nests, long bones are usually more complete, although diagenetic processes can conceal this trend. In addition, phalanges are not generally fragmented, which is not the case with Palaeolithic humanly produced assemblages.
- (4) The skeletal profile derived from a bearded vulture accumulation is specific and differs from those produced by other biological agents. It is characterised by a higher presence of fatty and small elements. A new utility index (BVBUI) has been defined to objectively verify the contribution of bearded vulture by means of a correlation between its values and %MAU. It should be applied in the same way as other human utility indexes, such as Modified General Utility Index or Food Utility Index, to infer a cause-effect relationship.

To our knowledge, there are two sites where the presence of bearded vultures has been confirmed, one archaeological and one palaeontological: these are El Mirón and Gritulu caves, respectively. However, it is likely that knowledge of the potential effect of this species on bone assemblages and the establishment of a way to distinguish its presence will increase the number of sites with remains recognisable as belonging to bearded vulture accumulating procedures. The guidelines presented here may help to understand the role played by it in archaeological assemblages where its presence has been suggested tentatively such as Caldeirão Cave (Davis *et al.*, 2007) and Noisetier (Costamagno *et al.*, 2008).

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