Archaeofauna 18 (2009): 79-98

A comparative study of analytic techniques for skeletal part profile interpretation at El Mirón Cave (Cantabria, Spain)

ANA BELÉN MARÍN ARROYO
Leverhulme Centre for Human Evolutionary Studies. University of Cambridge
The Henry Wellcome Building. Fitzwilliam Street CB2 1QH Cambridge. UK.
abm38@cam.ac.uk

(Received *20 November 2007*; Revised *5 March 2008*; Accepted *25 February 2009*)

ABSTRACT: The analysis of the skeletal part profiles identified at archaeological sites is of great significance as they hold valuable information about the life ways of the human groups who produced them, and simultaneously reflect post-depositional processes. As a consequence, the interpretation of such profiles, in combination with the identification of bone surface modification and bone fragmentation patterns are essential to any archaeozoological study as they prevent the creation of false economic explanations. Nevertheless, both the methodological and conceptual aspects of skeletal part studies are currently under intense debate within the scientific community. The archaeozoological literature provides several techniques which are in principle mutually exclusive, to deal with the problem. This paper presents a practical application of these techniques to three Magdalenian levels from El Mirón Cave (Cantabria, Spain). The study verifies the potential of each method by assessing its advantages and disadvantages, and improves interpretations about the economic behaviour of the human groups who occupied the cave. In particular, the residential function of the cave has been confirmed.

KEYWORDS: SKELETAL PART PROFILES, UTILITY INDEX, BONE DENSITY, ARP, ABCml, MAGDALENIAN, EL MIRÓN CAVE

RESUMEN: El análisis de los perfiles de representación esquelética recuperados en yacimientos arqueológicos resulta de gran relevancia por cuanto atesoran una valiosa información sobre los modos de vida de los grupos humanos que los generaron, además de ser el resultado de los diferentes procesos de atrición acontecidos en el depósito. En consecuencia, su interpretación, junto con la identificación tanto de las marcas presentes en la superficie ósea como del patrón de fracturación, se considera esencial en cualquier análisis arqueozoológico, si se desea evitar la formulación de explicaciones económicas erróneas. Sin embargo, este tipo de estudios es actualmente causa de intenso debate entre la comunidad científica, tanto desde el punto de vista metodológico como conceptual, encontrándose el arqueozoólogo con diferentes técnicas de aproximación al problema, en principio, excluyentes. En este escenario, se presenta aquí un ejemplo práctico de aplicación de dichas técnicas a tres niveles magdalenienses de la Cueva de El Mirón (Cantabria), de forma que, por un lado, se ha podido comprobar la potencialidad de cada método, evaluando así sus ventajas e inconvenientes, y por otro lado, se ha avanzado en el conocimiento del comportamiento económico de los grupos humanos que habitaron la cueva, confirmándose además su funcionalidad residencial.

PALABRAS CLAVE: PERFILES ESQUELÉTICOS, ÍNDICES DE UTILIDAD, DENSIDAD ÓSEA, ARP, ABCml, MAGDALENIENSE, CUEVA DE EL MIRÓN

INTRODUCTION

The skeletal part profiles of assemblages retrieved from archaeological sites possess valuable information regarding the economic strategies followed by prehistoric human societies, as they are result from decisions about carcass transport and use. Unfortunately, certain post-depositional factors, such as non-human biological agents and geochemical processes result in the differential conservation of specimens within archaeological deposits. This distorts the original skeletal part profiles and prevents its direct assessment (see the state of the question in Lyman, 1994; Marean & Frey, 1997; Domínguez-Rodrigo, 1999, 2002; Stiner, 2002; Marean *et al.,* 2004; Munro & Bar-Oz, 2004).

Binford's (1978) utility indices provide a more objective way of dealing with skeletal part profiles based on empirical principles and statistical tests. However, despite its conceptual promise, Binford's method has failed in its general application to archaeological assemblages due to its disregard of attritional processes. Thus, the utility indices led to the classification of deposits with a predominance of head and/or limb remains (Type II Sites) as kill sites or as the products of human scavengers (Marean & Frey, 1997). The addition of bone density studies and bivariate correlations with statistical significance (Lyman, 1985, 1992; Grayson, 1989) improved skeletal part analyses, as they introduced an additional explanation for attritional patterns and a more robust methodology. Nonetheless, the majority of sites were still classified as an indeterminate type due to the combined impact of multiple processes (Lyman, 1991, 1993). Therefore, in the mid-1980s, the concept of equifinality was first applied to the study of skeletal part profiles. Lyman (1994: 507) defines equifinality as «the property of allowing or having the same effect or result from different events».

Since then, several researchers (Stiner, 1991, 1994, 2004; Lam *et al.,* 1998; Marean & Kim, 1998; Bartram & Marean, 1999; Rogers, 2000a, 2000b; Marean & Cleghorn, 2003; Bar-Oz & Munro, 2004; Beaver, 2004; Faith & Gordon, 2007) have identified and analysed some potential causes of equifinality and have proposed new techniques and improvements to resolve them. The ultimate goal is to distinguish the agents that have created and modified faunal assemblages and their behaviour while bypassing the effect of attrition. In general, this research has focused on one of the following issues: (1) procedures for estimating skeletal part profiles, with special attention to calculating MNE and the importance of both ends and shafts in the representation of long bones (Marean & Frey, 1997; Marean, 1998; Marean & Kim, 1998; Klein *et al.,* 1999; Stiner, 2002, 2004; Pickering *et al.,* 2003; Cleghorn & Marean, 2004; Marean *et al.,* 2004); (2) analytical techniques for interpreting the relative abundance of skeletal elements by investigating both the potential attrition of the deposit and the economic behaviour of hunter-gatherer groups (Stiner, 1991, 1994; Lyman, 1994; Rogers, 2000a; Marean & Cleghorn, 2003; Beaver, 2004; Faith & Gordon, 2007); (3) the taphonomic effects of natural agents based on actualistic studies, (Klippel *et al.,* 1987; Binford *et al.,* 1988, Blumenschine, 1988, 1995; Marean & Spencer, 1991; Bartram, 1993; Bunn, 1993; Capaldo, 1995; Domínguez-Rodrigo, 1999); and (4) the relationship between potential attrition and bone density, with special attention to improving the reliability of density values (Binford, 1977; Lyman, 1984; Lam *et al*., 1998, 1999).

With increasingly more detailed excavations, thorough archaeozoological analyses (stressing the study of both bone shafts and ends) and a wider range of actualistic studies, the development and validation of analytical techniques to assess skeletal part profiles acquire greater urgency. Currently, several methods are available including the Anatomical Region Profiling (ARP) technique developed by Stiner (1991, 1994); the differentiation between anatomic parts of high and low survivorship (Marean & Cleghorn, 2003); the Shannon Evenness Index (Faith & Gordon, 2007); and the application of the Maximum Likelihood Principle (i.e.; ABCml Rogers, 2000a, 2000b). These all have their advantages and disadvantages, which has lead to much controversy (Marean & Kim, 1998; Marean, 1998; Outram, 2001, 2004; Stiner, 2002; Pickering *et al.,* 2003; Marean *et al.,* 2004).

Given this context, a practical study using a controlled actualistic study can improve the interpretation of faunal assemblages rather than continuing to discuss the conceptual validity of each technique. In addition, the strong and weak points of each method should become clear when they are directly compared. An archaeological test is a suitable way to model the complex post-depositional processes that take place in an archaeological site, and can account for the superposition of different taphonomical agents through time. An archaeological assemblage also provides other material remains (i.e., lithic and osseous artefacts, etc.) that can provide interpretations independent of the faunal assemblage. This it the case presented here.

As a starting point, three archaeological layers have been selected from the middle and late Magdalenian at El Mirón Cave, an inland montane site, still under excavation by L.G. Straus and M. González Morales, in Cantabrian Spain. The site has a residential function that was previously determined through the study of its faunal remains (Marín Arroyo 2007, 2008a, 2008b) and other archaeological evidence. In addition, the meticulous recovery of the archaeological material (González Morales & Straus, 2000) and the high level of attrition make this is an ideal site for this kind of analysis. The samples are also large enough to allow for the proper application of the different techniques for analysing skeletal part profiles. The present research also aims to promote the accurate study of skeletal part profiles in Spain. Until now these analysis have only been applied in a few promising studies (Davidson & Estévez, 1986; Blasco, 1995; Martínez, 1998; Yravedra & Domínguez-Rodrigo, 2009).

MATERIALS AND METHODS

El Mirón Cave

El Mirón Cave is located in the east of Cantabria province in the upper sector of the Asón Valley. It is situated at 260 m above sea level and its entrance faces south-west. This strategic position high on the western face of Monte Pando, overlooks the Ruesga valley, and lies at the foot of a mountain pass leading up to the Castilian Meseta (Straus *et al*., 2001, 2002).

El Mirón is a large karstic cave with a sizeable vestibule 30 m long and between 6 and 16 m wide, leading to a ramp that rises toward the cave interior for an additional 100 m. The main archaeological deposits that have been studied are located inside the vestibule (see Figure 1).

Three areas have been excavated by L.G. Straus and M.R. González Morales (2003a) since 1996. The *Cabin* is situated at the front of the vestibule; its name comes from a shepherd's cabin. It is a well-lit and exposed area of about 10 m^2, in the form of a 3 m square next to the southern wall of the cave. At the back of the vestibule, the *Corral* extends over a surface area of 12 m^2 next to the ramp leading to the interior of the cave. In this area, the microenvironmental conditions are more typical of a cave, as the area is more sheltered and receives less sunlight. Connecting both areas is, the 9x1 m^2 *Trench* (see Figure 1).

The deposit in El Mirón Cave consists of a thick, well-preserved stratigraphic sequence, ranging from the Mousterian to the Bronze Age. The levels studied in the present paper are Level 106, attributed to the late Magdalenian, and Levels 107.2 and 108, dated to the middle Magdalenian (Straus & González Morales, 2003b, 2007a) (see Table 1). The choice of these strata, all from the back of the vestibule, was based on their large

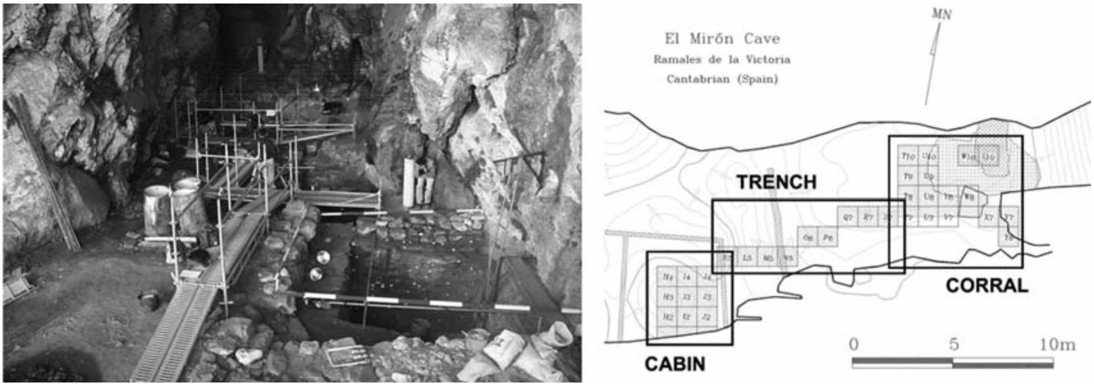


FIGURE 1

View and plan of the vestibule of El Mirón Cave, showing the three excavation areas being studied (Plan: E.Torres). Photo: M. R. González Morales.

Cultural Attribution	Level	BP	Calibrated dates*
Late Magdalenian	106	(GX-32382): 12,460±180	13,170-12,050 cal BC
Middle Magdalenian	107.2 108	(GX-22703): 13,660±70	14,740-13,940 cal BC
		(GX-32381): 13,710±70	14,800-14,010 cal BC
		(GX-23397): 14,710±160	16,570-15,190 cal BC
		(GX-27114): 14,850±60	16,560-15,850 cal BC
* Reimer *et al.,* 2004: CALIB 5.1 (Range @ 2 sigma, rounded to nearest 10 yrs.).			

TABLE 1

Radiocarbon dates of the levels being studied.

sample sizes, which allows statistically significant results to be obtained.

A great deal of evidence exists to suggest a residential function for the site, such as its strategic position (González Morales & Straus, 2000, 2003a), the wealth and diversity of the lithic and osseous artefacts (González Morales & Straus, 2005), the abundance of hearths (Straus & González Morales, 2007b) and the examples of both parietal and mobile art (González Morales *et al.,* 2007). However, recent results concerning the age of death of the prey consumed at the site (Marín Arroyo, 2007), the alternating use of the cave by birds of prey (Marín Arroyo *et al.,* 2009), and the process of bone staining with manganese oxide, as a consequence of organic decomposition phenomena (Marín Arroyo *et al.,* 2008), all suggest that the occupation was mainly seasonal, especially in the summer months. Therefore, this was probably a mountain site used by hunters to exploit herds of red deer when they were in the high summer pastures, and ibex on the adjacent rocky slopes. This pattern contrasts with coastal sites near the mouth of the Asón Valley that display winter seasonality in the Late Glacial (Marín Arroyo & González Morales, 2007).

The bone assemblage

The strata studied here are the ones which have yielded the largest numbers of osseous remains among the levels that have been analysed so far. Out of the total number of 92,356 remains studied, a bit over 94.5% come from Level 108 (Table 2). However, because of the high level of fragmentation of the assemblages in the three levels studied, only 4,940 remains could be identified to a skeletal element, 3,598 of which were also identified to taxon.

The full archaeozoological analysis (Marín Arroyo, 2007) has shown the existence of a subsistence strategy based almost exclusively on the consumption of red deer and ibex during the mid and late Magdalenian (see Figure 2). In this respect, El Mirón Cave is one of the few examples in Cantabrian Spain of a site that specialised in the hunting of two species (red deer, related to plains, and ibex, related to montane areas). This is evidenced by the pronounced dichotomy of the biotopes surrounding the site and the intentional choice of high-ranked species by small human populations, as I have argued elsewhere (Marín Arroyo, 2008c) (but see, for example, La Riera in Asturias [Altuna, 1986] or La Fragua in the lower Asón Valley [Marín Arroyo, 2004]). In addition, as the two species are of different sizes and susceptible of being transported in different ways, El Mirón is an ideal site at which to understand anatomical element choice patterns. Given the clear preference for the consumption of red deer and ibex, the present study will focus exclusively on these two taxa.

The taphonomy of the deposit displays great variability. Among the anthropogenic alterations that have been observed, 20.4% of bones identified to skeletal element in Level 106, 19.8% in Level 107.2 and 13.4% in Level 108 show cut marks produced during the butchery process. In addition, intense exploitation of bone marrow and

	Level 106				**Level 107.2**				**Level 108**			
	NISP	**MNE**	**MNI**	**W (g)**	**NISP**	**MNE**	**MNI**	**W (g)**	**NISP**	**MNE**	**MNI**	**W (g)**
Equus sp.	4	4	1	16.6	4	3	2	28	1	1	1	4.1
Bos/Bison					2	2	2	51	2	2	1	90.1
Cervus elaphus	228	126	6	931.4	206	116	6	808.7	1524	772	25	6696.6
Capreolus capreolus	2	2	1	1.8	13	13	2	9.6				
Capra pyrenaica	211	137	9	560.9	162	122	8	454.5	1096	557	10	3048.5
Rupicapra rupicapra	13	13	3	9.9	23	20	3	21.4	62	48	4	148.9
Sus sp.	1	1	1	0.3								
Canis sp.					5	5	2	3.3	4	4	1	3.3
Vulpes vulpes	1	1	1	0.1	3	3	1	1.2				
Felis sylvestris					1	1	1	2.5				
Lynx sp.					1	1	1	0.2				
Pantera pardus									1	1	1	0.8
Ursus sp.					1	1	1	1.9				
Martes sp.					3	3	1	1.7				
Erinaceus europeus									1	1	1	1.3
Oryctolagus cuniculus	9	8	2	4.3	6	6	3	7.2	2	2	1	0.7
Lepus sp.	3	3	2	4.4	4	4	2	5.4				
Big mammal	2			62.8	4			46.2	4			153.2
Medium mammal	657			1601.1	588			1267.9	2684			4061
Small mammal	5			0.5	3			1.1	4			
Non identifiable	984			749	1934			1046.6	81888			15291
Total identifiable	**1136**			**3194.1**	**1029**			**2711.8**	**5385**			**14208.5**
TOTAL	**2120**	**295**	**26**	**3943**	**2963**	**300**	**35**	**3758**	**87273**	**1388**	**45**	**29499**

TABLE 2

Number of Identified Specimens (NISP), Minimun Number of Elements (MNE), Minimum Number of Individual (MNI), and bone weight in grams (W) of bone remains in Levels 106, 107.2 and 108.

grease has been detected. Epiphyses and shafts fragments suffered dynamic fracture whilst fresh, while the presence of cylinders is extremely rare. Bone breakage was recognized in 89.3%, 82% and 87.3% of bones identified to skeletal element in Levels 106, 107.2 and 108, respectively. Together this evidence confirms the human origin of most of the deposit. Conversely, only 0.5% of the faunal remains identified taxonomically and anatomically display gnawing marks. Other biostratinomic alterations that have been observed are the action of scavenging birds and weathering. Finally the diagenetic alterations include vermiculations, dissolution, concretion and manganese staining.

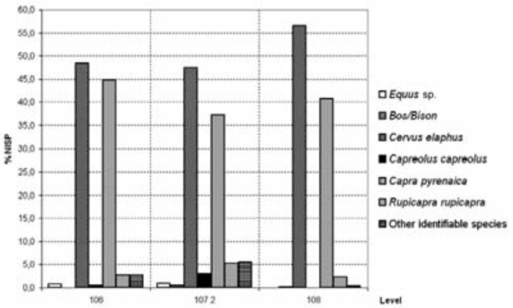


FIGURE 2

Taxonomical representation of the levels being studied of El Mirón Cave.

Quantification

One of the main factors affecting the interpretative potential of skeletal part profiles at archaeological sites is the thoroughness and precision in the recovery, identification and quantification of the bone remains, with major albeit controversial attention to the shaft fragments (see the «shaft critique» in Marean, 1998; Marean & Kim, 1998; Marean & Assefa, 1999; Marean *et al.,* 2004; contra Stiner, 2002, 2004, Outram, 2001, 2004). Justified precaution should be taken in this respect in the case of old excavations (Stiner, 1991: 461), because their assemblages do not always resemblance the original deposit as result of a biased recovery towards easy-to-identify remains and the importance given to faunal remains was not always what could be desired.

The excavation methods at El Mirón Cave were both rigorous and methodical. The archaeozoologist collaborated in all stages of recovery and identification of the assemblage, and ensured the consistent recovery of the bone remains. After the bones were extracted *in situ*, the sediment from the excavation was wet-sieved through 1mm screens, floated, washed and dried. It was then sieved through 2 and 4mm screens so that all fragments could be recovered. It has been proven that the use of small-meshed screens increases the recovery of small identifiable remains, such as fetal bones (Cannon, 1999). In the field laboratory there was no pre-classification into identifiable and unidentifiable material. All remains were considered identifiable until the specialist began her study. All the remains were numbered systematically for a more efficient analysis.

During the subsequent archaeozoological analysis, the only elements that were considered to be unidentifiable were small bone splinters and shaft fragments without any visible landmark. The first were grouped into four different categories: <1cm, ≈1cm, 1-2cm and >2cm and then counted, so that the degree of fragmentation could be assessed. In addition, fragments recovered by sieving were also classified as teeth, small bones (mainly carpals, tarsals and sesamoids) and small bone splinters and shafts (up to 2cm) when possible. Although it was a difficult and time-consuming task (Marean *et al.,* 2004: 92-93), 21 refits and 31 re-articulations were made, following a methodology similar to the one applied at La Fragua Cave in the lower Asón valley (Marín Arroyo, 2004, 2005). When shafts of a given skeletal element could not be identified taxonomically by taking into account their thickness and internal tissue (Barba & Domínguez-Rodrigo, 2005), they were grouped into three different mammal size categories (large, medium and small).

The identified bones were quantified using the following measures: Number of Identified Specimens (NISP), (Payne, 1975), Minimum Number of Individuals (MNI) (Klein & Cruz-Uribe, 1984), Minimum Number of Elements (MNE) and Minimum Animal Units (MAU) (Binford, 1978). In order to calculate the latter two values, both the long bone ends and shafts were taken into account. In the case of more diagnostic bone portions, such as long bone ends or vertebrae, each fragment was scrutinized in search of identifiable landmarks, both to the attribution to a specific skeletal element and the quantification of its completeness (Stiner, 1994, 2004; Marean *et al*., 2001). One identifiable bone could thus comprise one or more complete or partial landmarks. As emphasized by several researchers (Marean & Frey, 1997; Lam *et al.,* 1998; Marean, 1998; Marean & Kim, 1998; Bartram & Marean, 1999; Marean *et al.,* 2001; Pickering *et al.,* 2003; Cleghorn & Marean, 2004; Marean *et al.,* 2004; Barba & Domínguez-Rodrigo, 2005) and regarded as a normal procedure by others (Klein *et al*., 1999; Stiner, 2002), a more time-consuming effort has been made with shafts. Each of them was related to one or more portions of the whole element in length and section, so that possible overlapping could be assessed (Bunn, 1983; Marean *et al.*, 2004; Yravedra & Domínguez-Rodrigo, 2009). The final MNE of an element was then derived by determining the highest number of morphologically unique portions or features, obtained by summing landmarks or minimum possible complete diaphysis formed from shaft fragments. Refitting was used to reduce the number of incomplete landmarks (Marean *et al.*, 2001). Teeth were excluded in the quantification of crania as their dense structure can exaggerate their relative abundance in a faunal assemblage (Stiner, 1991). The results thus obtained are given in Table 3.

Analytical techniques

Bivariate scatter-plotting was the first technique used to study skeletal part profiles at archaeo-

Element	**Level 106**						**Level 107.2**						**Level 108**					
	Cervus elaphus			***Capra pyrenaica***			***Cervus elaphus***			***Capra pyrenaica***			***Cervus elaphus***			***Capra pyrenaica***		
	NISP	MNE	%MAU	NISP	MNE	%MAU	NISP	MNE	%MAU	NISP	MNE	%MAU	NISP	MNE	%MAU	NISP	MNE	%MAU
antler/horn	13	1	11.1	2	2	40.0	7	1	25.0	2	1	33.3	79	1	3.23	11	2	13.3
cranium	1	1	22.2	2	2	80.0	7	2	100.0	0	0	0.0	104	11	71.0	21	5	66.7
mandible	1	1	11.1	10	5	100.0	4	3	75.0	3	3	100.0	58	31	100.0	22	10	66.7
atlas	0	0	0.0	1	1	40.0	0	0	0.0	0	0	0.0	2	2	12.9	1	1	13.3
axial	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	3	2	26.7
cervical v.	7	4	17.8	3	1	8.0	2	2	20.0	0	0	0.0	67	8	10.3	4	4	10.7
thoracic v.	9	7	12.0	3	4	12.3	7	4	15.4	2	2	10.3	24	22	10.9	27	16	16.4
lumbar v.	5	2	7.4	20	5	33.3	4	3	25.0	7	5	55.6	45	8	8.6	61	11	24.4
sternum	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	2	3.8
scapula	0	0	0.0	2	2	40.0	2	1	25.0	1	1	33.3	9	5	16.1	13	3	20.0
humerus	7	2	22.2	1	1	20.0	1	1	25.0	0	0	0.0	65	15	48.4	24	2	13.3
radius/ulna	15	9	100.0	7	2	40.0	9	2	50.0	11	2	66.7	86	10	32.3	71	13	86.7
carpals	7	6	11.1	6	6	20.0	11	10	41.7	13	7	38.9	32	32	17.2	50	47	52.2
metacarpal	6	2	22.2	8	5	100.0	12	3	75.0	6	1	33.3	45	10	32.3	52	9	60.0
pelvis	5	3	33.3	1	1	20.0	2	2	50.0	0	0	0.0	42	10	32.3	16	5	33.3
femur	12	5	55.6	3	2	40.0	3	2	50.0	8	2	66.7	66	9	29.0	35	5	33.3
patella	0	0	0.0	0	0	0.0	0	0	0.0	2	0	0.0	4	4	12.9	3	3	20.0
tibia	10	3	33.3	3	2	40.0	5	2	50.0	4	2	66.7	66	11	35.5	31	6	40.0
tarsals	2	2	5.6	1	1	5.0	0	0	0.0	5	2	16.7	7	7	5.6	19	16	26.7
astragalus	0	0	0.0	1	1	20.0	1	1	25.0	3	2	66.7	5	4	12.9	10	11	73.3
calcaneus	2	2	22.2	1	1	20.0	0	0	0.0	6	3	100.0	6	5	16.1	8	4	26.7
metatarsal	11	3	33.3	21	5	100.0	12	2	50.0	0	0	0.0	54	8	25.8	44	15	100.0
1st phalange	8	4	11.1	13	8	40.0	5	3	18.8	6	5	41.7	49	22	17.7	74	17	28.3
2nd phalange	5	3	8.3	8	6	30.0	5	4	25.0	7	5	41.7	38	8	6.5	78	19	31.7
3rd phalange	11	11	30.6	13	11	55.0	27	16	100.0	13	6	50.0	44	26	21.0	29	25	41.7
Total NISP	137	71		130	74		126	64		99	49		997	269		707	253	
Highest MNE	11			11			16			7			32			47		

TABLE 3

Skeletal part representation in Levels 106, 107.2 and 108 at El Mirón Cave.

logical sites (Binford, 1978; Speth, 1983; Thomas & Mayer, 1983). The technique allows for visual examination of the relationship between skeletal frequencies and their utility or bone density. Better quantification of these relationships was achieved by applying statistical correlation coefficients, mainly Spearman's test (1904). This test is able to identify both linear and curvilinear relationships as it examines the degree of similitude from an ordinal point of view. However, to determine a causal relationship between density or utility and skeletal part survival, a positive or a negative correlation is not sufficient, and a high degree of statistical significance is required. In this respect, Grayson (1989) fixed 0.05 as a threshold value, which is to say that only when the null hypothesis is rejected with a 95% probability can the cause of the origin of the record be established.

In the present study, all anatomical elements have been used for comparison with the utility indices, in the conviction that it is precisely the absence of certain elements that we are trying to detect. Binford's MGUI has been applied here by averaging the values for both epiphyses to obtain the utility of long bones. Ribs, although quantified, were excluded from the study given the impossibility of an accurate estimation of their MNE, due to their high degree of fragmentation (the average length of identified rib portions is 3.7 cm) and the lack of an easily-measured section like that of long bone shafts. In addition, the articular part of the rib, of high bone density, which acts like a long bone in terms of its survival possibility, does not possess any landmark to permit its identification to taxon (Cleghorn & Marean, 2004: 57). In the case of density, the unrepresented anatomical parts were eliminated from the analysis, as their consideration could alter the results significantly, and it is not certain that they were brought to the site at all (Novecosky & Popkin, 2005). The effect of attrition on the skeletal part profiles can be clearly identified using the elements represented in the assemblage.

Currently, computed tomography (CT) is the most widely-accepted method for measuring the density of bone mineral content. Here, Lam *et al.* (1999) BMD_1 data (Bone Mineral Density) were used, except when an internal shape correction was needed. In those cases BMD_2 values for reindeer were applied for both red deer and ibex. The data set is calculated using Lyman's scan sites for the various skeletal parts (1984). Instead of taking the average density of each element, the maximum value has been chosen as more representative of the sensitivity of each element to attrition (Cleghorn & Marean, 2004), as the recovery of only a fragment with particular morphological characteristics suffices for its identification.

Since Lyman first proposed the correlation analyses, various improvements have been developed. First, Beaver (2004) used Fuzzy-set Theory to identify the mathematical relationships of necessity and sufficiency among the causes –utility indices and bone density – and the results – the observed skeletal part profiles. In addition to rigorously characterizing the bulk and gourmet transport strategies defined by Binford (1978), the new technique discerns whether bone density is a determining or limiting factor in skeletal part representation. Hence, if the correlation between density and %MAU results in a triangular scatter in the lower right-hand corner of the scatterplot, a relationship of need exists between both variables, i.e., high density is required in order for an element to be represented, although other causes, such as utility, may modify the final frequency. On the other hand, if the triangular scatter is in the upper left-hand corner, density is the determining factor and the main cause of survival.

Second, Marean & Cleghorn (2003) proposed separating the fauna into high-survival (all of the long bones, mandibles and cranium) and low-survival groups (all vertebrae, ribs, pelvis, scapulae, carpals, tarsals and phalanges) before carrying out the correlations with the utility indices. This classification was determined by examining the likelihood of survival of different bones mainly based on experiments with carnivores but also with other taphonomic processes. Bones in the low-survival set either have significant proportions of trabecular tissue and high grease content, or are small in size. In both cases they are especially attractive to scavengers. More importantly, they lack large areas of dense cortical bone without trabeculae (Cleghorn & Marean, 2004). Thus, these researchers aimed to sidestep the effects of attritional processes that were expected to affect all the elements in each group uniformly. The high survival set should thus correlate well with utility indices in cases of differential transport, whilst the survivorship of the low survival set is more likely to correlate with bone density under cases of attrition, although this is not clear (Cleghorn & Marean, 2004). Despite the concerns about the suitability of this technique for analysing a non-carnivore ravaged assemblage, this technique is included here to provide a more complete comparative analysis of skeletal part representation techniques.

Third, Faith & Gordon (2007) have developed a statistical technique to objectively differentiate hunting strategies when comparing the skeletal part profiles of high survival bones and utility indices. It consists of calculating the Shannon Evenness Index (Shannon & Weaver, 1949) of the skeletal part profiles and comparing them with different established ranges of validity for each type of behaviour. These values were obtained by mathematically simulating hypothetical deposits for several sample sizes. Logically, the larger the sample is, the more exact the distinction between strategies will be, as they become statistically more significant.

Fourth, Stiner's (1991, 1994, and 2002) Anatomical Region Profiling (ARP), enables the homogeneous comparison of the survivorship of different regions of the skeletal. This method is more of a visual approach than a statistical technique and is based on the assumption that each anatomical region has a similar chance of survivorship, taking into account their average density values as obtained by Lyman (1994). In this sense, the effect of attrition can be ruled out by «sticking to comparisons of parts that fall within a narrower, well-defined density range that it is widely distributed in the vertebrate skeleton» (Stiner, 2002: 979).

Finally, Rogers (2000b) has developed an *Analysis of Bone Counts by Maximum Likelihood* (ABCml) based on the application of the Maximum Likelihood Principle, which assumes that the best estimators for the parameters on which a certain probability function depends, are those that maximise the product of the density function associated with each of the values of the available statistical sample, or a likelihood function (Kay, 1993). In this method, the fraction of the osseous record that is taken to a site by each agent (normally human groups at residential or hunting camps) is α_k, while the total number of animals transported is represented as k. Once they have been deposited, the bones suffer an attritional process of variable intensity, characterised by a parameter β, and the likelihood of survival, in the absence of better estimates, is obtained as a function of the bone density (Rogers, 2000a). A value of $\beta=1$ implies that only half the bones survive, whereas if $\beta=2$, the survival percentage is reduced to 25%. Each k agent displays different transport strategies, known as «configurations», each with a certain probability of taking place. These result in variation in the skeletal part profiles contributed to the site. Configurations should be established before the method is applied, by using ethnographic studies, by following theoretical principles such as the Optimal Foraging Theory or by applying Utility Indices. By making use of the information associated with all the osseous remains in the assemblage, the method is able to obtain the most likely values of the parameters $\alpha_{k,}$ β and k, which are of direct archaeological interest. In addition, the method provides a goodness of fit test (χ^2) and error analysis in order to check its validity.

RESULTS

With the aim of identifying the effect of both selective transport and attrition on the skeletal part profiles at El Mirón Cave, MNE values were first grouped into the nine anatomical regions proposed by Stiner (1991). The results are presented in Figure 3. Although this technique was not developed to assess the degree of attrition, given that there is no complete anatomical part in the assemblages and that standarized MNE values remain quite low for all of them, a high loss of material is indicated. Supposing that the degree of attrition can be measured as the difference between 1 and the average standardized MNE when the latter values are quite enough, this loss can be roughly quantified here at about 70-90%. On the other hand, if attrition processes could be truly ruled out by the application of this technique, limb and cranial remains would dominate and could be viewed as an economic pattern biased against the axial skeleton. However, as Stiner also admits (1994), there is slightly lower survivorship among neck and axial anatomical parts. These parts have lower density according to Lyman's (1994) photon densitometry values, a phenomenon that is even more marked in Lam et *al.*,'s (1999) CT data. Thus differential density could also explain the results. Therefore, it is not possible to determine why the axial elements are underrepresented using this method (Stiner, 2002: 983).

Next, a statistically more rigorous method, bivariate correlations, were made between %MAU and %MGUI, and between %MAU and maximum bone density, respectively. The results are given in Figures 4 and 5.

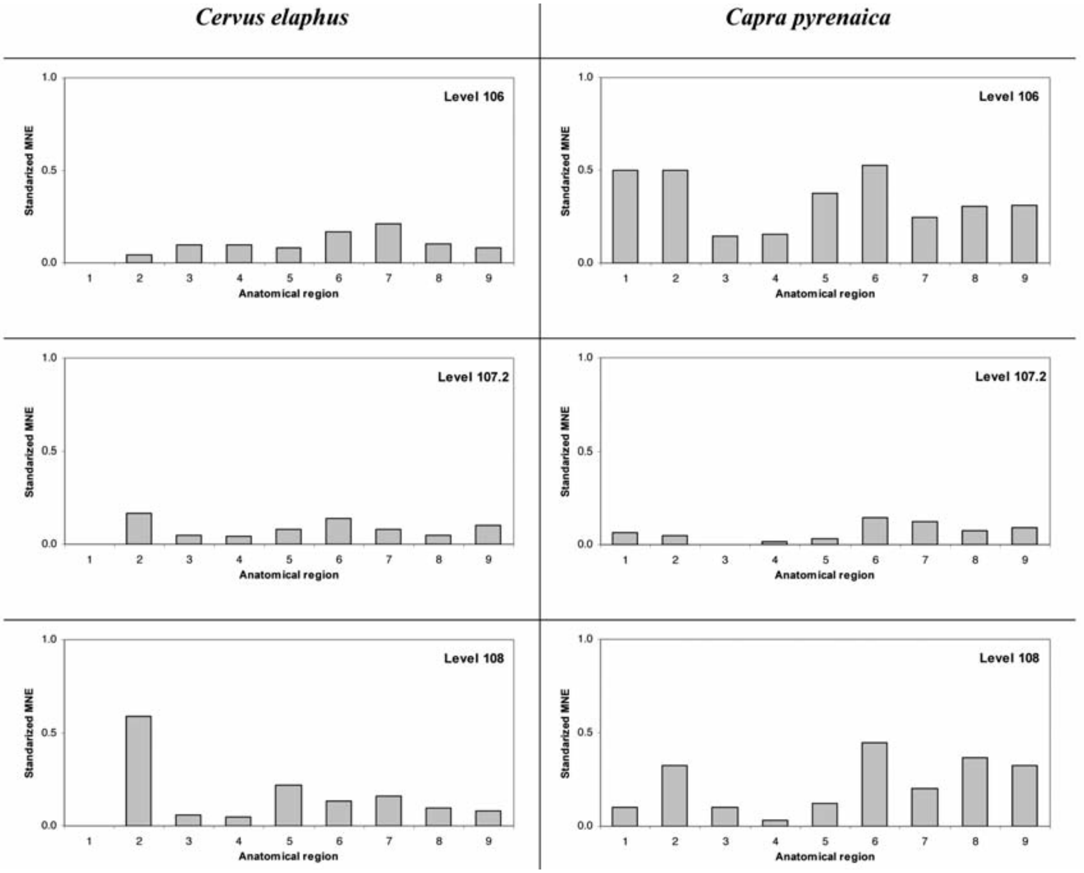
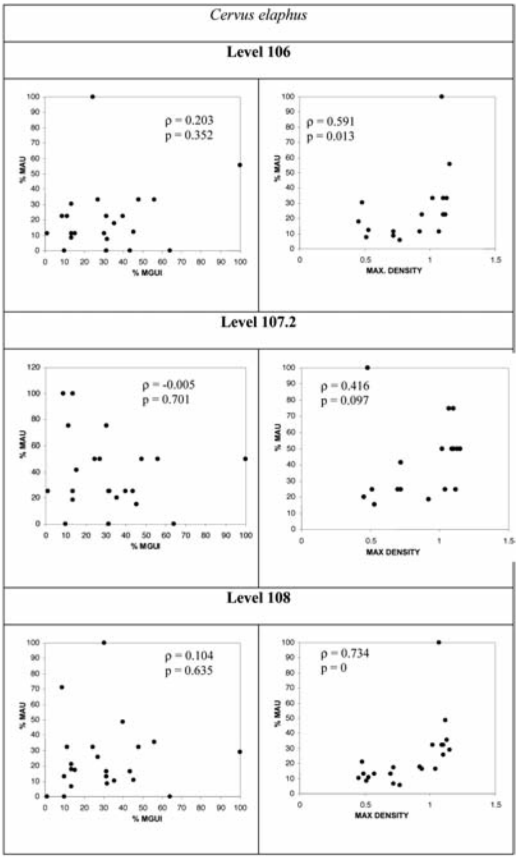


FIGURE 3

Anatomical part representation of red deer and ibex remains from El Mirón Cave, based on nine anatomical regions (from Stiner, 1991). 1: horn/antler; 2: head; 3: neck; 4: axial; 5: upper front; 6: lower front; 7: upper hind; 8: lower hind; 9: feet.

The correlation analysis reveals a pronounced alteration of skeletal part representation as a consequence of attritional processes, particularly in Levels 106 and 108. Thus it is impossible for the method to identify economically meaningful patterns. However, following the theoretical principles suggested by Beaver (2004), the correlation between the skeletal part representation of red deer and bone density (unlike ibex) presents a noticeably triangular scatter towards the lower right-hand corner of the graph, indicating a relationship between the two variables. Thus, density would have acted as a limiting factor in the bone assemblage, but is not the only factor causing variation. This suggests that human transport limited by prey body size may have also influenced the skeletal part profiles.

To detect the differential effect that attrition had on high or low utility elements, correlations have been made between %MAU and %MGUI of the elements in the high survival group (following Marean & Cleghorn, 2003; Figure 6). No conclusive (statistically significant) results were obtained. This may be due to the high fragmentation of long bone shafts as a result of bone marrow consumption. To test this assumption, a correlation was made between the NISP/MNE and Binford's Marrow Utility Index (1978) for red deer and ibex in Level 108. The results shown in Figure 7 indicate a positive and significant relationship between the two variables, which suggests that bone fragmentation is related to marrow exploitation.



Cervus elaphus

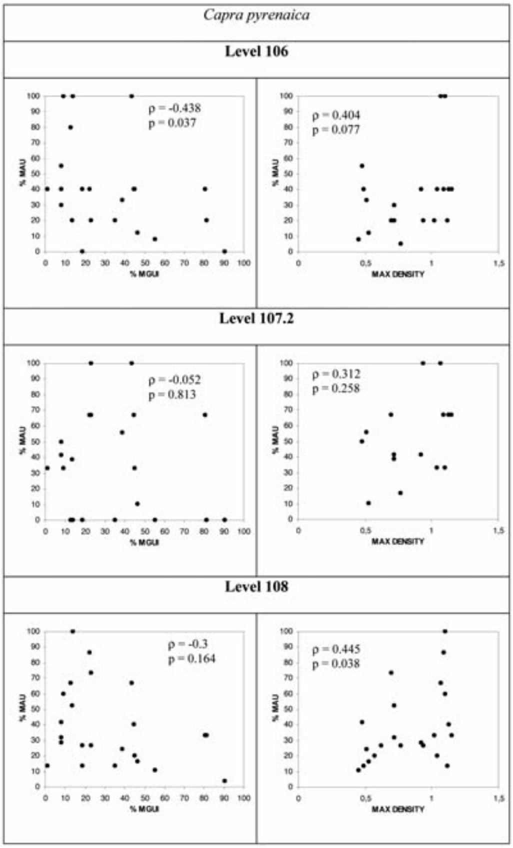
Level 106

Level 107.2

Level 108

FIGURE 4

Correlations between %MAU and %MGUI and maximum bone density for *Cervus elaphus*.



Capra pyrenaica

Level 106

Level 107.2

Level 108

FIGURE 5

Correlations between %MAU and %MGUI and maximum bone density for *Capra pyrenaica*.

Fragmentation of bones prior to deposition could have been magnified by subsequent attritional processes, leading to large quantities of shaft splinters that are almost impossible to identify and quantify. In fact, the analysed levels contain over 75,000 bone fragments (about 80% of the total) under 2 cm in length. A similar problem to identify shaft splinters has been found in the analysis of other Spanish archaeological sites (Yravedra & Domínguez-Rodrigo, 2009), and no solution has been suggested. Apart from that, a possible weakness of the method could contribute to its failure, either due to the very low intensity of carnivore activities observed in El Mirón Cave or due to the lack of axial elements in the analysis.

The Shannon Evenness Index has also been calculated in Level 108, with results of 0.936 for red deer and 0.931 for ibex, for MNE totals of 94 and 60 respectively. The red deer value lies within the bulk 95% range according to Faith and Gordon's results for a sample size of 100 (2007: Table 4), while the ibex value can be placed within unbiased, bulk and unconstrained 95% ranges for a sample size of 50, with a likely bulk explanation. Thus, despite the biasing effect of attritional processes, a selective transport strategy has been identified, more strongly in the case of red deer due to the larger sample size.

Lastly, the ABCml method (Rogers, 2000b) was applied to NISP and MNE measurements for red deer and ibex in the studied levels. NISP and MNE delimit the range of the elements actually deposited, because, as Rogers (2000a) points out, both measurements are distorted but they bracket the real value. In the present study, two behavioural alternatives have been proposed. These are:

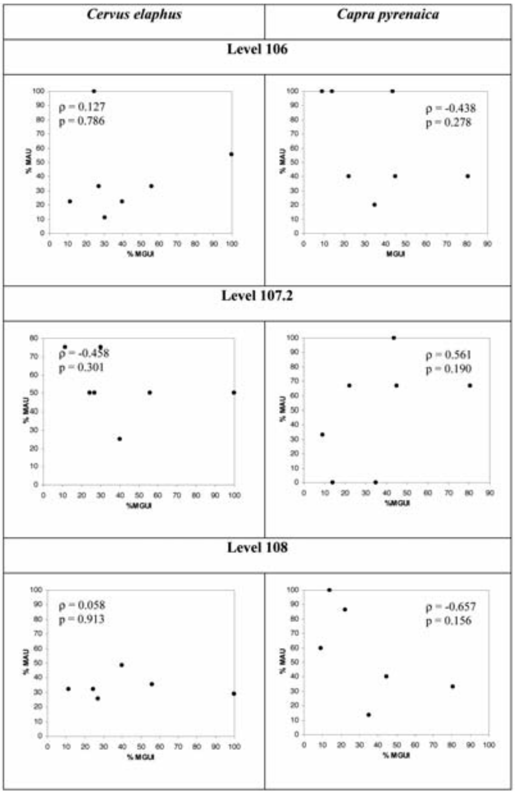


FIGURE 6

Correlations between %MAU and %MGUI for the high survival elements of *Cervus elaphus* and *Capra pyrenaica* in Level 108 according to Marean & Cleghorn (2003).

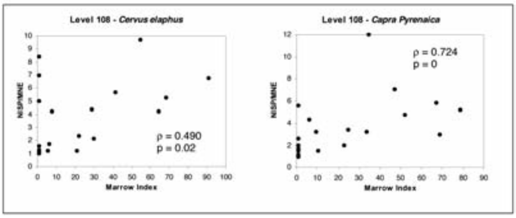


FIGURE 7

Correlation between Fragmentation Index (NISP/MNE) and Marrow Utility Index by Binford (1978) in Level 108 (Middle Magdalenian). *Cervus elaphus* r=0.4, p=0.02; *Capra pyrenaica* r=0.72, p<0.01.

- *Selective transport without processing in the field*. Precedence is given to bringing the skeletal parts containing the most meat back to the base camp. In this way, dead weights are avoided and the amount of energy transported is maximised.
- *Selective transport with processing in the field*. Processing of variable intensity took place in the field, depending on prey size. This means that the anatomical parts from which meat can be most easily removed were abandoned at the kill sites. In addition, two levels of processing (slight and intensive) have been defined, which could be a response to variations in the distance of the hunting areas from the residential camps (Cannon, 2003).

The anatomical configurations associated with each of these choices and their likelihoods of occurring are summarised in Tables 4 and 5. The first alternative was obtained by applying Binford's Meat Utility Index (1978) with estimates for the maximum load and distance transported (Marín Arroyo, 2007). In the second case, various ethnographic observations have been taken as a model (Monahan, 1998). The results in each case are presented in Tables 6, 7 and 8 and refer to: the real number of individuals (κ), attrition factor (β), residential site indicator (α_0), kill site indicator (α_1), chi-square statistic (χ^2), and statistical significance (prob). Hence, the higher the value of (α_0), the greater the likelihood that the site was residential.

As can be seen in Tables 6, 7 and 8, the best outcomes from this method (lowest value of the χ^2 and of the statistical significance) correspond to the alternative with intensive processing in the field (3 out of 12 cases with statistical significance at .05 and another one at 0.1; low probabilities of rejecting the model except for ibex-Level 107.2-NISP and ibex-Level 108-MNE), while the alternative of no field processing shows the worst fit (only one case out of 12 with statistical significance at 0.1; high probabilities of rejecting the model in most cases). This suggests the existence of a behavioural pattern that cannot be interpreted exclusively using utility indices, as it is likely that a large part of the appendicular skeleton would have been abandoned at the kill locations after the meat had been removed. This can also be interpreted in terms of the way of life of the hunter-gatherers who occupied El Mirón Cave during the Magdalenian. Thus, in the absence of the necessary environmental conditions required to store food throughout their territory (milder and damper winters in comparison with other archaeological regions), they would have had to transport the useable parts of their prey to the base-camp immediately to prevent losing them.

SELECTIVE TRANSPORT WITHOUT PROCESSING IN KILL-SITE							
Configuration	**Probability Red deer (%)**	**Probability Ibex (%)**	**Feet**	**Head**	**Axial**	**Forelimb**	**Rear limb**
1	20.1	27.7	Yes	Yes	Yes	Yes	Yes
2	18.9	26.2	No	Yes	Yes	Yes	Yes
3	18.7	23.8	No	No	Yes	Yes	Yes
4	11.9	14.6	No	No	No	Yes	Yes
5	31.5	7.7	No	No	No	No	Yes

TABLE 4

Definition of selective transport without processing in the field. «Yes» indicates that the anatomical part is brought to the camp site.

SELECTIVE TRANSPORT WITH PROCESSING IN KILL-SITE							
Butchering level	**Configuration**	**Probability Red deer (%)**	**Probability Ibex (%)**	**Head**	**Axial**	**Forelimb with feet**	**Rear limb with feet**
Low	1	60	80	Yes	Yes	Yes	Yes
	2	20	10	No	Yes	No	Yes
	3	20	10	No	Yes	No	No
High	1	20	60	Yes	Yes	Yes	Yes
	2	40	20	No	Yes	No	Yes
	3	40	20	No	Yes	No	No

TABLE 5

Definition of selective transport with processing in the field. «Yes» indicates that the anatomical part was brought to the camp site.

	Cervus elaphus						***Capra pyrenaica***					
	106		**107.2**		**108**		**106**		**107.2**		**108**	
	NISP	**MNE**	**NISP**	**MNE**	**NISP**	**MNE**	**NISP**	**MNE**	**NISP**	**MNE**	**NISP**	**MNE**
κ	8.9	7.2	11.5	3.3	100.3	32	17	13.9	8.4	6.2	73.6	23.7
β	0	1.74	2.73	2.17	0	0	3.79	2.99	0	2.83	0	2.28
α_0	0.07	0.18	0.07	0.05	0.11	0.06	0.42	0.09	0.01	0.29	0.01	0.34
α_1	0.93	0.82	0.93	0.95	0.89	0.94	0.58	0.91	0.99	0.71	0.9	0.66
χ^2	16.33	10.5	6.12	1.7	150.96	48.98	2.95	11.1	14.66	3.62	95.64	1.5
prob.	0.994	0.938	0.705	0.111	1	1	0.292	0.951	0.988	0.395	1	0.087

TABLE 6

Results of the ABCml application for red deer and ibex in the case of selective transport without carcass processing in the kill-site.

	Cervus elaphus						*Capra pyrenaica*					
	106		107.2		108		106		107.2		108	
	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE
κ	3.3	2.7	19.6	19.8	10.1	22.6	11.3	5.1	2.6	8.2	43.8	4.7
β	1.61	2.1	3.87	4.21	0.33	2.9	4.05	3.04	1.06	3.79	2.87	0
α_0	1	1	1	1	0.5	1	1	1	1	1	1	0.32
α_1	0	0	0	0	0.5	0	0	0	0	0	0	0.68
χ^2	2.50	0.81	3.18	8.35	2.35	0.51	0.25	0.43	4.12	3.14	0.61	6.03
prob.	0.525	0.153	0.635	0.961	0.497	0.083	0.031	0.066	0.751	0.629	0.106	0.89

TABLE 7

Results of the ABCml application for red deer and ibex in the case of selective transport and some carcass processing in the kill-site.

	Cervus elaphus						*Capra pyrenaica*					
	106		107.2		108		106		107.2		108	
	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE
κ	11.5	11.6	53	53.1	47.1	61.2	18.2	9	3.4	12	59.7	4.3
β	2.41	3.08	4.78	5.42	1.87	3.6	4.48	3.56	1.28	4.32	3.1	0
α_0	0.59	0.73	0.84	0.96	0.46	0.73	0.98	1	0.68	1	0.9	0.27
α_1	0.41	0.27	0.16	0.04	0.54	0.27	0.02	0	0.32	0	0.1	0.73
χ^2	1.09	0.84	0.22	0.18	0.68	0.24	1.34	0.65	2.56	0.57	0.66	4.37
prob.	0.22	0.16	0.026	0.019	0.122	0.029	0.28	0.115	0.535	0.097	0.117	0.776

TABLE 8

Results of the ABCml application for red deer and ibex in the case of selective transport and intensive carcass processing in the kill-site.

Given that the model fits reasonably well with a strategy of light or intense carcass processing in the field, El Mirón likely functioned as a residential settlement, where prey were consumed after selective transport. This is shown by the high values of α_0 that indicate high probabilities that such a strategy occurred, in many cases approaching 100%.

Finally, the intense attritional processes took place within the deposit has also been confirmed. β factors are clearly greater than 1, and a survival rate of only 10% of the initial bone assemblage is estimated. This agrees with the interpretation made from Stiner's Anatomical Regions Profiling method (see Figure 3).

DISCUSSION

The interpretation of skeletal part profiles recovered from archaeological deposits as indicators of human economic behaviour is currently a topic of active debate and research. The analytical procedures for interpreting anatomical frequencies are a particularly contentious issue. Several methods have been developed in the last fifteen years to attempt a more objective analysis by circumventing the biases of attritional processes. However, there is still controversy about the suitability of these methods. This problem is addressed here by comparing the application of several of these methods to a well-excavated archaeological assemblage in northern Spain.

The following observations have been made about the different analytical methodologies that have been assessed. First, the ARP method offers an easy technique with which to analyze the skeletal part profiles of an assemblage. It allows one to draw certain economic conclusions in a quick and visual way, especially, if attrition has been low. If attrition is pronounced, the relatively low but still real differences in the average density of each anatomical part, (more accurate when using Lam *et al.*'s [1999] CT data) increasingly influence the interpretation of the results. For example, Figure 8 shows the graphs of skeletal part profiles presented following the ARP method for a hypothetical accumulation of a hundred red deer individual under different transport strategies and degrees of attrition. The disappearance of skeletal elements from the deposit is a response to the exponential formula proposed by Rogers (2000b) and is based on the values of maximum density. As can be seen, certain conclusions can be reached about the original assemblage through the comparison of the survival percentages of each region, taking into the account the differences in their bone density. In the case of the studied levels from El Mirón Cave, the mean survival percentage that has been obtained (see Figure 3) could fix the degree of attrition β at about 3. Given this, the axial skeleton could be slightly overrepresented in relation to limb bones for red deer, which would be consistent with the selective transport of this part of the carcass to the base camp for more complete processing. This agrees with the ABCml results. Unfortunately, as Stiner admits (2002: 982) her method is only reliable for investigating food acquisition strategies with respect to cranial and limb bones, which might not be adequate for this case. However, ARP remains a useful technique due, above all, to its simplicity.

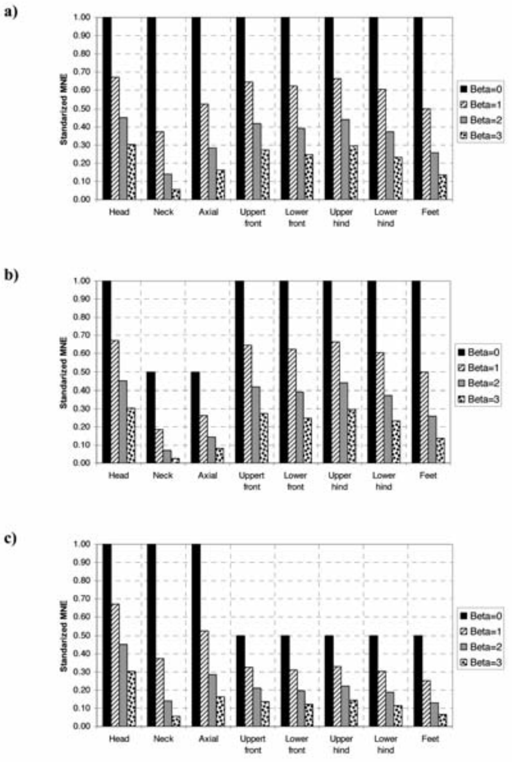


FIGURE 8

ARP results for a deposit of 100 red deer individual for different attrition levels [from β=0 to β=1 following Rogers (2000b)] and transport strategies: a) 100% complete contribution; b) 50% complete contribution, 50% head and limbs; c) 50% complete contribution; 50% head and axial.

Secondly, since they first appeared in archaeozoological studies (Binford, 1978), anatomical utility indices have dominated the analysis of skeletal part profiles, as they permit a simple and objective method to investigate differential transport patterns. However, although these represented the first real quantitative means for describing human choices in terms of carcass exploitation, the results were disappointing, particularly in archaeological deposits. The explanation for this problem may be found in the very definition of the method, as it ignores field processing and delayed transportation of the most useful anatomical parts to base-camp—as was seen in the Nunamiut case.

Unfortunately, Nunamiut behaviour is not applicable in every geographic area, especially where the climate or the presence of scavenging animals does not allow food to be stored near kill sites. In these cases, transportation must be immediate to maximize energetic returns, and limits exist on the load that can be carried. The meat will be removed from the most easily processed parts and these skeletal parts will be abandoned at the kill sites (Cannon, 2003). As a consequence, the frequency of long bones in the skeletal assemblage deposited at archaeological sites will be lower than expected, invalidating the conventional application of utility indices. In addition, the lack of consideration of attritional processes impedes the direct application of utility indices when bone conservation is poor.

Furthermore, the bivariate correlations between %MAU and %MGUI and %MAU and bone density proposed by Grayson (1989) and Lyman (1985, 1992) cannot be easilty applied either, as they usually lead to results that are not statistically significant. Faunal assemblages from archaeological deposits must be treated as palimpsests formed by more than one accumulation agent (humans, carnivores, rodents, birds, etc.) and various diagenetic alterations. Consequently, when skeletal part profiles are being interpreted, actualistic studies cannot be compared directly with archaeological bones assemblages (Domínguez-Rodrigo, 1999: 19).

This problem has been recognized by other scholars (Marean & Frey, 1997; Marean & Cleghorn, 2003) who have suggested improvements to the correlation technique. Nevertheless, these have proven to be insufficient in the case of El Mirón Cave. This method and other parallel methodologies (Beaver, 2004; Faith & Gordon, 2007) have come up against the added difficulty of bone disintegration, which severely constrains the usefulness of these techniques. A less anthropogenically-altered assemblage might be interpreted more appropriately using these methods, as the potential of identifying bone shafts would increase.

It should be noted that the classification made by Marean & Cleghorn (2003) into elements with high and low probabilities of survival, is mainly derived from actualistic studies made on carnivores. The access of these agents was limited at El Mirón as indicated by the few teeth marks, fractures and coprolites that have been identified. Therefore, this technique may not be well suited for this site. In addition, if the axial skeleton is eliminated from the analysis, and the entire interpretative load falls upon the long bones and mandible (high survival group), crucial anatomical elements are being excluded from the study. These bones are important to understand the function of the settlement and human economic behaviour (Cleghorn & Marean, 2004). In fact, according to recent modern ethnographic observations (Monahan, 1998; O'Connell *et al.,* 1990), the appendicular skeleton is to a large extent abandoned in the field after the meat has been removed when transport costs are a factor. Thus, it is not realistic to determine the function of the base camp based on the small proportion of these elements, when they were in fact transported. Furthermore, if the strategy obtained by applying the method proposed by Faith & Gordon (2007) is the transport of the whole animal, in reality this only proves an equal contribution of cranial and appendicular skeletal remains. As no remains from the axial skeleton are included in the analysis, the interpretation becomes biased.

To resolve this problem, methods should be used to eliminate the effects of attrition on the bone assemblages, as well as those that result from variable economic strategies that contrast with the determinism of utility indices. This is the case of the ABCml method developed by Rogers (2000b).

The ABCml method based on the application of the Maximum Likelihood principle is able to estimate the most likely number of individuals deposited at a site in the proportion that can be attributed to each type of behaviour in relation with the transportation of anatomical parts, and the intensity of bone disintegration. It thus constitutes the first truly multivariate approach to the phenomenon of deposit formation. In fact, one of the main advantages of Rogers' method is its ability to analyze data along three axes: representation, density and utility (Cleghorn & Marean, 2004: 62), unlike the correlation method which is only capable of comparing two variables. This method can also reconstruct the initial number of individuals consumed. However, it has been criticised because of its excessive complexity, its eminently theoretical nature and lack of experimental support needed to tackle the problem of equifinality, the use of bone density values that are currently unrealistic, its disregard of carnivore bone deletion or the excessive duality (camp or kill-sites) in settlement functionality (Domínguez-Rodrigo, 2002; Marean & Cleghorn, 2004).

The present study has contributed to skeletal part studies, by choosing maximum bone density (using data from Lam *et al.,* 1999) and by modelling behavioural patterns based on available ethnographic observations. Together these enable a suitable up-to-date approach to the problem of equifinality. As a result, the approach followed here is considered to be a reliable option as long as the hypotheses on which it is based are true. These are, after all, the same procedures as those currently being applied by other researchers (Rogers

& Broughton, 2001: 772). The difference here is that in Roger's method, these hypotheses are made explicit at the outset (Rogers, 2000b). This study can not be criticized for failing to consider carnivore since carnivores had at most a marginal role in the formation of the El Mirón assemblage. Regardless, new research into the factors that influence bone destruction or carcass transport can easily by incorporated as they become available.

The application of this method has reaffirmed the use of El Mirón Cave as a residential site in the Late Glacial. This is evidenced by the significant initial contribution of high-utility axial elements, despite the high butchery costs that would justify the transport of these parts back to the base camp. Subsequently, it post-depositional processes preferentially destroyed these low-density parts so that ultimately the denser cranial and appendicular elements predominated.

Finally, it should be stressed that after applying the various methodologies, it is clear that interpretations of skeletal part representation should not be based on any single analytical technique. The use of several methods allows a more accurate interpretation and, at least reduces uncertainty as much as possible.

ACKNOWLEDGEMENTS

This research was supported by a Predoctoral Fellowship from the Basque Government (Spain). Thanks to Andrew Ugan for his help with ABCml software. I am also grateful to Peter Popkin and David Ocio for their useful comments and critical evaluations during all of the stages of this work and to three anonymous reviewers for their comments on an earlier draft of this manuscript. The present paper would not have existed without the cooperation and help of M.R. González Morales and L.G. Straus, co-directors of El Mirón Cave Prehistory project. I acknowledge them for giving me the chance to study the archaeozoological assemblage. This paper was edited by Lawrence Straus.

REFERENCES

ALTUNA, J. 1986: The mammalian faunas from the Prehistoric Site of La Riera. In: Straus, L.G. & Clark, G. (eds.): *La Riera Cave. Stone Age Hunter-Gatherer Adaptations in Northern Spain*. Anthropological Research Papers 36, Arizona: 237-274; 421-479; 481-497.

BAR-OZ, G. & MUNRO, N. 2004: Beyond Cautionary Tales: A Multivariate Taphonomic Approach for Resolving Equifinality in Zooarchaeological Studies. *Journal of Taphonomy* 2(4): 201-222.

BARBA, R. & DOMÍNGUEZ-RODRIGO, M. 2005: The taphonomic relevance of the analysis of bovid long limb bone shaft features and their application to element identification: study of bone thickness and morphology of the medullary cavity. *Journal of Taphonomy* 3: 17-42.

BARTRAM, L.E. 1993: *An Ethnoarchaeological Analysis of Kua San (Botswana) Bone Food Refuse*. Unpublished Ph.D dissertation. University of Wisconsin, Madison.

BARTRAM, L.E. & MAREAN, C.W. 1999: Explaining the 'Klasies pattern': Kua ethnoarchaeology the Die Kelders Middle Stone Age archaeofauna, long bone fragmentation and carnivore ravaging. *Journal of Archaeological Science* 26: 9-29.

BEAVER, J.E. 2004: Identifying necessity and sufficiency relationships in skeletal-part representation using fuzzy-set theory. *American Antiquity* 69: 131-140.

BINFORD, L.R. 1977: Forty-seven trips: a case study in the character of archaeological formation processes. In: Wright, R.V. (ed.): *Stone tools as cultural makers: Change, Evolution and Complexity*. Australian Institute of Aboriginal Studies, Camberra: 24-36.

BINFORD, L.R. 1978: *Nunamiut Ethnoarchaeology*. Academic Press, New York.

BINFORD, L.R.; MILLS, M.G.L. & STONE, N.M. 1988: Hyena scavenging and its implications for the interpretation of faunal assemblages from FLK 22 (the *Zinj* floor) at Olduvai Gorge. *Journal of Anthropological Archaeology* 7: 99-135.

BLASCO SANCHO, M.F. 1995: *Hombres, fieras y presa. Estudio arqueozoológico y tafonómico del Paleolítico Medio de la Cueva de Gabasa 1 (Huesca)*. Monografías Arqueológicas 38. Universidad de Zaragoza, Zaragoza.

BLUMENSCHINE, R.J. 1988: An experimental model of the timing of hominid and carnivore influence on archaeological bone assemblages. *Journal of Archaeological Science* 15: 483-502.

BLUMENSCHINE, R.J. 1995: Percussion marks, tooth marks and the experimental determination of the timing of hominid and carnivore access to long bones at FLK Zinjanthropus, Olduvai Gorge, Tanzania. *Journal of Human Evolution* 29: 21-51.

BUNN, H.T. 1983: Comparative analysis of modern bone assemblages from a San Hunter-gatherer camp in the Kalahari desert, Botswana, and from a spotted hyena den near Nairobi, Kenya. In: Clutton-Brock, J. & Grigson, C. (eds.): *Animals and archaeology:*

hunters and their prey: 143-148. B.A.R. (International Series) 163. Oxford.

BUNN, H.T. 1993: Bone assemblages at base camps: a further consideration of carcass transport and bone destruction by the Hadza. In: Hudson, J. (ed.): *From Bones to Behavior: Ethnoarchaeological and Experimental Contributions to the Interpretation of Faunal Remains*: 156-168. Southern Illinois University Press, Carbondale.

CANNON, M.D. 1999: Mathematical Model of the Effects of Screen Size on Zooarchaeological Relative Abundance Measures *Journal of Archaeological Science* 26: 205-214.

CANNON, M.D. 2003: A model of central place forager prey choice and an application to faunal remains from the Mimbres Valley, New Mexico. *Journal of Anthropological Archaeology* 22: 1-25.

CAPALDO, S.D. 1995: *Inferring hominid and carnivore behavior from dual-patterned archaeological assemblages*. Unpublished Ph.D dissertation. Rutgers University, New Jersey.

CLEGHORN, N. & MAREAN, C.W. 2004: Distinguishing selective transport and in situ attrition: a critical review of analytical approaches. *Journal of Taphonomy* 2: 43-67.

DAVIDSON, I. & ESTÉVEZ, J. 1985: Problemas de Arqueotafonomía. Formación de yacimientos con fauna. *Quaderns* I: 67-84.

DOMÍNGUEZ-RODRIGO, D. 1999: The study of skeletal part profiles: an ambiguous taphonomic tool for zooarchaeology. *Complutum* 10: 15-24.

DOMÍNGUEZ-RODRIGO, M. 2002: Hunting and Scavenging by Early Humans: The State of the Debate. *Journal of World Prehistory* 16(1): 1-54.

FAITH, J.T. & GORDON, A.D. 2007: Skeletal element abundance in archaeofaunal assemblages: economic utility, sample size, and assessment of carcass transport strategies. *Journal of Archaeological Science* 34: 872-882.

GONZÁLEZ MORALES, M.R. & STRAUS, L.G. 2000: La cueva del Mirón (Ramales de la Victoria, Cantabria): Excavaciones 1996-1999. *Trabajos de Prehistoria* 57(1): 121-133.

GONZÁLEZ MORALES, M.R. & STRAUS, L.G. 2005: The Magdalenian sequence of El Mirón Cave (Cantabria, Spain): an approach to the problems of definition of the Lower Magdalenian in Cantabrian Spain. In: Dujardin, V. (ed.): *Industrie osseuse et parures du Solutréen au Magdalénien en Europe*: 209-219. Mémoires de la Société Préhistorique Française 39. Paris.

GONZÁLEZ MORALES, M.R.; STRAUS, L.G. & MARÍN ARROYO, A.B. 2007: Los omóplatos decorados magdalenienses de la Cueva del Mirón (Ramales de la Victoria, Cantabria) y su relación con las Cuevas del Castillo, Altamira y El Juyo. *Zona Arqueológica* 7(1): 483-494.

GRAYSON, D.K. 1989: Bone transport, bone destruction, and reverse utility curves. *Journal of Archaeological Science* 16: 643-652.

KAY, S.M. 1993: *Fundamentals of Statistical Signal Processing: Estimation Theory*. Printice Hall International Inc., Englewood Cliffs, NJ.

KLEIN, R.G. & CRUZ-URIBE, K. 1984: *The Analysis of Animal Bones from Archaeological Sites*. The University of Chicago Press, Chicago.

KLEIN, R.G.; CRUZ-URIBE, K. & MILO, R.G. 1999: Skeletal Part Representation in Archaeofaunas: Comments on "Explaining the 'Klasies Pattern': Kua Ethnoarchaeology, the Die Kelders Middle Stone Age Archaeofauna, Long Bone Fragmentation and Carnivore Ravaging" by Bartram & Marean. *Journal of Archaeological Science* 26: 1225-1234.

KLIPPEL, W.E.; SNYDER, L.M. & PARMALEE, P.W. 1987: Taphonomy and archaeologically recovered mammal bone from southeast Missouri. *Journal of Ethnobiology* 7: 155-169.

LAM, Y.M; CHEN, X.; MAREAN, C.W. & FREY, C. 1998: Bone density and long bone representation in archaeological faunas: comparing results from CT and photon densitometry. *Journal of Archaeological Science* 25: 559-570.

LAM, Y.M.; CHEN, X. & PEARSON, O.M. 1999: Intertaxonomic variability in patterns of bone density and the differential representation of bovid, cervid, and equid elements in the archaeological record. *American Antiquity* 64(2): 343-362.

LYMAN, R.L. 1984: Bone density and differential survivorship of fossil classes. *Journal of Anthropological Archaeology* 3: 259-299.

LYMAN, R.L. 1985: Bone frequencies: differential transport, *in situ* destruction, and the MGUI. *Journal of Archaeological Science* 12: 221-236.

LYMAN, R.L. 1991: Taphonomic problems with archaeological analyses of animal carcass utilization and transport. In: Purdue, J.R.; Klippel, W.E. & Styles, B.W. (eds.): *Beamers, bobwhites, and blue-points: tributes to the career of Paul W. Parmalee*: 125-138. Illinois State Museum Scientific Papers, vol. 23. Springfield.

LYMAN, R.L. 1992: Anatomical considerations of utility curves in Zooarchaeology. *Journal of Archaeological Science* 19: 7-22.

LYMAN, R.L. 1993: Density-mediated attrition on bone assemblages: New insights. In: Hudson, J. (ed.): *From Bones to Behavior: Ethnoarchaeological and Experimental Contributions to the Interpretation of Faunal Remains*: 7-22. Center for Archaeological Investigations. Southern Illinois University at Carbondale, Carbondale.

LYMAN, R.L. 1994: *Vertebrate Taphonomy*. Cambridge University Press, Cambridge.

MAREAN, C.W. 1998: A critique of the evidence for scavenging by Neanderthals and early modern humans: new data from Kobech Cave (Zagros Mountains, Iran), Die Kielders Cave 1 layer 10 South Africa. *Journal of Human Evolution* 35: 111-136.

MAREAN, C.W. & CLEGHORN, N. 2003: Large mammal skeletal element transport: applying foraging theory in a complex taphonomic system. *Journal of Taphonomy* 1: 15-42.

MAREAN, C.W. & ASSEFA, Z. 1999: Zooarchaeological evidence for the faunal exploitation behavior of Neandertals and Early Modern Humans. *Evolutionary Anthropology* 8: 22-37.

MAREAN, C.W. & SPENCER, L.M. 1991: Impact of Carnivore Ravaging on Zooarchaeological Measures of Element Abundance. *American Antiquity* 56: 645-658.

MAREAN, C.W. & FREY, C. 1997: Animal bones from caves to cities: reverse utility curves as methological artefacts. *American Antiquity* 62: 698-716.

MAREAN, C.W. & KIM, S. 1998: Mousterian large mammals from Kobech Cave. *Current Anthropology* 39: 79-113.

MAREAN, C.W.; ABE, Y.; NILSSEN, P. & STONE, E. 2001: Estimating the minimum number of skeletal elements (MNE) in zooarchaeology: a review and a new image-analysis GIS Approach. *American Antiquity* 66: 333-348.

MAREAN, C.W.; DOMÍNGUEZ-RODRIGO, M. & PICKERING, T.R. 2004: Skeletal element equifinality in zoorchaeology begins with method: the evolution and status of the 'shaft critique'. *Journal of Taphonomy* 2: 69-98.

MARÍN ARROYO, A.B. 2004: *Estudio arqueozoológico, tafonómico y de distribución espacial de la fauna de mamíferos de la Cueva de La Fragua (Santoña - Cantabria)*. Ediciones TGD, Santander.

MARÍN ARROYO, A.B. 2005: Aplicación de un sistema de información geográfica (SIG) al estudio Arqueozoológico-Tafonómico de la Cueva de La Fragua (Santoña - Cantabria). *Complutum* 17: 73-87.

MARÍN ARROYO, A.B. 2007: *La fauna de mamíferos en el Cantábrico Oriental durante el Magdaleniense y Aziliense: Nuevos enfoques y líneas de investigación arqueozoológicas*. Unpublished Ph.D Dissertation. Universidad de Cantabria, Santander.

MARÍN ARROYO, A.B. 2008a: El yacimiento paleolítico de la Cueva del Mirón: Resultados de la aplicación de nuevas metodologías arqueozoológicas. In: Díez, C. (ed.): *Zooarqueología hoy. Encuentros hispano-argentinos*: 69-87. Servicio de Publicaciones de la Universidad de Burgos, Burgos.

MARÍN ARROYO, A.B. 2008b: Patrones de movilidad y control del territorio en el Cantábrico Oriental durante el Tardiglacial. *Trabajos de Prehistoria* 65(1): 29-45.

MARÍN ARROYO, A.B. 2008c: Demografía y cambio ambiental. Hipótesis para el cambio económico en el cantábrico oriental durante el Tardiglacial. *Complutum* 19(1): 47-66.

MARÍN ARROYO, A.B. & GONZÁLEZ MORALES, M.R. 2007: La Fragua Cave, a seasonal hunting camp in Lower Asón Valley (Cantabria, Spain) at the Pleistocene-Holocene transition. *Antropozoologica* 42(1): 61-84.

MARÍN ARROYO, A.B.; LANDETE RUIZ, M.D.; VIDAL BERNABEU, G.; SEVA ROMÁN, R.; GONZÁLEZ MORALES, M.R. & STRAUS, L.G. 2008: Archaeological implications of human-derived manganese coatings: a study of blackened bones in El Mirón Cave, Cantabrian Spain. *Journal of Archaeological Science* 35(3): 801-813.

MARÍN ARROYO, A.B.; FOSSE, P. & VIGNE, J.D. 2009: New evidences of bone accumulation by bearded vulture at an archaeological site: El Mirón Cave (Spain). *Journal of Archaeological Science* 36: 284-296.

MARTINEZ, J. 1998: *El modo de vida neandertal: Una reflexión en torno a la ambigüedad en la interpretación de la subsistencia durante el Paleolítico medio cantábrico*. Unpublished Ph.D dissertation. Universidad Autónoma de Barcelona, Barcelona.

MONAHAN, C. 1998: The Hadza carcass transport debate revised and its archaeological implications. *Journal of Archaeological Science* 25: 404-424.

MUNRO, N.D. & BAR-OZ, G. 2004: Debating issues of equifinality in ungulate skeletal parts studies. *Journal of Taphonomy* 2(1): 1-13.

NOVECOSKY, B.J. & POPKIN, P. 2005: Canidae volume bone mineral density values: an application to sites in western Canada. *Journal of Archaeological Science* 32: 1677-1690.

O'CONNELL, J.F.; HAWKES, K. & BLURTON JONES, N. 1990: Reanalysis of large mammal body part transport among the Hadza. *Journal of Archaeological Science* 17: 301-316.

OUTRAM, A.K. 2001: The scapula representation could be the key: A further contribution to the 'Klasies Pattern' debate. *Journal of Archaeological Science* 28: 1259-1263.

OUTRAM, A.K. 2004: Applied Models and Indices vs. High-Resolution, Observed Data: Detailed Fracture and Fragmentation Analyses for the Investigation of Skeletal Part Abundance Patterns. *Journal of Taphonomy* 2: 167-184.

PAYNE, S. 1975: Partial recovery and sample bias. In: Classon, A. (ed.): *Archaeozoological Studies*: 7-17. North Holland, Amsterdam.

PICKERING, T.; MAREAN, C.W.; & DOMINGUEZ-RODRIGO, M. 2003: Importance of limb bone shaft fragments in zooarchaeology: a response to 'On *in situ* attrition and vertebrate body part profiles' 2002, by M.C. Stiner. *Journal of Archaeological Science* 30: 1469-1482.

REIMER, P.J.; BAILLIE, M.G.L.; BARD, E.; BAYLISS, A.; BECK, J.W.; BERTRAND, C.J.H.; BLACKWELL, P.G.; BUCK, C.E.; BURR, G.S.; CUTLER, K.B.; DAMON, P.E.; EDWARDS, R.L.; FAIRBANKS, R.G.; FRIEDRICH, M.; GUILDERSON, T.P.; HOGG, A.G.; HUGHEN, K.A.; KROMER, B.; MCCORMAC, F.G.; MANNING, S.W.; RAMSEY, C.B.; REIMER, R.W.; REMMELE, S.; SOUTHON, J.R.; STUIVER, M.; TALAMO, S.; TAYLOR, F.W.; VAN DER PLICHT, J. & WEYHENMEYER, C.E. 2004: IntCal04 Terrestrial radiocarbon age calibration, 26 - 0 ka BP. *Radiocarbon* 46(3): 1029-1058.

ROGERS, A.R. 2000a: On equifinality in faunal analysis. *American Antiquity* 65: 709-723.

ROGERS, A.R. 2000b: Analysis of bone counts of maximum likelihood. *Journal of Archaeological Science* 27: 111-125.

ROGERS, A.R. & BROUGHTON, J.M. 2001: Selective transport of animals parts by ancient hunters: A new statistical method and an application to the Emeryville Shellmound fauna. *Journal of Archaeological Science* 28: 763-773.

SHANNON C.E. & WEAVER, W. 1949: *The mathematical theory of communication*. University of Illinois Press, Urbana.

SPEARMAN, C.E. 1904: «General intelligence», objectively determined and measured. *American Journal of Psychology* 15: 201-293.

SPETH, J.D. 1983: *Bison kills and bone counts*. University of Chicago Press, Chicago.

STINER, M.C. 1991: Food procurement and transport by human and no-human predators. *Journal of Archaeological Science* 18: 455-482.

STINER, M.C. 1994: *Honor Among Thieves: A Zooarcheological Study of Neandertal Ecology*. Princeton University Press, Princeton.

STINER, M.C. 2002: On *in situ* attrition and vertebrate body part profiles. *Journal of Archaeological Science* 29: 979-991.

STINER, M.C. 2004: A comparison of photo densitometry and computed tomography parameters of bone density in ungulate body part profiles. *Journal of Taphonomy* 2: 117-145.

STRAUS, L.G. & GONZÁLEZ MORALES, M.R. 2003a: A Spanish time tunnel: El Mirón Cave. *Athena Review* 3(3): 67-74.

STRAUS, L.G. & GONZÁLEZ MORALES, M.R. 2003b: El Mirón Cave and the ^{14}C chronology of Cantabrian Spain. *Radiocarbon* 45(1): 41-58.

STRAUS, L.G. & GONZÁLEZ MORALES, M.R. 2005: El Magdaleniense de la Cueva del Mirón (Ramales de la Victoria, España): observaciones preliminares. In: Bicho, N. (ed.): *O Paleolítico. Actas do IV Congresso de Arqueología Peninsular*: 49-62. Promontoria Monográfica 02. Universidad do Algarve, Faro.

STRAUS, L.G. & GONZÁLEZ MORALES, M.R. 2007a: Further radiocarbon dates for the Upper Paleolithic of El Mirón Cave (Ramales de la Victoria, Cantabria, Spain). *Radiocarbon* 49(3): 1205-1214.

STRAUS, L.G. & GONZÁLEZ MORALES, M.R. 2007b: Early Tardiglacial human uses of El Mirón Cave (Cantabria, Spain). In: Kornfled, M.; Vasil'ev, S. & Miotti, L. (eds.): *On shelter's ledge: Histories, theories and methods of rockshelter research*: 83-93. B.A.R. (International Series) 1655. Oxford.

STRAUS, G.L.; GONZÁLEZ MORALES, M.R.; FARRAND, W.R. & HUBBARD, W.J. 2001: Sedimentological and stratigraphic observations in El Mirón, a late quaternary cave site in the Cantabrian Cordillera, Northern Spain. *Geoarchaeology: An International Journal* 16(5): 603-630.

STRAUS, L.G.; GONZÁLEZ MORALES, M.R.; FANO, M. & GARCÍA-GELABERT PERA, M.P. 2002: Last glacial human settlement in Eastern Cantabria (Northern Spain). *Journal of Archaeological Science* 29: 1403-1414.

THOMAS, D.H. & MAYER, D. 1983: Behavioural faunal analysis of selected horizons. In: Thomas, D. (ed.): *The archaeology of Monitor Valley 2. Gatecliff Shelter*: 353-390. Anthropological Papers 59. American Museum of Natural History, New York.

YRAVEDRA, J. 2001: *Zooarqueología de la Península Ibérica: implicaciones tafonómicas y paleoecológicas en el debate de los homínidos del Pleistoceno Medio-Superior*. B.A.R. (International Series) 979. Oxford.

YRAVEDRA, J. & DOMÍNGUEZ-RODRIGO, M. 2009: The shaft-based methodological approach to the quantification of long limb bones and its relevance to understanding hominid subsistence in the Pleistocene: application to four Palaeolithic sites. *Journal of Quaternary Science* 24(1): 85-96.