

Evidence for Bone Grease Rendering During the Upper Paleolithic at Vale Boi (Algarve, Portugal)

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ABSTRACT

Recently excavated faunas from the Upper Paleolithic site of Vale Boi in Algarve (southern Portugal) provide early evidence of resource intensification in the form of bone grease rendering, a labor-intensive technique for maximizing the fat yield from ungulate carcasses, alongside exploitation of rabbits. The geography and chronology of the occurrences of these subsistence phenomena may indicate expanding dietary breadth in Upper Paleolithic foragers. Evidence of bone grease rendering begins with the early Gravettian period at Vale Boi, based on the co-occurrence of abundant fire-cracked rock, stone anvils, and the systematic fragmentation spongy bone. Tests for density-mediated attrition in rabbits and ungulates indicate that the patterns of body part representation in the ungulate remains were not biased substantially by post-depositional processes. The onset of resource intensification and dietary expansion in the Algarve is in general agreement with patterns observed for the northern Mediterranean Rim. However, the coupling of heavy rabbit exploitation and bone grease-rendering in the early Gravettian at Vale Boi is distinctive and, as such, occurs relatively early for the Upper Paleolithic overall.

INTRODUCTION

Changes in human predator-prey interactions can take many forms but are perhaps most demonstrable with how nutrition is squeezed from ungulate carcasses, specifically the addition of bone grease-rendering, a labor-intensive technique, to the long established practice of cold marrow extraction (Stiner 2002, 2003). Another source of evidence may come from changes in foragers' emphasis on certain classes of small game (e.g., Davis et al. 1994; Munro 2004; Stiner 2001, 2003; Stiner et al. 2000; Tchernov 1998). Because these shifts in human diet and predator-prey ecology did not occur everywhere at once during the Pleistocene in Europe, the geography and chronology of their occurrence is of great interest and may reflect shifting demographic conditions, although competing explanations must also be explored. Resource intensification often is provoked by increases in human population densities and the

stresses that demographic growth places on traditional food supplies.

The Paleolithic of the Algarve region of southern Portugal has come under investigation only recently (Bicho 1993, 1994, 2001; Bicho et al. 2000; Stiner 2003). The Algarve is ecologically distinctive for its juxtaposition of rich Atlantic and Mediterranean marine communities, geographic isolation, and a declining terrestrial large mammal fauna after roughly 12,000 years ago (compare Antunes et al. 1989; Cardoso 1989, 1995; Davis 2002; Valente 2000). Here we present new zooarchaeological evidence from the Upper Paleolithic open site of Vale Boi (Bicho 2001) (Figure 1). Research at this site is ongoing, and hence the faunal samples are still limited. Some results are sufficiently robust, however, to warrant presentation here. The Algarve region presents us with an important test case, due to its remoteness relative to the earliest geographic centers of Paleolithic cultural transition.

THE SITE OF VALE BOI

The recently discovered site of Vale Boi today lies less than 2.5 km inland, just east of the town of Budens (Bicho 2001). The site presently is unique in the Algarve region in that it contains rich deposits of Gravettian, Solutrean, and early Magdalenian material, possibly underlain by late Mousterian deposits separated from the Upper Paleolithic layers by a depositional hiatus. The site is positioned on a wide, gentle talus below a low limestone cliff. Several excavation seasons at Vale Boi have more than doubled the number of known Upper Paleolithic bone points in all of Portugal, and these artifacts are accompanied by much manufacturing debris.

The data from the Vale Boi faunal assemblage derive from the 2000, 2001, 2002, and 2003 excavation seasons, with the samples from 2000 and 2001 completely studied. The fauna were identified, using a hierarchical coding system developed by Stiner (2002, 2004). Specimens are assigned to either a taxonomic categories of species, genus or body size (e.g., medium ungulate) class. Specimens were also classified to skeletal element and portion-of-element, as well as age (based on bone fusion), and side. Damage observations include burning and tool marks, among other observations.

Several ungulate species occur in the faunal assemblages of Vale Boi (Table 1). Red deer (*Cervus elaphus*) is the dominant ungulate throughout, followed by horse (*Equus caballus ferus*), along with low frequencies of aurochs (*Bos primigenius*), ibex (*Capra ibex cf. iberica*), pig (*Sus scrofa*), and another very small asine-type equid (*E. cf. hydruntinus*). The remains of rabbits (*Oryctolagus cuniculus*) occur in significant numbers in all of the Upper Paleolithic levels, but especially in the Gravettian, where shellfish (mainly limpets, *Patella* spp.) also are present. As climate cooled and sea level dropped with the approach of the Last Glacial Maximum, the site's position became situated farther inland. Gatherable marine shellfish would have been farther away from the encampment and perhaps less worthwhile to transport to it in the later Upper Paleolithic phases.

Young red deer and equid remains, almost all from fetuses or recently born fawns and foals, co-occur with roughly equal numbers of fully adult animals, most of which may be females (Stiner, unpublished data). This result suggests that the mothers and their infants were hunted in the Vale Boi area during the spring. Delicate pore structures are well preserved in many bone specimens. The axial elements were carried to the site by humans and suffered extensive fragmentation on-site. Despite the great fragility of their partly formed bones and teeth,

the fawns/foals are also represented by a full range of body parts.

Mild burning damage and cut marks on the Vale Boi bones occur in low but typical frequencies for Mediterranean Paleolithic faunas. The intensity of the burning damage seldom exceeded carbonization. Cone fractures indicative of marrow processing are prevalent (>15% of large mammal NISP), and the medullary cavity of virtually every major element was opened by humans. The bones are also exceptionally fragmented, yet they often are recognizable. Extensive fragmentation of spongy bone parts is accompanied by large quantities of fire-cracked rock (Table 2) and well-worn anvil stones with large shallow depressions (Figure 2); no pit features have been found in the sediments. The relative quantities (kg) of bone and manuported stone vary through the G25 strata series for reasons not yet fully understood; small scale differences in colluvial action could account for some of this variation. However, the co-occurrences of fire-cracked rock and large, pitted stone anvils, and highly fragmented bone throughout the Upper Paleolithic is most important to the present discussion.

BONE GREASE RENDERING: BACKGROUND & EXPECTATIONS

Two families of bone-processing techniques exist among foraging and other peoples for extracting nutrients from bone (reviewed in Stiner 2005). Although both techniques emerged within the Paleolithic period, "cold" marrow extraction was the only technique in use for the bulk of prehistory. This extraction technique focuses almost exclusively on removing consolidated marrow from medullae (large central cavities) of major limb bones and mandibles of large mammals, along with the brain. The procedure requires only a few simple, widely available tools and, though it can be facilitated by heat, marrow extraction is easily accomplished without it. The peripheral elements of the body—legs and heads—are the main targets for cold marrow extraction. Paleolithic people rarely left good marrow untouched, and for this reason fragmented bone is characteristic of Paleolithic archaeofaunal assemblages (Stiner 1994, 2005).

The second family of bone processing techniques emerged during the Upper Paleolithic (though not in all regions) and is a good deal more complex. Heat-in-liquid rendering (*sensu* Binford 1978; Brink 1997; Delpech & Rigaud 1974; Lupo & Schmitt 1997; Wandsnider 1997), also called "bone grease rendering", allows a wider range of nutrients to be extracted per carcass. The technique is far more labor-intensive than cold processing methods,

however. The advantages of the method are greatest where key resources are limited, whether due to unpredictable supplies or prey, constriction of hunting territories, or both. For this extraction technique, large amounts of spongy bone tissues of vertebrae and softer limb ends (Figure 3) are fragmented or pulverized, and then boiled in water by such methods as adding heated stones to the mixture. The heated fatty components float to the top of the mixture and form discrete, relatively pure layers of fat that can be skimmed-off and stored. Heat-in-liquid techniques maximize both the protein and fat yields per carcass, well in excess of what is possible from cold extraction techniques alone (Binford 1978; Lupo & Schmitt 1997; Wandsnider 1997). The purified fatty components can be stored for months (Soffer 1989).

A grease-rendering operation may use containers composed of simple sheets of animal hide, sealed baskets or wooden vessels. Of course the organic components of grease rendering toolkits are seldom if ever preserved, but the *combination* of other debris is characteristic: (1) exceptional comminution of (fresh) bones; (2) large quantities of heat-fractured and heat-scarred stone, and (3) large, pitted stone anvils. Subterranean pits may also be found, but these are less likely to be preserved in recognizable form. Bone grease rendering may greatly affect the appearance and identifiability of skeletal elements in faunal assemblages, mainly by reducing spongy bone parts at a greater rate than is typical of cold marrow extraction (Binford 1978; Brink 1997). Thus, while the co-occurrence of the above phenomena in a site can indicate that bone grease rendering occurred, other potential explanations for the patterns of bone fragmentation, and especially the preferential destruction of spongy bone parts, must be excluded (*sensu* Binford & Bertram 1977; Brain 1981; Lyman 1984; Marean & Spencer 1991). Of particular concern is the possibility of density-dependent loss of spongy bone parts arising from non-human mechanical factors. This question normally is evaluated with the help of independent structural density standards for skeletal parts of the same or similar prey species, derived by the photon densitometry technique (reviewed by Lyman 1994) or the computed tomography technique (Lam et al. 1998, 1999). If independence between prey body part representation in an archaeofauna and inherent bone density distributions can be demonstrated for the assemblage, and evidence of carnivore activity is minimal or absent, then the extreme patterns of comminution cannot be explained simply as post-cultural damage. Under these conditions, one may also observe good retention of fragile pore structures on fracture planes. Other sources of confusion for

research on grease rendering are situations in which stone boiling and/or milling stones were likely applied to plant foods and/or stone-heated sweat lodges (saunas) were used.

No convincing cases of heat-in-liquid techniques have been reported for the Mousterian on the Mediterranean Rim or elsewhere in Eurasia. This is not surprising in light of other zooarchaeological evidence for narrow diets rich in highly ranked prey during the Middle Paleolithic period and low human population densities overall (Stiner 2001, 2005; Stiner et al. 2000). Cold marrow extraction was pushed to its full potential in most Middle Paleolithic cases, but no further than this (Kuhn & Stiner 2001). More intensive forms of processing of ungulate carcasses certainly are apparent, however, by the late Upper Paleolithic (Magdalenian) in France and Germany (Audouze 1987; Audouze & Enloe 1991; David & Enloe 1993; Delpech & Rigaud 1974; Weniger 1987), and possibly as early as the Gravettian in Central Europe (see Svoboda et al. 1996 on Moravia). Similar evidence has come to light at Vale Boi in the Algarve, beginning in the Gravettian and continuing through the Magdalenian.

PATTERNS OF ANATOMICAL REPRESENTATION IN PREY

Over 100 portion-of-element codes were used to classify specimens, allowing for a detailed consideration of body part representation despite the high level of fragmentation of the mammal remains. Many of these portions-of-elements coincide with "scan sites" developed by Lyman (1984, 1994). Information on body part survivorship by scan site for rabbit (*Oryctolagus cuniculus*) remains is presented in Appendix 1, and for all ungulate remains combined (*Capra*, *Cervus*, *Bos*, *Equus*, large cervids, medium ungulates and large ungulates) in Appendix 2. The ungulate remains are lumped into one sample for the analysis of density-mediated attrition (below), so that non-specific axial elements could be considered alongside easily identified appendicular elements. This was necessary due to the continuous body size gradient of the medium to large ungulate species in the Vale Boi faunas. The horses of Vale Boi were relatively small in stature, for example, and there is considerable size overlap with red deer. Somewhat smaller ungulates, such as wild boar, are present but rare. Only the aurochs stands out as being exceptionally large, but these remains are uncommon in the material examined thus far. We also examined the body part data according to genus-specific divisions for the appendicular anatomy of the most common taxa (*Cervus* and *Equus*).

The frequency with which each scan site is represented by taxon in the assemblage was tallied and then divided by the number of expected frequency of scan sites (based on the highest MNI value of 26 for *O. cuniculus*, and 30 for the combined ungulate assemblage). This procedure yields percentage survivorship values by scan site (following Lyman 1984). The Vale Boi rabbit bone survivorship results were compared to *O. cuniculus* density values published by Pavao and Stahl (1999). In the case of the ungulate remains, the entire assemblage was combined for step-wise comparisons to density parameters obtained by photon densitometry (PD) technique for *Ovis*, *Odocoileus* (Lyman 1994), and *Bison* (Kreutzer 1992), and to density parameters by computed tomography technique (CT) for *Rangifer* and *Equus* by Lam et al. (1999). Correlations and regression statistics are used to evaluate the strength of the relation between the density parameters and observed patterns of bone survivorship in the Vale Boi assemblages.

Figures 4 and 5 present standardized body part profiles for rabbits and ungulates of Vale Boi, respectively, following Stiner's profiling method (1991, 2002, 2004). One sees considerable representation of axial body parts, despite the intensively crushed state of the fauna. Body part representation is reasonably complete for the rabbits, if the exceptionally high occurrence of calcanei (MNE=55) is subtracted from the profile (Figure 4). As demonstrated below, bone density cannot account for this anomaly, and thus a non-economic cultural explanation (such as preferential curation of this bone) must be considered. The ungulate body part profile (Figure 5) represents all taxa as a means for accommodating axial body parts that cannot be identified to species or genus. This comparison is complicated by the important fact that several fetal or neonate deer and equids are represented in the assemblages, suggesting spring occupations at Vale Boi. These very young animals are apparent—or most countable—from petrous bones and certain lower hind limb elements (such as the distal tibia) among the skeletal remains. Prior research indicated that one third to one half of all individuals were deer fawns and horse foals (Stiner 2003). Subtraction of the identifiable parts of these young individuals from the sample results in a much more even profile, though mildly biased to lower limb parts above the foot.

The next question here is whether variation in density of bones predicts survivorship of parts in the Vale Boi material. The ungulates appear to have been intensively smashed, beyond what is expected from cold marrow extraction, but neonate and fetal bones appear relatively well preserved. To what extent might

post-depositional attrition bias our attempts to identify bone grease rendering at the site? Since some elements are better suited to identifying species, others only general ungulate body size classes, and body size ranges overlap greatly in the Vale Boi ungulates, we combined all ungulates into one sample and ran the skeletal survivorship data against a range of density comparators obtained for similarly-sized modern animals skeletons (*Odocoileus*, *Bison*, *Rangifer* & *Equus*). Our strategy is to look for consistency in results for the Vale Boi ungulates among the series of comparators. If the results are similar among the comparisons, then we have a basis for evaluating the potential importance of density-mediated attrition of softer bones, despite having combined results for all of the Vale Boi ungulate taxa in this analysis. In addition, we compare the condition of the ungulate bones to those of the dominant small game animal in the Gravettian and Magdalenian layers—rabbit (*Oryctolagus*). Unlike the situation for ungulate carcasses, which may frequently have been processed at kill sites and then selectively transported according to meat and grease yields, rabbit carcasses should have been brought to the site whole. The survivorship of rabbit bones therefore should be least affected by human transport biases and least sensitive to density-mediated bias given good post-depositional preservation. The rabbit results therefore provide an interpretive standard for assessing the causes of any body part biases observed in the Vale Boi ungulates.

The relation between rabbit density parameters and rabbit bone survivorship in Vale Boi (all layers) is not significant (Figure 6 and Table 3a). For the ungulates, correlations were run for all portions of all elements (Table 3a), and for the subset of element portions that correspond best to published scan sites (Figure 6 and Table 3b, following Stiner 2002, 2004). The latter procedures helps to correct for the imperfect relationship between identifiability and countability of skeletal features and the areas of bones for which density scan parameters are available. The relations between the ungulate density parameters obtained by photon densitometry (PD) or computed tomography (CT) and ungulate bone survivorship in Vale Boi vary from insignificant to significant. However, the majority of results for the corrected data set (Table 3b) indicate nonsignificant relations, except for *Odocoileus* deer ($p=0.007$). The r^2 values in both sets of comparisons (Tables 3a & 3b) indicate that density can explain only 5-10% of all variation in skeletal survivorship in the Vale Boi prey animals, except for *Odocoileus* deer which could be as high as 21%. Some biases are apparent in

ungulate body part representation, but density-mediated attrition does not explain most of them.

We assume that rabbit carcasses likely arrived at Vale Boi in whole form, whereas ungulate carcasses could have been subject to transport biases, processing biases, or both. The standardized body part profiles are of some help on this question, because they are not very sensitive to density mediated attrition (Stiner 2002, 2004). The mild bias against spongy bone tissues apparent in the ungulate data are almost certainly the result of human selection biases, first at the time of transport (because density is also linked to nutritional yield), but probably also from intensive bone processing to extract grease that followed on-site.

DISCUSSION

The Upper Paleolithic faunas of Vale Boi in western Algarve display an emphasis on ungulate hunting, supplemented to variable degrees by marine shellfish and small mammals. There is evidence of grease rendering of large game carcasses from the Gravettian onward, based on the co-occurrence of fire-cracked rock, stone anvils, and zooarchaeological evidence that includes highly fragmented spongy bone. Grease rendering methods most likely gain importance in forager systems, when and where rates of encounters with large mammal prey decreases. Few examples dating to the Gravettian are known, a fact explained either by a lack of recognition of carcass processing techniques in general or because there was special incentive for this behavior in southern Portugal. Available information for the western Algarve also indicates heavy use of rabbits as early as the Gravettian. The timing of such resource intensification and dietary expansion is in temporal agreement with the patterns observed for the northern Mediterranean Rim. The coupling of heavy rabbit exploitation and grease rendering of ungulate prey with the Gravettian of Algarve is distinctive.

Presently we only have data for the Gravettian to early Magdalenian in western Algarve, but there clearly was fairly heavy use of quick small game—rabbits—throughout the Upper Paleolithic phases represented there. Greatest use of rabbits occurs in the Gravettian, probably the warmest phase in the Vale Boi sequence and coincides with shellfish collecting (Table 1), when the shoreline would have been closest to the site, but apparently before the expansion of forest at the end of the Pleistocene (Madeyska 1999). Overall, one might conclude from the evidence on dietary breadth, in combination with that for bone grease rendering, that intensification in the western Algarve occurred as early as the

Gravettian, perhaps 25-26,000 years ago. This is coeval or only slightly prior to when lagomorphs became very important on the northern Mediterranean Rim at Riparo Mochi (ca. 25,000 years ago, Stiner et al. 2000; but see Hockett & Bicho 2000). Additionally, Vale Boi is also among the earliest documented cases of grease rendering of ungulate prey in Europe. The challenge in future work at Vale Boi will be to distinguish larger trends in subsistence organization from local (site-to-site) differences in subsistence strategies. It is possible that resource intensification was provoked by early impoverishment of large mammal communities in this southernmost edge of Iberia (see also Hockett & Haws 2002). Extreme reliance on marine resources follows in the Mesolithic of western Algarve.

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Table 1. Preliminary faunal distributions in the Upper Paleolithic Vale Boi cultural sequence as fractions of the total sample from square G25 of the 2000-2001 excavations (from Stiner 2003).

Units (cuts)*	Size (MNI)	Shellfish (NISP)	Rabbit (NISP)	Equid (NISP)	red deer (NISP)	MU (NISP)	Aurochs (NISP)	Ibex (NISP)
1-3 (early Magdalenian)	101	.00	.04	.24	.41	.32	.00	.00
4-7 (Solutrean)	254	.07	.17	.09	.39	.28	.00	.00
8-9 (Proto-Solutrean)	380	.13	.21	.04	.32	.30	.00	.00
10 (late Gravettian)	226	.13	.28	.03	.30	.25	<.01	.00
11-15 (Gravettian)	489	.12	.36	.05	.24	.22	.00	.01
16-25 (Gravettian)	906	.16	.55	.01	.10	.15	.01	<.01

Notes: Sample size is the number of identified specimens (NISP) for vertebrates, but minimum number of individuals (MNI) for shellfish in order to correct for significant differences in fragment sizes of identifiable remains. (*) Culture assignments are preliminary.

Table 2. Weight (kg) percentage distributions for manuported stone, bones, and food shells by time-ordered, culturally defined units in Vale Boi (from Stiner 2003).

Unit & Cut	Culture*	% Stone	% Bone	% Shell	Total kg
1-3	early Magdalenian	84	16	0	1.690
4-7	Solutrean	82	18	<1	10.622
8-9	Proto-Solutrean?	68	30	2	10.429
10	late Gravettian	73	25	2	6.595
11-15	Gravettian	80	19	1	22.631
16-25	Gravettian	59	37	4	19.284

* Culture assignments are preliminary. The majority of heavy stone material is fire-cracked rock and/or stone anvils.

Table 3. Correlation statistics for the relation between skeletal survivorship in Vale Boi prey animals and density standards for obtained from experimental studies of various taxa.

Density standard taxon & technique	Bibliographic source	N	r	r ²	p
a. All potential portions and elements:					
rabbit, <i>Oryctolagus</i> (PD)	Pavao & Stahl 1999	38	.249	.062	.132
reindeer, <i>Rangifer</i> (CT)	Lam et al. 1999	71	.308	.095	.009
bison, <i>Bison</i> (PD)	Kreutzer 1992	74	.234	.055	.045
American deer, <i>Odocoileus</i> (PD)	Lyman 1994	78	.251	.063	.027
horse/zebra, <i>Equus</i> (CT)	Lam et al. 1999	71	.249	.062	.037
b. Identifiable portion codes used in this study for major ungulate bones which correspond best to published scan sites:					
reindeer, <i>Rangifer</i> (CT)	Lam et al. 1999	41	.232	.054	.439
bison, <i>Bison</i> (PD)	Kreutzer 1992	41	.254	.065	.109
American deer, <i>Odocoileus</i> (PD)	Lyman 1994	41	.461	.213	.007
horse/zebra, <i>Equus</i> (CT)	Lam et al. 1999	40	.235	.055	.145

Notes: (PD) photon densitometry technique for measuring bone density in modern comparator species; (CT) computed densitometry technique.

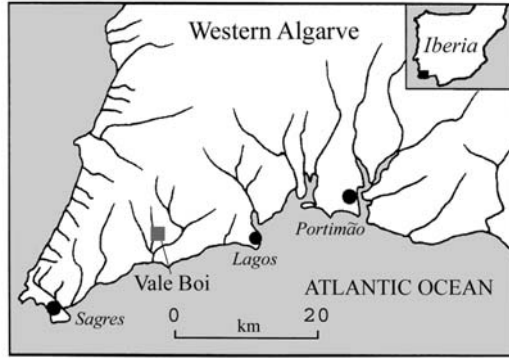


Figure 1. Location of the Paleolithic site of Vale Boi in the western Algarve.



Figure 2. Example of stone anvil from Vale Boi, probably used for intensive bone smashing. Arrows indicate the central, pitted depression resulting from repeated use.

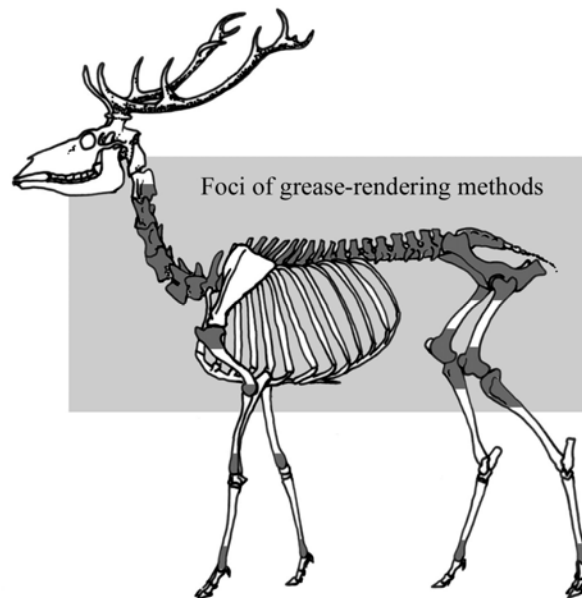


Figure 3. Foci of grease-rendering methods in the ungulate skeletal anatomy (from Stiner 2003).

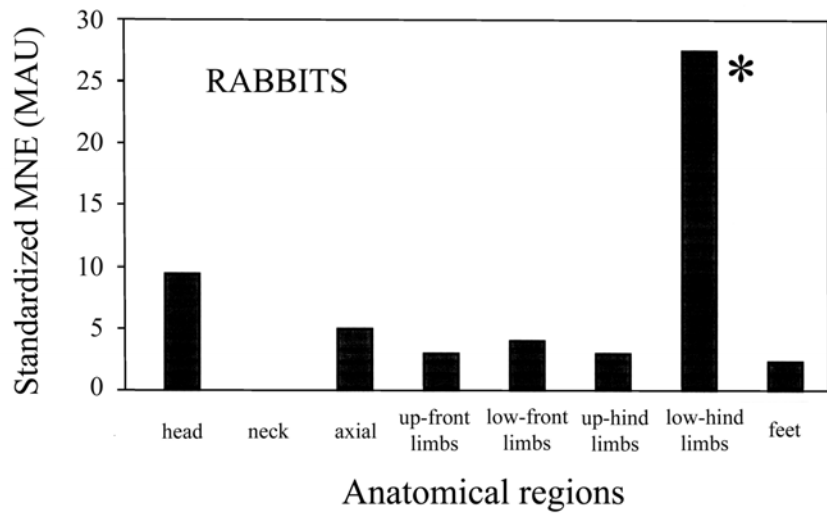


Figure 4. Standardized body part profile for rabbits from all layers of Vale Boi. (*) Anomalously high value for the lower hind limb region is due only to the exceptional abundance of rabbit calcanei (MNE=55). Cultural layers are combined for this analysis to increase sample size.

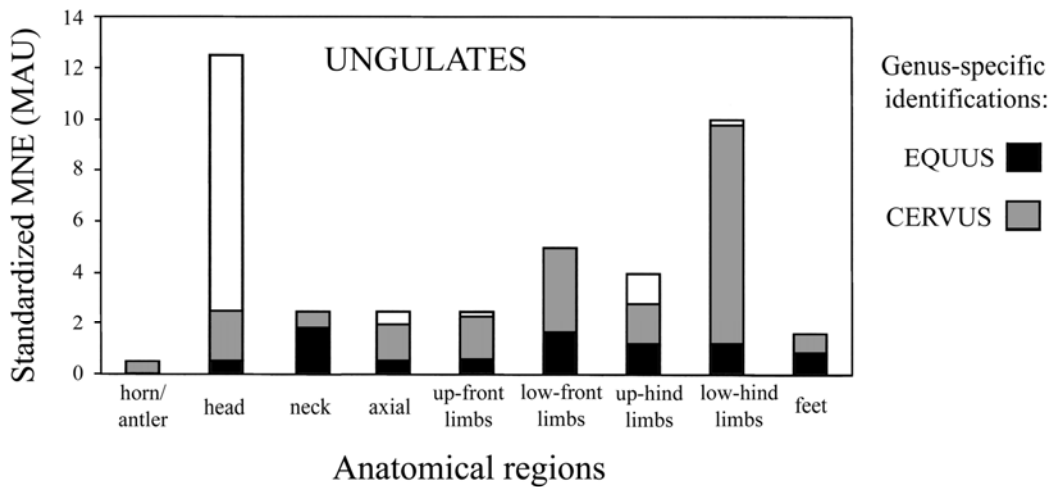


Figure 5. Standardized body part profile for all ungulate remains from Vale Boi, with the genus-specific contributions of *Cervus* and *Equus* indicated as subsets of the whole. Note that genus- and species-specific identifications center on regions other than the axial zone. Anomalously high values for the head and the lower hind limb regions are explained mainly by the presence of fetal and neonate individuals in the assemblages, which are evidences by hardened petrous bones and certain rear limb elements. Cultural layers are combined for this analysis to increase sample size.

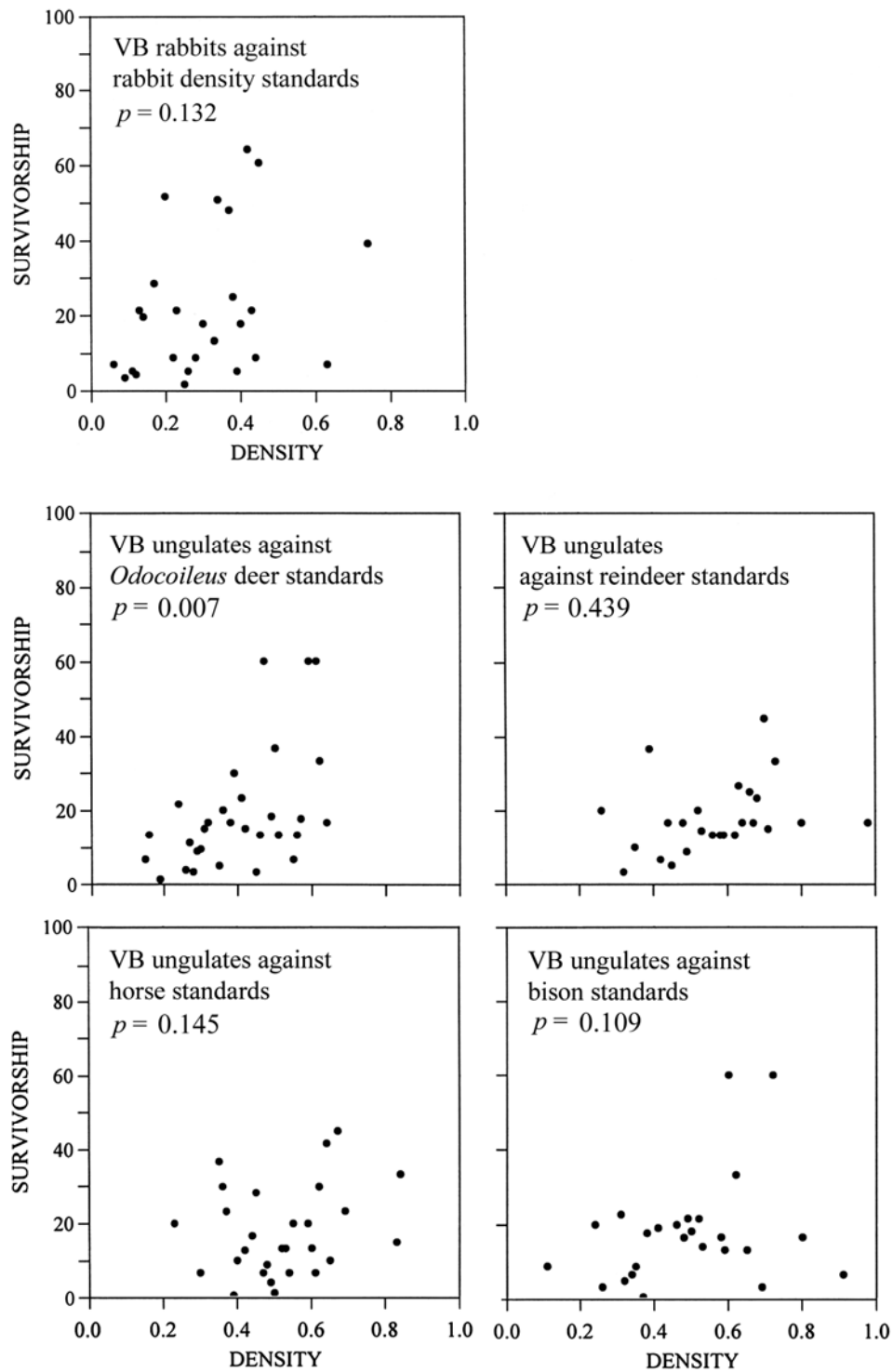


Figure 6. Relations between bone density and body part representation in rabbits and ungulates from Vale Boi, using independent bone density standards obtained experimentally by photon densitometry or computed tomography techniques on selected modern species.

Appendix 1. Body part survivorship data for Vale Boi rabbits, and density standards used (from Pavao & Stahl 1999).

Scan site	Density <i>Oryctolagus cuniculus</i>	% Survivorship
AC1	0.42	69.2
AS1	0.28	11.5
AT1	0.33	0
AX1	0.46	0
CA1	0.2	88.5
CA2	0.34	105.8
DN1	0.43	42.3
DN2	0.74	42.3
DN3	0.28	7.7
DN4	0.22	9.6
DN5	0.14	5.8
FE1	0.26	11.5
FE2	0.28	0
FE3	0.41	0
FE4	0.39	5.8
FE5	0.26	1.9
FE6	0.63	7.7
HU1	0.43	3.8
HU2	0.25	1.9
HU3	0.34	3.8
HU4	0.4	13.5
HU5	0.4	25
IL1	0.38	26.9
IL2	0.45	65.4
IS1	0.17	30.8
IS2	0.37	51.9
LUI	0.35	0
MC1	0.12	0
MC2	0.13	0
MT1	0.11	5.8
MT2	0.06	7.7
MT3	0.12	3.8
PA1	0.25	0
PH1	0.1	0
PH2	0.08	0
PU1	0.17	0
RA1	0.14	30.8
RA2	0.14	26.9
RA3	0.13	23.1
RA4	0.12	5.8
RA5	0.11	5.8

Scan site	Density <i>Oryctolagus cuniculus</i>	% Survivorship
RI1	0.04	0
RI2	0.06	0
RI3	0.07	0
RI4	0.05	0
RI5	0.01	0
SP1	0.33	17.3
SP2	0.13	0
SP3	0.09	3.8
ST1	0.07	0
TI1	0.54	0
TI2	0.33	11.5
TI3	0.3	19.2
TI4	0.26	3.8
TI5	0.44	9.6
UL1	0.2	23.1
UL2	0.23	23.1
UL3	0.12	0
UL4	0.14	0

Appendix 2. Body part survivorship data for Vale Boi ungulates, and density standards used from comparisons.

Scan site	Density <i>Odocoileus</i>	Density <i>Rangifer</i>	Density <i>Bison</i>	Density <i>Equus</i>	Survivorship % for Vale Boi ungulates
AC1	0.27	0.64	0.53	0.65	16.7
AS1	0.47	0.68	0.72	0.67	60
AS2	0.59	0.7	0.62	0.64	60
AS3	0.61	0.63	0.6		60
AT1	0.13	0.47	0.52	0.51	6.7
AT2	0.15	0.42	0.91	0.47	6.7
AT3	0.26	0.49	0.34	0.54	6.7
AX1	0.16	0.62	0.65	0.53	13.3
AX2	0.1	0.42	0.38	0.37	0
AX3	0.16	0.42	0.97	0.4	0
CA1	0.41	0.52	0.46	0.45	20
CA2	0.64	0.8	0.8	0.69	16.7
CA3	0.57	0.66	0.49	0.55	26.7
CA4	0.33	0.73	0.66	0.72	40
CE1	0.19	0.45	0.37	0.5	1.3
CE2	0.15	0.43	0.62	0.41	1.3
cuboid				0.5	0
cuneiform	0.72	0.71	0.43	0.6	10
DN1	0.55	0.65	0.53	0.66	0
DN2	0.57	0.75	0.61	0.69	0
DN3	0.55	0.63	0.62	0.61	6.7
DN4	0.57	0.67	0.53	0.6	20
DN5	0.57	0.56	0.53	0.52	13.3
DN6	0.31	0.66	0.57	0.64	13.3
DN7	0.36	0.98	0.49	0.83	16.7
DN8	0.61	0.99	0.79	0.99	0
fibula		0.68		0.59	0
FE1	0.41	0.39	0.31	0.35	36.7
FE2	0.36	0.35	0.34	0.3	10
FE3	0.33	0.35	0.34	0.36	26.7
FE4	0.57	0.57	0.45	0.59	0
FE5	0.37	0.4	0.36	0.46	10
FE6	0.28	0.32	0.26	0.3	3.3
FE7		0.3		0.24	0
lateral mall	0.52		0.56		0.67
HU1	0.24	0.26	0.24	0.23	20
HU2	0.25	0.31	0.25	0.25	3.3
HU3	0.53	0.61	0.45	0.64	0
HU4	0.63	0.62	0.48	0.55	0
HU5	0.39	0.48	0.38	0.36	30
hyoid			0.36	0.31	0
IL1	0.2	0.43	0.22	0.29	3.3

Scan site	Density <i>Odocoileus</i>	Density <i>Rangifer</i>	Density <i>Bison</i>	Density <i>Equus</i>	Survivorship % for Vale Boi ungulates
IL2	0.49	0.7	0.52	0.69	30
IS1	0.41	0.67	0.5	0.83	13.3
IS2	0.16	0.3	0.19	0.3	3.3
LU1	0.29	0.49	0.31	0.48	8.9
LU2	0.3	0.45	0.11	0.42	8.9
LU3	0.29	0.51	0.39	0.43	1.1
MC1	0.56	0.63	0.59	0.55	13.3
MC2	0.69	0.69	0.63	0.66	0
MC3	0.72	0.79	0.69	0.84	0
MC4	0.72	0.59	0.6	0.67	3.3
MC5	0.58	0.48	0.46	0.56	3.3
MC6	0.49	0.68	0.53	0.6	6.7
MCII				0.64	0
MCIV				0.74	0
MR1	0.51	0.58	0.52	0.59	13.3
MR2	0.55	0.57	0.59	0.75	3.3
MR3	0.65	0.65	0.67	0.91	0
MR4	0.74	0.54	0.51	0.71	3.3
MR5	0.57	0.41	0.4	0.58	3.3
MR6	0.46	0.59	0.48	0.6	13.3
MRII				0.87	0
MRIV				0.83	0
navicular				0.71	13.3
NC1	0.5	0.56	0.48		13.3
NC2	0.39	0.62	0.64		13.3
NC3	0.33	0.55	0.77		13.3
PA1	0.62	0.57		0.57	10
P11	0.31	0.48	0.48	0.67	30
P12	0.36	0.56	0.46	0.67	10
P13	0.42	0.71	0.48	0.62	30
P21	0.57	0.49	0.41	0.59	26.7
P22	0.28	0.64		0.57	30
P23	0.25		0.46		15.0
P31	0.35	0.48	0.32	0.4	10
PU1	0.25	0.58	0.55	0.44	10
PU2	0.46	0.54	0.39	0.42	0
RA1	0.24	0.53	0.48	0.37	23.3
RA2	0.42	0.57	0.56	0.51	0
RA3	0.62	0.73	0.62	0.84	33.3
RA4	0.68	0.38	0.42	0.43	3.3
RA5	0.38	0.49	0.35	0.42	16.7
RI1	0.43	0.47	0.27	0.36	1.5
RI2	0.26	0.49	0.35	0.39	0.7
RI3	0.4	0.62	0.57	0.5	0
RI4	0.24	0.65	0.55	0.55	0

Scan site	Density <i>Odocoileus</i>	Density <i>Rangifer</i>	Density <i>Bison</i>	Density <i>Equus</i>	Survivorship % for Vale Boi ungulates
RI5	0.14	0.4	0.33	0.51	0
SC1	0.19	0.37	0.27	0.36	0
SC2	0.16	0.4	0.26	0.37	0
scaphoid	0.98	0.7	0.42	0.62	33.3
SP1	0.36	0.66	0.5	0.64	23.3
SP2	0.49	0.73	0.48	0.67	0
SP3	0.23	0.73	0.28	0.55	0
SP4	0.34	0.69	0.43	0.66	0
SP5	0.28	0.48	0.17	0.28	0
ST1	0.22				6.7
TH1	0.24	0.38	0.42	0.32	7.2
TH2	0.27	0.53	0.38	0.49	4.1
TI1	0.3	0.35	0.41	0.3	10
TI2	0.32	0.44	0.58	0.44	16.7
TI3	0.74	0.71	0.76	0.82	0
TI4	0.51	0.53	0.44	0.55	3.3
TI5	0.5	0.39	0.41	0.45	36.7
trapmag/ magnum	0.74		0.52	0.62	13.3
UL1	0.3	0.49	0.34	0.43	26.7
UL2	0.45	0.68	0.69	0.65	3.3
UL3	0.44				13.3
unciform	0.78	0.72	0.44	0.67	10

Note: Values in boldface represent identifiable portion codes used in this study for major ungulate bones which correspond best to published scan sites.