Measurements of bones of seven female Barrosãs and one male Barrosão (*Bos taurus* L. 1758): a baseline for zooarchaeologists with notes on the evolution of Portuguese aurochsen and cattle

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Abstract:

Measurements of the bones of 7♀ and 1♂ Barrosã cattle from Portugal are presented. These may serve as a baseline for osteometrical studies of Bos *in Iberia. Sexual dimorphism varies: shaft width measurements show considerable dimorphism while those of the M$_3$ and metapodial lengths show little. An osteometrical survey of late Pleistocene to modern Portuguese* Bos *reveals Pleistocene-Holocene (Magdalenian-Early Mesolithic) size reduction that accords with Bergmann's rule. During the Mesolithic aurochsen dwarfed slightly possibly due to overhunting. Some large Chalcolithic* Bos*, probably aurochsen, had increased in size after the Mesolithic. Neolithic to Muslim period* Bos *were smaller and probably therefore domestic. Predator pressure relaxed during the Neolithic with the arrival of domesticated livestock allowing aurochsen to recover some of their former size – a scenario with parallels in the Near East and Denmark. After the* reconquista, *cattle increased in size. Modern Barrosã are even more robust – reflecting selection for meat and power.*

Key words*:* Bos primigenius*,* Bos taurus*, Barrosã, Bergmann's rule, livestock improvement, sexual dimorphism, osteometry.*

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Os barrosãos dão magníficos bois de trabalho, sendo estimadíssimos para a tracção de pesadas carregos, pelos acidentados caminhos das margens do Douro. Para talho, este gado fornecia belíssimas reses, no período áureo de pecuária nacional. Joaquim Sabino de Sousa atribuía ao gado barrosão 783 quilos de pêso vivo e uma percentagem de carne limpa de 67% . . . A aptidão galatófora das vacas barrosãs atinge uma média anual de 1.200 litros de leite de alta percentagem butirosa, o qual se emprega no fabrico de manteiga.

José Miranda do Vale (1949) – Gado Bissulco: Suínos. Bovinos. Arietinos. Caprinos. « A TERRA e o HOMEM » Colecção de livros agrícolas. 4.a Secção – A exploração e a Criação de Animais – N.º 2. Lisboa, Livraria Sá da Costa. p. 101.

1. INTRODUCTION

Somewhere in the Near East, ten or eleven thousand years ago, people began domesticating the aurochs, *Bos primigenius*. This gave rise to our smaller domestic cattle *B. taurus* (Zeuner 1963; Peters *et al.* 2005). Whether aurochsen in other parts of Europe were independently domesticated is still uncertain, although current evidence points to a Near Eastern origin (Verdugo *et al.* 2019). While aurochsen became extinct in southern Sweden around 4,500 BC, they survived in Jutland until *c.* 500 BC (Aaris-Sørensen 1999) and the last surviving aurochs died in Poland in 1627 (Zeuner 1963: 203). Here in Portugal, from Iron Age times onwards, there is no secure evidence for the continued existence of the aurochs. It had probably become extinct in the Chalcolithic or Bronze Age (Castaños 1991). Early Holocene Portuguese *Bos* (i.e., aurochsen from the Mesolithic) were considerably larger than their Iron Age to Medieval-Muslim domesticated descendants with little overlap (Davis *et al.* 2018) and, as in the Near East (Davis 1981); late Pleistocene Iberian aurochs were larger still. In other words size variations of Portuguese *Bos* show a three step descent from very large in the late Pleistocene, to smaller in the early Holocene to even smaller, once domesticated. Like so many mammals of that time, the great size of late Pleistocene aurochsen compared with those from the early Holocene, was presumably an adaptation to lower temperature, another example of Carl Bergmann's (1847) rule. A possible slight increase in size of aurochsen in the Chalcolithic will be discussed below, but due to small size of the samples, an explanation of this partial size recovery (i.e., size increase) remains within the realm of speculation. At the Neolithic archaeological site of Lameiras, near Sintra, Portugal, remains of *Bos* were found that are similar in size to domesticated cattle. These are therefore among the earliest known cattle from Portugal (Davis *et al.* 2018). In Europe and the Near East, distinguishing between bones of the large wild and bones of the smaller domesticated forms can be done osteometrically (Higham 1968; Degerbøl and Fredskild 1970; Driesch and Boessneck 1976). However, for certain measurements of certain bones there can be some overlap between small female aurochsen and large male domestic cattle.

Zooarchaeologists usually measure the bones they study to determine size and shape. Measurements can help identify remains to the species level, distinguish between closely related taxa like bison and cattle, sheep and goat, horse and donkey, and even sometimes determine the sex of the animal to which the bone belonged (Boessneck and Driesch 1978; Guintard 1994; Davis *et al.* 2012; Davis *et al.* 2018). A chronological sequence of animal bone measurements can be used to detect size and shape variation through time. Such changes may reflect factors like

a) climate change such as the rise in temperature at the Pleistocene-Holocene frontier 'causing' a decline in size, (Kurtén 1960; Davis 1981; Klein and Cruz-Uribe 1984);

b) overhunting, for example, during the Mesolithic (Davis and Detry 2013);

c) domestication when large mammals like aurochsen, goats, wild boar and sheep underwent a reduction in size (Higham 1968; Grigson 1969; Uerpmann 1979; Darwin 1885 vol.1) and even

d) stock improvement.

Within a lineage of domesticated livestock it is assumed that a size increase represents an 'improvement' – some examples include cattle in many parts of the Roman Empire – larger than their Iron Age predecessors and post Medieval cattle in many parts of Europe - larger than their earlier Medieval ancestors (Matolsci 1970; Teichert 1984; Audoin-Rouzeau

1995; Albarella 1997a, b; Davis 1997; Peters 1998; Davis and Beckett 1999; Breuer *et al.* 2001; Forest and Rodet-Belarbi 2002; Schlumbaum *et al.* 2003; Davis 2008; Thomas *et al.* 2013). Size can therefore be related to these four, perhaps more, different factors and it is the zooarchaeologist's task to try and understand which of these factor(s) was/were responsible for the various different size changes that we are able to observe in the zooarchaeological record of Portugal since the last Ice Age and until the present day. This task requires a degree of imagination and many of the suggestions made, especially herein, are difficult to prove and therefore need to be treated cautiously! This article is a subjective and speculative first attempt to interpret the succession of *Bos* remains in Portugal and will no doubt undergo modifications when more data are available.

In order to compare samples of cattle bones from different regions and/or different periods it helps to have a local baseline set of measurements – a benchmark in other words. Often archaeological samples of cattle bones are few in number and hence comparisons of their size are difficult. Simpson *et al.* (1960) devised a method whereby measurements of different bones within the same sample can be pooled and compared to a baseline of measurements taken from a 'benchmark' individual or, perhaps safer, a 'benchmark' sample of skeletons or group of skeletons of a specific breed (if a domestic animal) from a particular location. Some examples include *Sus* in England (Albarella and Payne 2005); *Bos*, *Ovis*, *Capra* and *Gazella* in Mehrgarh, Baluchistan (Meadow 1984); *Bos taurus* in North America (Reitz and Ruff 1994), *Bos primigenius* in England (Wright and Viner-Daniels 2015) and *Ovis* in England (Davis 1996).

The first aim of this article is to provide such a baseline in the form of measurements of the limb bones and teeth of seven adult cows and one adult bull all belonging to a particular herd of the traditional Portuguese breed – the Barrosã – originally from the Terras de Barroso in northern Portugal. An example will be presented where the seven adult female Barrosãs are used for comparison with pooled width and pooled length measurements of various limbbones from the Moslem and Christian periods in Portugal – using the "log ratio method". The Barrosã skeletons were collected by us over a period of eight years from 2009 to 2016. These eight skeletons are

housed in the reference collection of skeletons of the Laboratório de Arqueociências (LARC) in Lisbon. Measurements taken on these eight skeletons will be presented along with some notes on this beautiful breed (see fig. 1) and its recent history. The second aim of this article is to describe some results obtained so far in a study of the evolution, essentially changes in size and shape of bones, of *Bos* in Portugal since the end of the Pleistocene using our Barrosã specimens as a baseline.

2. MATERIAL

The eight skeletons of adult Barrosãs come from the herd of approximately 100 head kept by one of us (AS) at the Herdade do Freixo do Meio, Montemor-o-Novo, Alentejo and at Cruzetinhas, Parreira,
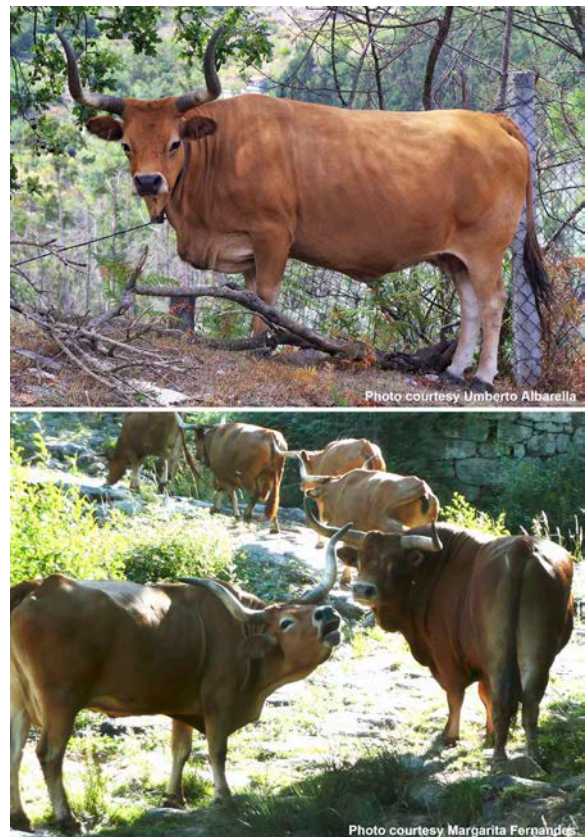

Fig. 1: Barrosã cattle today. Photographs taken by Margarida Fernandes and Umberto Albarella in the Terra de Barroso during the early part of the 21st century.

Chamusca, Ribatejo. These Barrosãs originated from the Boticas region in northern Portugal. Most of the skeletons are fairly complete and include a mandible, scapula, humerus, radius, metacarpal, pelvis, femur, tibia, astragalus, calcaneum and metatarsal. These are the bones generally identified and recorded from archaeological sites. Since 2000, one of us (SD) has been engaged in a long-term study of animal remains from archaeological sites in Portugal. Almost all sites studied have included teeth and bones of *Bos* (both wild and domesticated forms) and date from the Mousterian culture of the late Pleistocene (some 30,000 years ago) to the 17th century AD.

3. METHODS

The majority of the modern Barrosãs were collected as fully de-fleshed skeletons from animals that had died in the field. Several however still had some flesh attached when collected and these were prepared as in Davis and Payne (1992). Measurements were taken with vernier callipers to the nearest tenth of a millimetre in the manner recommended by Driesch (1976) and Davis (1996). These include the measurements, mostly of the distal ends of long-bones, commonly taken by zooarchaeologists such as the widths and depths of the condyles, distal width and the shaft width and total length of the bone. Some measurements not included in Driesch (1978) are shown in fig. 2.

4. A FEW WORDS ABOUT THE BARROSÃ BREED (from Lima 1859; Lima e Santos, 1996; Gouveia *et al*. 2001; Faria 2007; Porter *et al*. 2016).

The Barrosã is one of 14 native breeds of Portuguese cattle. It has long lyre-shaped horns whose great length and shape are unique among Portuguese cattle (see figs. 1 and 3). Its coat is light-brown, with a white ring around the muzzle and white 'spectacles' around the eyes. Bulls are often put to fight one another in struggles known as chegas de bois. Visit for example: https://www.youtube.com/watch?v=3zGtEtK47hY. The name Barrosã was first used by Silvestre Bernardo Lima (the "*primeiro*

zootechnista da Peninsula") in a series of articles that appeared in *O Archivo Rural* in 1859 – a time when these cattle were beginning to be shipped to England in very large numbers. He wrote (Lima 1859) that in the Barroso region 134 bulls covered 12,000 cows. And bulls begin their task at around two years of age and sometimes as young as 18 months and continued until 8, 10 or even 15 years! He describes a siring bull as *...uma das criaturas mais priviligiadas e felizes de Barroso, um honrado senhor destas terras, em quanto vale e póde ser touro*. Cows are medium sized with a withers height of 118-123 cm and weighing 300-400 kg. Bulls are about the same size and work oxen weigh some 400-500 kg. They are known for their fast growth, early maturation and excellent meat with its regular distribution of fat. Originally this breed was primarily kept for its meat and power. An additional source of revenue was obtained from any extra milk left over from milking calves and following weaning. One proof of this was illustrated by the traditional local manufacture of "*bicas*" *de manteiga* – wooden butter pats. Today the Barrosã carcass has an excellent muscle/bone ratio around 3,8 (Martins in Gouveia *et al*. 2001). The milk, though not abundant - 12 litres per day at the height of lactation – is very rich with a 5-6% butter content (Nogueira 1900). Lima (1859) wrote that these 12 litres would provide as much as one kilo of butter or three kilos of cheese – a yield considerably greater than produced by many other breeds of cattle at that time. Lima e Santos (1996) has emphasized the important role that the Barrosã played in fertilizing the soils with some 37% of the nitrogen entering cultivated fields being derived from barrosã cattle. Prior to the introduction of motorised vehicles these animals were an important source of energy for traction and transport. Figure 3 is an early 20th century photograph of a large number of Barrosãs at a fair in Barcelos, Minho province, taken by Emílio Biel.

After Britain adopted a free trade policy in 1842, large numbers of Barrosã cattle were shipped live from Porto where they became known locally as *os bois do barco* (see also Martins in Gouveia *et al*. 2001). Prior to shipment, five to seven year-old animals would be fattened for 6 months in the nearby fertile areas around Maia. This trade proved very
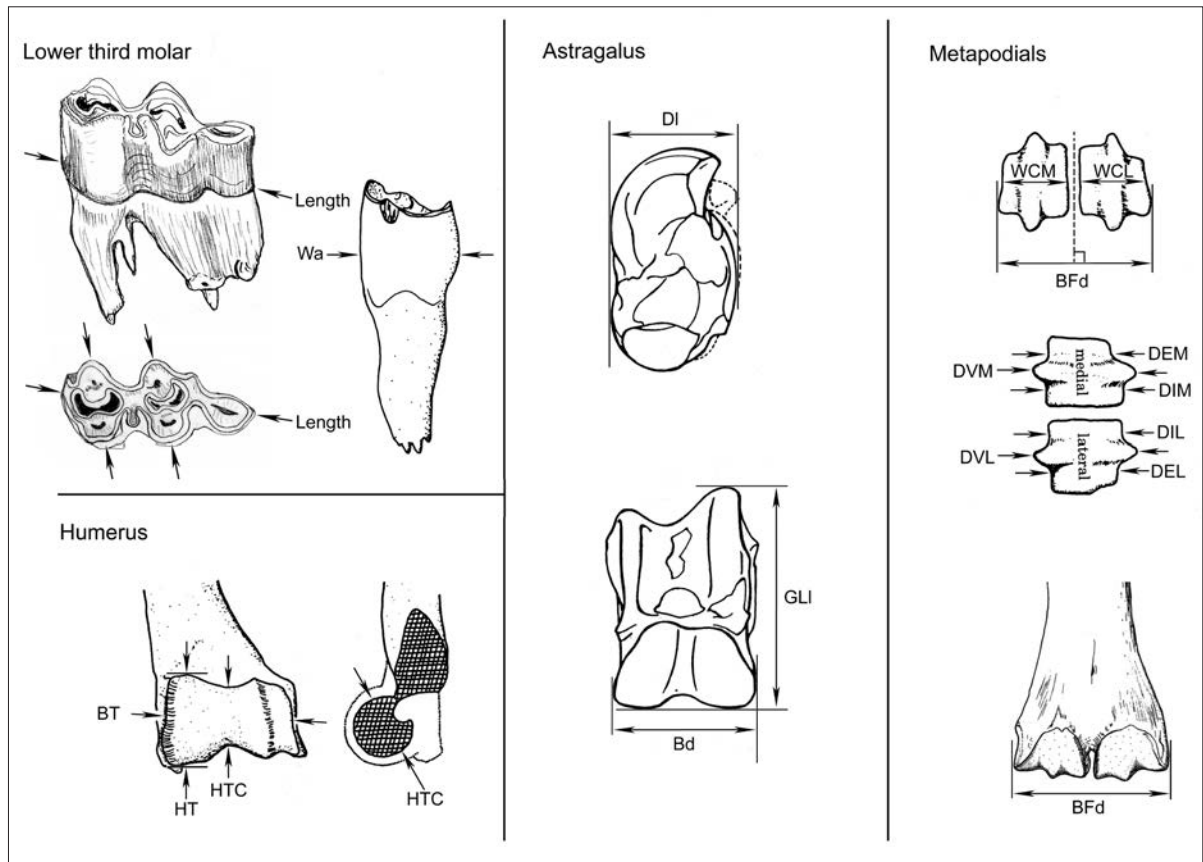
Fig. 2: Sketches of a lower third molar tooth, distal humerus, astragalus (from Driesch 1976) and distal metapodial to show how measurements are taken. These follow Driesch (1976) and Davis (1996).

Fig. 3: An early 20th century photograph taken by Emílio Biel which shows a large number of Barrosãs at a fair in Barcelos, Minho province, northern Portugal. Courtesy Paulo Gaspar Ferreira, "In-Libris".

lucrative and between 1847 and 1860, the local price of Barrosãs doubled. By the 1870s over 17,000 head of Barrosã were being exported annually to Britain – a *gargantua insaciável deste género de subsistências* as Bernardo Lima wrote and where their meat was designated "Portuguese beef". The peak period of export was between 1868 and 1884 when cattle occupied fourth place in Portugal's exports. The exact figure exported to England in 1871 given by Ferreira Torres (in Gouveia *et al.* 2001) was 18,350 head of cattle, most Barrosã, with a value of 1,192,950$00! In those times one of their principal functions was as a work animal for which steers were used. (In the Minho calves were castrated at age 12 to 18 months and by the mid 20th century this age was lowered to 6 – 7 months.) The Barrosã cattle on the quaysides of Porto were, besides the famous Rabelo boats, an important attraction for tourists. Unfortunately rinderpest arrived in England with cattle from the Baltic region and the subsequent imposition of import controls, as well as competition from refrigerated meat from America and New Zealand, meant that the trade to Britain in Barrosãs declined and was over by 1920. But by the early 1940s the Barrosã was still very well represented in northern Portugal. And with 224,062 Barrosã and 228,014 Mirandesa, these two breeds constituted half the 831,674 cattle found in Portugal at that time (Porter *et al.* 2016). Changes in land use in the 1960s led to a decline in numbers of Barrosã and by 1972 they numbered 114,357. By 1981 they were mainly kept in farms above 600 metres altitude. Garcia *et al.* (1981) paint a fairly depressing picture of the state of this breed in the 1970s and complain of the lack of government support for improving the breed. However, conservation measures were started and a herd book and breed society (*registo zootécnico*) established in 1981. In 1990 there were 7396 animals in the herd book (*livro genealógico*). In 1993 the *Associação dos Criadores de Bovinos de Raça Barrosã* (Association of Barrosã breeders; AMIBA) was established and in 1994 the *Agrupamento de Produtores de Carne Barrosã* undertook to designate the meat of this breed as *Denominação de Origem Protegida* or "DOP" (in English this is PDO or Protected Designation of Origin). Today the meat is especially appreciated for its flavour, perhaps in part due to the

Barrosã being an early maturing breed that begins intramuscular fat deposition (marbling) before reaching maturity (Beja Pereira pers. comm.). In 2004 there were 7100 breeding cows kept by 3100 breeders and a similar number in 2010. The last census undertaken in 2013 records 6710 breeding cows. And an official flyer printed in 2018 mentions 6809 breeding females and 348 males. Today, as Porter *et al.* (2016) write, the breed is "rather shorter in withers height, though heavier, than 150 years ago..." – a comment that appears to be borne out by our osteometrical studies (see below).

Early genetical studies indicated that the Barrosã has had no admixture of African mtDNA (Porter *et al.* 2016). However, a study of the genes involved in milk production point to a possible close connection between the Barrosã and African and Zebu cattle rather than cattle of central Europe (Beja Pereira and Ferrand in Gouveia *et al.* 2001). The analysis of whole-genomes of native cattle from the Iberian Peninsula confirms that eight breeds, including Barrosã, display significant gene flow from African taurine cattle and include maternal (mitochondrial DNA) and paternal (Y-chromosome) lineages from multiple origins (Fonseca *et al.* 2019). Interestingly, individual Iberian cattle breeds are genetically very distinct with high levels of differentiation observed from the analysis of classic highly variable autosomal markers, i.e. microsatellites, and whole-genomes (Martin-Burriel *et al.* 2011; Beja-Pereira *et al.* 2003; Fonseca *et al.* 2019). Their breed denominations have been shown to agree with population structure inferred from these genetic data. [We are grateful to Catarina Ginja for her clarifications concerning these recent genetical studies.]

Fig. 4 (next page): Measurements in millimetres of the modern Barrosã bones and teeth in the LARC reference collection. Tooth wear stages follow Grant (1982). Measurements were taken as described in Driesch (1976) and Davis (1996). Approximate values are in parentheses. Animals came from Herdade do Freixo do Meio, Foros de Vale Figueira, Montemor-o-Novo, Alentejo or Cruzetinhas, Parreira, Chamusca, Ribatejo. Note that the following are missing certain bones: 2491 (tibia), 2726 (calcaneum, metatarsal) and 2730 (pelvis).

LARC Nº & sex:		2300♀	2491♀	2638♀	2701♀	2702♀	2725♀	2726♀	2730♂
Herd location:		Montemor	Montemor	Chamusca	Chamusca	Chamusca	Chamusca	Chamusca	Chamusca
Date of death:		Summer 2009	2012?	oct-13	2015	2015	2015/6	2016?	May/June 2016
P_4 wear stage		h	j	g	j	g	-	g	h
M_1 wear stage		o	o	k	n	l	-	k	k
M_2 wear stage		l	k	k	l	k	-	k	k
M_3 wear stage		m	k	k	l	h	h	j	k
M_3	Length	36,5	38,7	38,3	40,3	39,3	39,7	40,8	42,2
M_3	Wa	17	16,7	17,4	17,3	17,9	17,2	17,5	18,4
M_3	Wb	14,9	16	16,2	16,3	16,9	15,6	16,7	16,7
SCAPULA	SLC	48,8	48,5	54,8	50,8	59,3	54,4	58,4	67,3
	GLP	70,2	69,6	80,6	71,9	73,3	69,1	77,4	-
	ASG	51,2	56,4	53	64,6	54,5	54,1	54,2	59,9
HUMERUS	GLC	245,8	242,2	258,4	254,2	253,8	253,2	265,3	286,5
	SD	36,4	36,2	38,7	35,3	40,7	37,6	42,6	45,9
	BT	69,6	69,6	73,6	73,3	77,4	73,9	75,2	85,5
	HT	41,9	42,5	45,2	42,5	46,9	45,7	46,3	54,3
	HTC	30	31,2	35,7	32,6	35,7	34,3	34,7	39,7
RADIUS	GL	263,8	269,4	283,9	-285,3	287,6	280,7	285,4	312,6
	Bp	78,3	77,6	85,4	81,5	86,2	83,4	85,8	100
	BFp	71,3	69	74,2	75,3	78,9	74,7	77,4	84,9
	SD	40	39,1	39,9	39,2	47,8	43,3	48,6	55,5
METACARPAL	GL	180,5	191,1	193	192,1	194,9	201,7	204,7	204,2
	BFp	50,9	51,3	58,4	54,9	58,2	58,5	60,6	68
	SD	33,4	30,7	35	29,7	35,1	36,4	37,5	44,4
	BFd	57,9	59,3	62,4	50,8	61,2	61,6	63,9	71,9
	WCM	27,8	29	29,6	27,5	29,1	28,7	30,2	35,4
	WCL	27,3	27,4	30	26,3	27,3	28,4	29,2	32,7
	DEM	21,8	22,8	24,4	23,7	24,9	24,4	24	27,9
	DVM	30,2	30,3	33	31,6	33,5	33,3	32,6	37,2
	DIM	25,8	26	29	27,6	29,1	28,9	28,5	32,5
	DEL	20,4	21,4	22,7	22	24	22,6	23,6	26,8
	DVL	29,2	30,1	32,5	31,5	33,1	-32,3	32,6	37
	DIL	25,6	26,9	29,4	27,6	29,4	28,8	28,9	33,3
PELVIS	SHPu	15,4	14,4	18,5	14,8	18,7	18,2	19,1	-
	SBPu	25,2	24,8	25,8	23,3	25,5	26	25,7	-
	MRDA	18,3	8,9	12,4	17,2	12,2	-14,7	-12,2	-
FEMUR	GLC	330,2	329,7	356	344,9	352,2	343,3	356,4	401
	SD	33,6	32,8	39,4	36,7	38,9	38,6	39,6	45,9
TIBIA	GL	324,8	-	349,8	348,3	351,8	357,3	356,9	385,4
	SD	38,2	-	41,4	39,5	42,6	40,4	45,2	50,2
	Bd	60,4	-	64,9	62	67,6	64,9	67,6	74,8
	Dd	47,2	-	50,3	46,8	50,7	49,6	50,8	57
CALCANEUM	GL	126,8	126,8	136,8	135,2	140	139,6	-	150,4
ASTRAGALUS	GLl	62,4	65,3	71,9	69,4	70,8	69,9	69,8	73,5
	Bd	39,8	39,1	43,2	40,8	44	40,6	45,3	48,9
	Dl	32,8	34,9	39	38,5	39	36,9	38,8	41,3
METATARSAL	GL	212,1	220,6	228,1	227,8	229,7	232,5	-	231,3
	SD	28	25,9	28,9	25,9	29,1	30,3	-	34,7
	BFd	52,1	52,6	56,2	51,3	57,2	56	-	64,1
	DIM	25,3	25,6	27,9	26,5	28,2	27,8	-	29,9
	DIL	25,4	26,3	28,7	27,9	29	28,7	-	31,1

5. OSTEOMETRY

5.1. THE MODERN BARROSÃ SKELETONS IN THE LARC COLLECTION

Fig. 4 provides the measurements of lower third molar teeth and limb-bones of eight Barrosã skeletons in our reference collection of modern vertebrate skeletons. Fig. 5 gives the average values of the measurements of the seven females which we suggest could be used as a baseline or osteometric 'bench mark' for comparisons with cattle bones from archaeological sites in the Iberian Peninsula.

One important consideration when studying measurements of animal bones from archaeological sites is to determine the sexual composition of the sample being studied. In the case of large food animals like cattle, this is important as it can indicate what kind of economy was practised. A sample of mainly adult females would no doubt be derived from a milking herd, while one with numerous oxen probably indicates their use for power.

Another reason why it is important to ascertain the sex ratio is that if one finds a change in the average size of cattle in the course of time, one needs to question whether this difference reflects a real size change or merely a change in the sex ratio. This is because cattle, like fallow deer, goats, etc., show a marked degree of sexual dimorphism with males considerably larger than females. Hence if one finds a change in the average size of cattle in a chronological sequence one needs to question whether this difference reflects a real size change or merely a change in the sex ratio. The average size of bones of a sample consisting mainly of cows would of course be less than the average size of one consisting mainly of bulls. We demonstrated that an unbalanced proportion of the sexes was not responsible for the average size increase of Portuguese cattle following the *reconquista* by plotting (in fig. 6) the sexual identification obtained from the ancient DNA of 21 metacarpals from 15th century Beja (Davis *et al.* 2012). This shows that both females and males increased in size after the Muslim period and we were able to suggest that the Christians improved cattle. However, the amount of sexual dimorphism can vary depending on which bone and which measurement is considered. Figures 5, 7 and 8 show the amount of difference between the seven Barrosã cows and the single bull in our modern sample for each of the 41 measurements taken on the lower third molar tooth and the nine limb-bones. A note of caution is required. Like all living things, bones vary. Thus, using just a single bull skeleton may be dangerous. Ideally, we need to compare the measurements of the seven cow skeletons with those of a similar number of bulls. In the coming decades as our reference collection inevitably grows, it will be possible to undertake a more secure study. In the meantime, and until more bull skeletons are forthcoming, we shall make some speculations!

Let us see how different bones and their measurements vary in the degree of their sexual dimorphism; i.e., the shapes of the bones of the two sexes differ. The third molars in our Barrosã collection show little sexual size-dimorphism (around 4 – 8%) which confirms the findings of Degerbøl (1963) and Degerbøl and Fredskild (1970: 87). The lengths of both metacarpals and metatarsals also display a similarly small (around 3 – 5%) amount of dimorphism which would appear to bear out Lima (1859) when he described barrosãos as *...animais de tamanho médio, não sendo os machos muito maiores do que as fêmeas, embora um pouco mais corpulentos* ["...medium-sized animals, with the males not being much larger than the females, although somewhat more corpulent"]. The end of Lima's sentence makes it seem likely that in most cattle the differences between the sexes are more apparent in the bone widths than in their lengths. Indeed, inspection of figures 5, 7 and 8 reveals that overall this does seem to be the case. Shaft widths (SD) of the six principal long-bones all display significant dimorphism ranging from a 20% (humerus) to a 31% (metacarpal) difference. To take the astragalus as an example; note its greatest lateral length (GLl) varies by a mere 7% while its distal width (Bd) varies by 17%. For the metacarpal, the width of the medial condyle (WCM) and distal width (BFd) also appear to separate the sexes reasonably well with a 23% and 19% difference respectively. This agrees with what we suggested for the sample of a-DNA sexed metacarpals from 15th century Beja (Davis *et al.* 2012). It is often assumed that for artiodactyls, whose males carry large horns or antlers on their heads and/or whose males engage in combat, it is the bones of the fore-limb that

Fig. 5: Mean values and their standard deviations and coefficients of variation (CV) of the measurements in millimetres of the seven adult Barrosã cows for use as a baseline for comparative purposes in the Iberian Peninsula. On the right are the measurements of the single bull and the differences between this bull's measurements and the cow averages in millimetres and expressed as percentages. Note that several skeletons lacked one or two bones.

Bone	Measurement	N	Cows			Bull	♂-♀ diff.	%
			Mean	sd	CV			
M₃	Length	7	39,1	1,43	3,7	42,2	3,1	7,9
M₃	Wa	7	17,3	3,81	2,2	18,4	1,1	6,4
M₃	Wb	7	16,1	6,77	4,2	16,7	0,6	3,7
SCAPULA	SLC	7	53,6	4,37	8,2	67,3	13,7	25,6
	GLP	7	73,2	4,34	5,9	-	-	-
	ASG	7	55,4	4,34	7,8	59,9	4,5	8,1
HUMERUS	GLC	7	253,3	7,64	3	286,5	33,2	13,1
	SD	7	38,2	2,64	6,9	45,9	7,7	20,2
	BT	7	73,2	2,83	3,9	85,5	12,3	16,8
	HT	7	44,4	2,07	4,7	54,3	9,9	22,3
	HTC	7	33,5	2,24	6,7	39,7	6,2	18,5
RADIUS	GL	7	279,2	9,05	3,2	312,6	33,4	12
	Bp	7	82,6	3,57	4,3	100	17,4	21,1
	BFp	7	74,4	3,39	4,6	84,9	10,5	14,1
	SD	7	42,6	4,11	9,7	55,5	12,9	30,3
METACARPAL	GL	7	194	7,85	4	204,2	10,2	5,3
	BFp	7	56,1	3,81	6,8	68	11,9	21,2
	SD	7	34	2,89	8,5	44,4	10,4	30,6
	BFd	7	60,4	2,54	4,2	71,9	11,5	19
	WCM	7	28,8	0,95	3,3	35,4	6,6	22,9
	WCL	7	28	1,28	4,6	32,7	4,7	16,8
	DEM	7	23,7	1,07	4,5	27,9	4,2	17,7
	DVM	7	32,1	1,39	4,3	37,2	5,1	15,9
	DIM	7	27,8	1,42	5,1	32,5	4,7	16,9
	DEL	7	22,4	1,24	5,6	26,8	4,4	19,6
	DVL	7	31,6	1,45	4,6	37	5,4	17,1
	DIL	7	28,1	1,44	5,1	33,3	5,2	18,5
PELVIS	SHPu	7	17	2,05	12,1	-	-	-
	SBPu	7	25,2	0,92	5,4	-	-	-
	MRDA	7	13,7	3,26	23,8	-	-	-
FEMUR	GLC	7	344,7	11,2	3,3	401	56,3	16,3
	SD	7	37,1	2,83	7,6	45,9	8,8	23,8
TIBIA	GL	6	348,2	12,01	3,5	385,4	37,2	10,7
	SD	6	41,2	2,47	6	50,2	9	21,8
	Bd	6	64,6	2,92	4,5	74,8	10,2	15,8
	Dd	6	49,2	1,79	3,6	57	7,8	15,9
CALCANEUM	GL	6	134,2	6	4,5	150,4	16,2	12,1
ASTRAGALUS	GLl	7	68,5	3,39	4,9	73,5	5	7,3
	Bd	7	41,8	2,34	5,6	48,9	7,1	17
	Dl	7	37,1	2,43	6,5	41,3	4,2	11,3
METATARSAL	GL	6	225,1	7,5	3,3	231,3	6,2	2,8
	SD	6	28	18	6,4	34,7	6,7	24
	BFd	6	54,2	2,51	4,6	64,1	9,9	18,3
	DIM	6	26,9	1,26	4,7	29,9	3	11,2
	DIL	6	27,7	1,48	5,4	31,1	3,4	12,3

show greatest dimorphism. Inspection of the differences in figures 5 and 7 indicates that equivalent bones (humerus-femur, radius-tibia, metacarpal-metatarsal) show that fore- and hind-limbs are hardly different at all. Indeed, the femur length and shaft width are more dimorphic than humerus length and shaft width!

That the dental measurements only show a small intersex difference means that teeth can probably be used as a useful indicator of animal size with little need to worry about any imbalances in the sex ratios of the samples being compared. Figure 9 demonstrates the use of our new method for separating males from females using adjusted measurements taken on
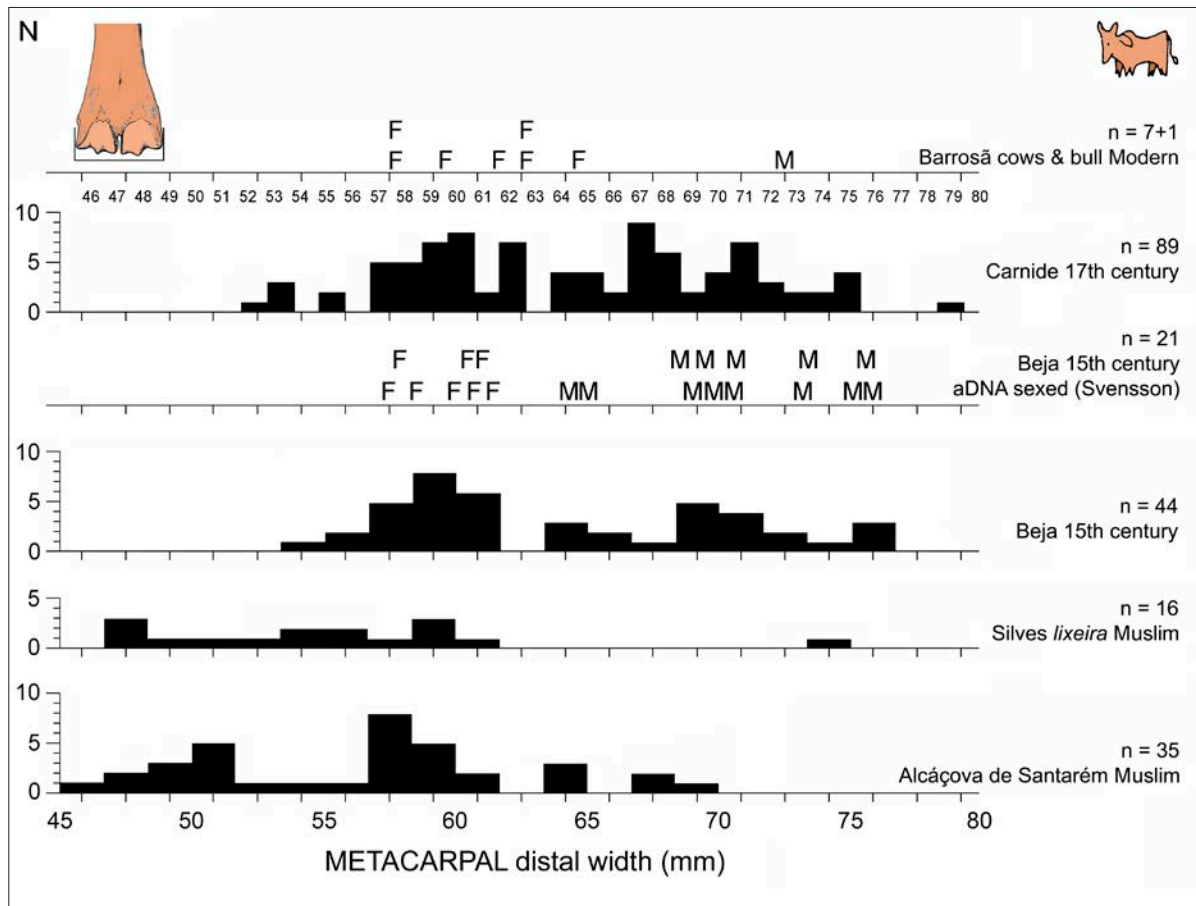
Simon J. M. Davis, Alfredo Sendim

Fig. 6: Variation of cattle size in southern Portugal in Muslim and Christian times. Stacked histograms of measurements of the width of the distal articulation (BFd) of metacarpals from Muslim period Alcáçova de Santarém (9th – 12th centuries); Silves lixeira (rubbish pit; 12th-13th centuries); silos from 15th century Beja; and silos from 17th century Carnide (from figure 1 in Davis *et al.* 2018). The purpose of this graph is to check whether or not chronological average size changes were the result of a change in the sex ratio. "N" refers to sample size. Note that the larger samples from Muslim Santarém and 15th century Beja have bimodal distributions, which, it was presumed, represent the two sexes. For Beja, this presumption could be corroborated by aDNA sexing of 21 of these 44 metacarpals whose sex is plotted above (see Davis *et al.* 2012), M being male and F female. On the top axis are the seven Barrosãs (F) and single Barrosão (M). It was concluded that the bimodal distributions of these measurements at both Beja and Santarém reflect the differences in widths of distal metacarpals between the sexes and therefore the size increase of cattle between Muslim and Christian periods was a real one and not one due to a change of the sex-ratios over time. Note also the apparent wider spread of the male plots. Perhaps some were work animals with splayed distal ends.

the metacarpal, a bone that, as we have seen above, shows a relatively large amount of measurable sexual dimorphism (the 'Watson adjustment'; Davis *et al.* 2018). We are grateful to the mathematical skills of our colleague John Watson for his help. While a simple scatter of plots of metacarpal length (GL – up the 'y' axis) versus distal width (BFd – along the 'x' axis) often shows two reasonably clearly separated clouds of dispersion which probably represent the

sexes offset either side of an oblique line (see fig. 2 in Davis *et al.* 2018). For the 'x' axis, Watson recommended multiplying BFd by 4· 7 and then subtracting the result from GL. This makes the line dividing males from females vertical instead of oblique. Thus for the measurements of the seven female Barrosãs and single male Barrosão, there is a clear left – right separation which had already been indicated using the genetically sexed (from ancient DNA) cattle

metacarpals from Beja (Davis *et al.* 2012). By repeating this plot of metacarpal length versus [(4· 7 x distal width) – metacarpal length] for various collections of Portuguese cattle metacarpals from the Iron Age through to post-Medieval times (Alcáçova de Santarém, Beja and Carnide; fig. 9), it appears that cattle metacarpals (and presumably their carcasses too) became increasingly robust (and perhaps even a little shorter-limbed) from Iron Age+Roman+Muslim times (the red line at 77 mm) to 15th+17th century (the green line at 101 mm). And a further increase probably occurred after the 17th century as the plots for the modern Barrosã cattle indicate (see the graph on the right side of fig. 9) shown by the blue line at 112 mm. One might speculate that this represents local selection for increasingly powerful animals and/or heavier carcasses with a greater yield of meat etc. Let us now go further back in time and view *Bos* size variation from the end of the Pleistocene until modern times.

5.2. *BOS* FROM LATE PLEISTOCENE TO MODERN TIMES IN PORTUGAL

[for clarity, samples are grouped within coloured rectangles, squares or ellipses in the chronological sequences in figures 10 and 11].

Having now established our baseline of measurements for the 8 Barrosã cattle and understood how their sexes differ, figures 10 and 11 show measurements of metacarpals and astragali respectively from archaeological sites in Portugal that date from the late Pleistocene (at the bottom) until the present day (at the top). Sample sizes for metacarpals are generally small due to their often poor preservation with medial and lateral condyles broken away from one another. However, the advantage of considering measurements (such as BFd) of this bone is that we can easily see if average size variations are the result of a bias in the sex ratio as in figure 6 which shows reasonably clearly that the Muslim to 15th century size increase occurred in both sexes. And as suggested, reflects improvements undertaken by the Christians following the *reconquista*. The advantage of using astragali is that this bone is compact and often well preserved. Hence archaeological samples often contain numerous measurable astragali.

Measurement	Male - Female % difference	Measurement	Male - Female % difference
Metatarsal - GL	2,8	Metacarpal - DIM	16,9
M_3 - Wb	3,7	Astragalus - Bd	17
Metacarpal - GL	5,3	Metacarpal - DVL	17,1
M_3 - Wa	6,4	Metacarpal - DEM	17,7
Astragalus - GLl	7,3	Metatarsal - BFd	18,3
M_3 - length	7,9	Metacarpal - DIL	18,5
Scapula - ASG	8,1	Humerus - HTC	18,5
Tibia - GL	10,7	Metacarpal - BFd	19
Metatarsal - DIM	11,2	Metacarpal - DEL	19,6
Astragalus - DI	11,3	Humerus - SD	20,2
Radius - GL	12	Radius - Bp	21,1
Calcaneum - GL	12,1	Metacarpal - BFp	21,2
Metatarsal - DIL	12,3	Tibia - SD	21,8
Humerus - GLC	13,1	Humerus - HT	22,3
Radius - BFp	14,1	Metacarpal - WCM	22,9
Tibia - Bd	15,8	Femur - SD	23,8
Tibia - Dd	15,9	Metatarsal - SD	24
Metacarpal - DVM	15,9	Scapula - SLC	25,6
Femur - GLC	16,3	Radius - SD	30,3
Humerus - BT	16,8	Metacarpal - SD	30,6
Metacarpal - WCL	16,8		

Fig. 7: Sexual dimorphism. The differences between the average of the seven female measurements and those of the single male, expressed as a percentage, in order of magnitude calculated from fig 5. Measurements at the top show little difference between sexes while those at the bottom show greater differences. Note that the third molar tooth shows a very slight amount of dimorphism as do most long-bone lengths. Bone widths however show substantial differences with the shaft width of the radius and metacarpal showing the greatest inter-sex difference.

THE PLEISTOCENE – HOLOCENE CHANGE

The two metacarpals from the Magdalenian and the single astragalus from the Solutrean at Vale Boi [in the mauve squares] are very clear outliers. Since they are pre-Neolithic (and Pleistocene) it is safe to assume these bones belonged to aurochsen. They are massive compared to aurochsen from the Mesolithic (early Holocene) [in the green rectangles]. This Pleistocene – Holocene dwarfing of aurochsen probably reflects changes in environmental conditions such as temperature and/or resources.

Two important factors known to affect mammalian body size are environmental temperature/thermoregulation and resource availability. With regards to the first, many mammals and birds show a
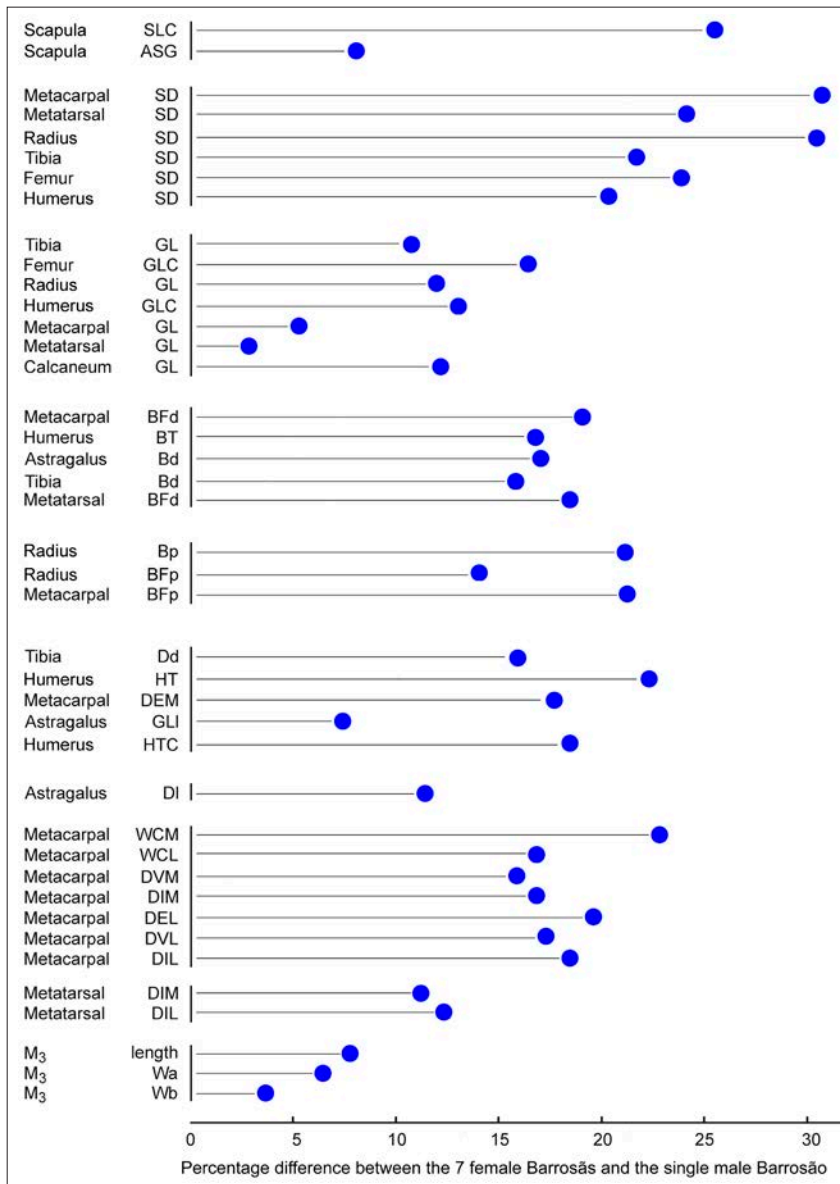
Fig. 8: Barrosãs and the Barrosão – sex-dependent size differences for the various measurements of the lower third molar tooth and nine limb-bones. Differences expressed as a percentage between the average values of the measurements of the seven Barrosãs and the single Barrosão. The vertical "0" line represents the means of the seven cow measurements. The distances between this line and the blue circles represent the percentage differences between the two sexes. The raw data are in fig. 4 and are grouped as for the sheep in Davis (2000) and interestingly show a very approximately similar pattern of sexual dimorphism for the different measurements. It is clear that while long-bone shaft widths show considerable inter-sex differences the lower third molar tooth and metapodial lengths show very little difference.

clear increase in body size with latitude – often used as a proxy for temperature – a trend that was first observed by Carl Bergmann in 1847 and which is now referred to as Bergmann's rule. It is one of several ecogeographical rules and states (see Salewski and Watt 2017) that within species and amongst closely related species of homeothermic animals a larger size is often achieved in colder climates than in warmer ones, which is linked to the temperature budget of these animals (Rensch 1959: 40-46; Mayr 1963: 318-324). It has been criticised, most notably

by McNab (1971), Geist (1987) and Dayan *et al.* (1991). Ashton *et al.* (2000) however, demonstrated that most species of mammals do indeed show an inverse relationship between their size and the temperature of the environment. The actual cause of this apparent relation between body size and temperature is much debated and Ashton (2002) admits that the processes responsible for Bergmann's rule "remain somewhat of a black box". A consideration of geometry provides a plausible and logical explanation as Bergmann (1847) had suggested. Volume,
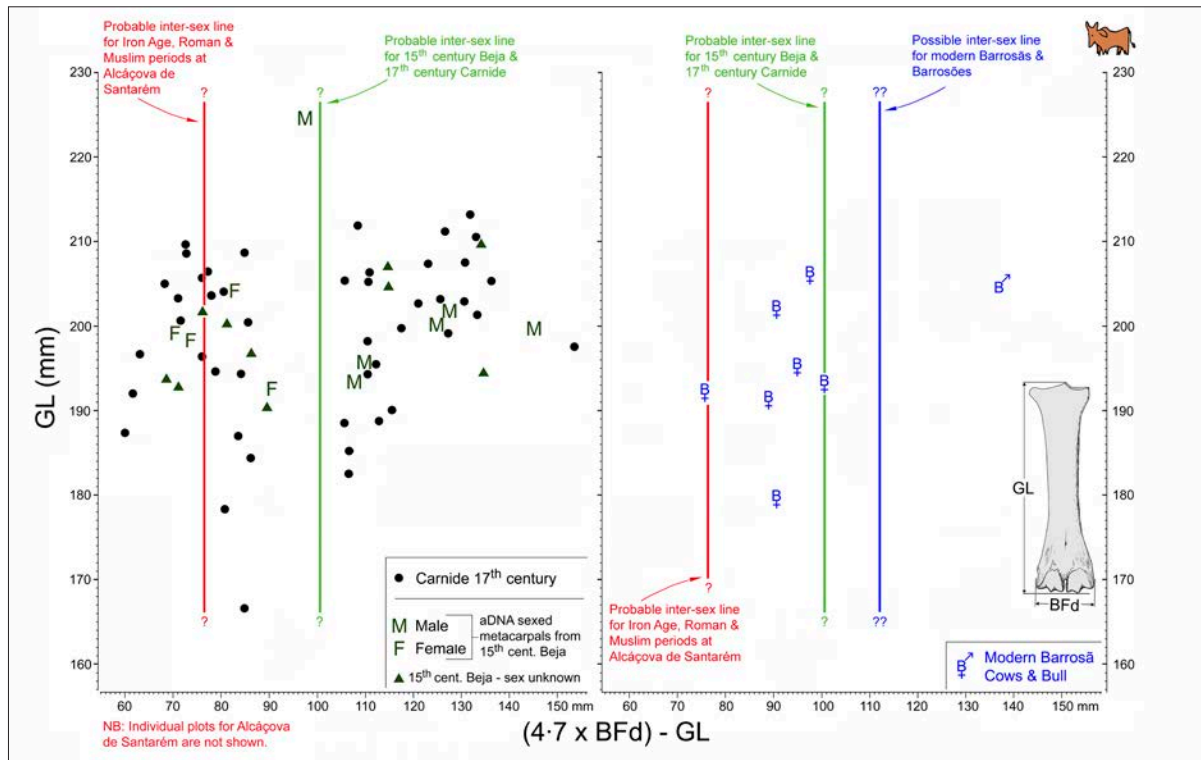
Fig. 9: A plot of the greatest length (GL) of metacarpals against the value obtained by multiplying metacarpal distal width (BFd) by 4.7 and then subtracting the result from GL (the 'Watson adjustment'; John Watson pers. comm.). This has the effect of rotating the intersex dividing line so that it becomes vertical instead of oblique. These lines have values that lie between approximately 75 and 115 mm. On the left graph are the 17th century Carnide metacarpals shown as black solid circles and the 10 aDNA sexed and 10 unsexed ones from 15th century Beja (Davis *et al.* 2012) shown as dark green tri-angles and letters 'F' and 'M' respectively. It is clear that measurements of the Carnide and Beja specimens group (with one exception) into two distinct clouds – presumably the females on the left and the males on the right. On the right graph, and shown in blue, are the seven modern Barrosã cows and the single Barrosão bull. These have shifted to the right in comparison with the Carnide and Beja specimens; i.e., they have wider values for BFd. The intersex line for Beja and Carnide is shown in green while the guesstimated line for the Barrosã is shown in blue. A consideration of the intersex line for Iron Age, Roman and Muslim period cattle metacarpals from Alcáçova de Santarém (individual plots not shown; data in Davis 2006) is shown in red in both graphs and is probably some 24 mm to the left of the Beja/Carnide inter-sex line. Thus it appears that there was a gradual shift to the right from approximately 77 mm (Iron Age, Roman and Muslim Santarém) to approximately 101 mm (Beja and Carnide) to very approximately 112 mm (eight modern Barrosã).

which produces heat, increases to the power 3. Surface area, which dissipates heat, only increases to the power 2. Hence a large body has a relatively small surface area and should be a better conserver of heat in a cold environment. Conversely, a small body with relatively greater surface area will be able to lose heat more efficiently. Herreid and Kessel (1967) demonstrated that by doubling body weight mammals and birds can lower heat loss per unit weight by 30 per cent. However, mammalian body size may be linked with another important factor

– resource availability – especially while the animal is growing (Geist 1987; 1998; Klein and Cruz-Uribe 1996; Wolverton *et al.* 2009; Huston and Wolverton 2011). Resources are often more abundant in temperate regions where soils are rich and plant growth rapid in the growing season. In the tropics soils are often infertile and in the Arctic the growing season is short. If so, then temperature only acts indirectly. North of latitude 60º, presumably where food is in short supply, reindeer decrease in size (Geist 1998: fig. 1-9). In their study of geographic clines in body
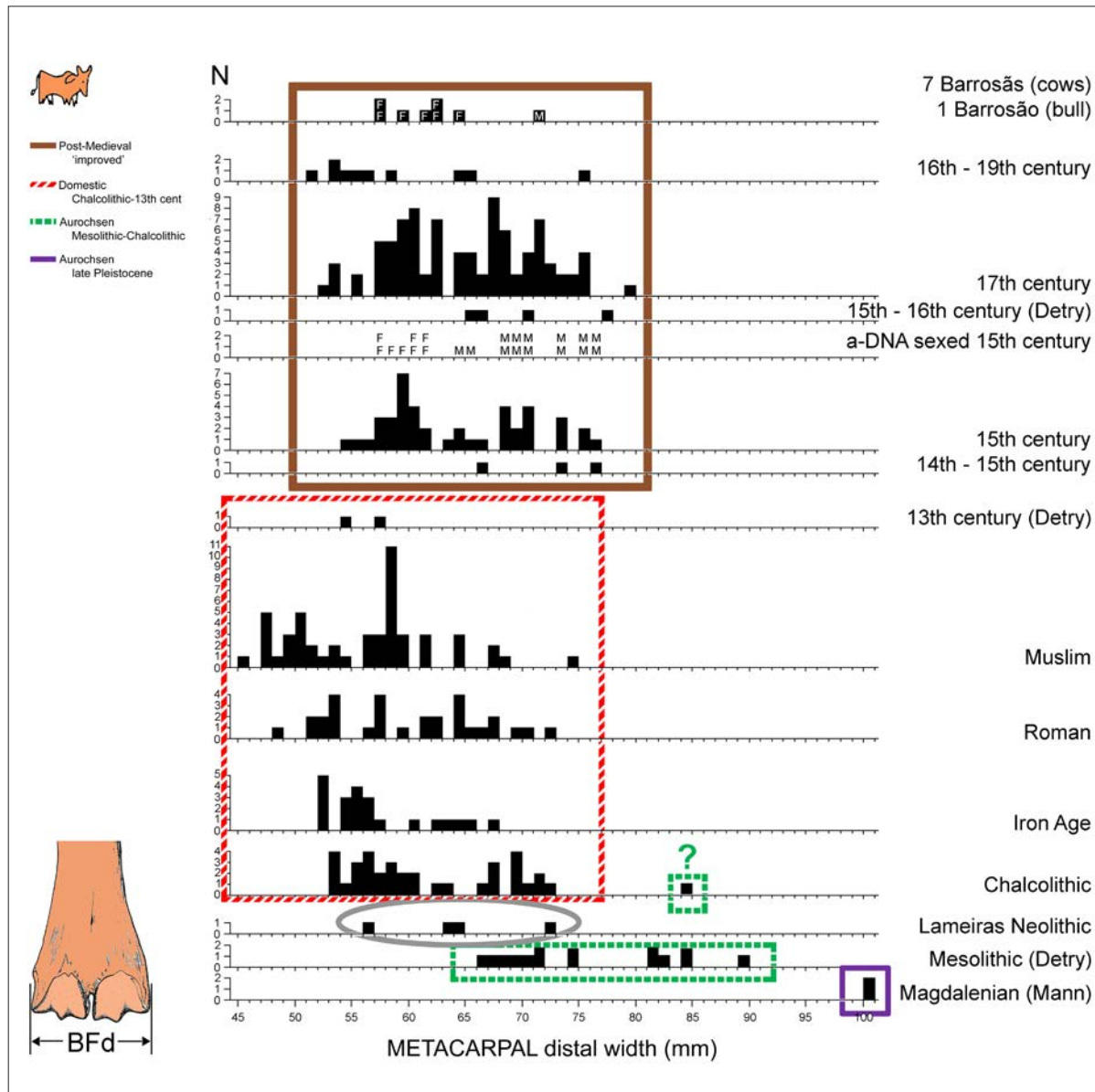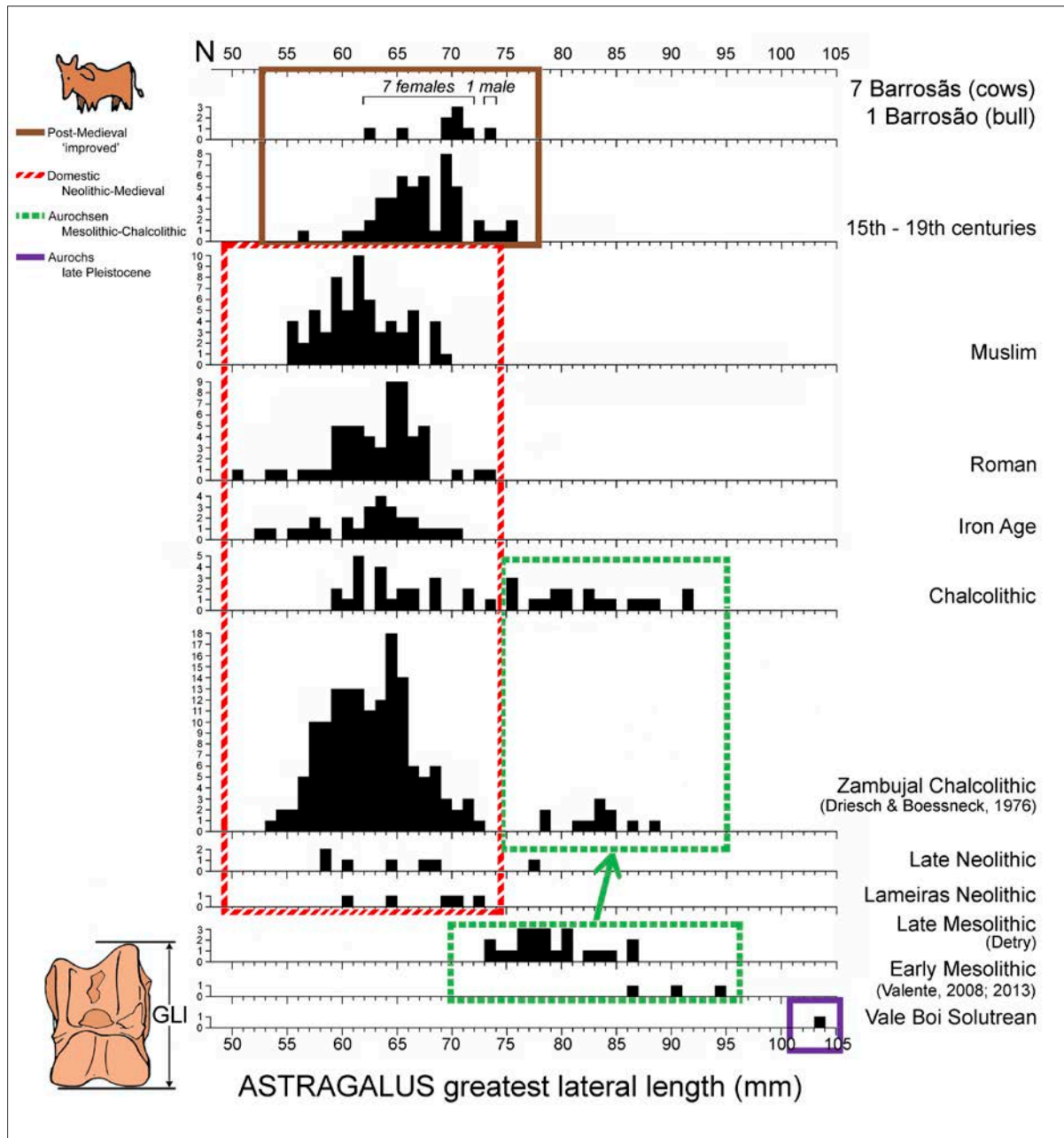
Fig. 10: Chronological changes in size of Bos (aurochs and cattle) in Portugal modified from figure 4 in Davis et al. (2018). These are stacked histograms of measurements of the width of the distal articulation (BFd) of metacarpals. "N" refers to sample size. The seven female and single male Barrosãs are shown at the top and further down are the 21 ancient DNA sexed Beja metacarpals (see Davis et al. 2012). The two very large Magdalenian specimens enclosed in the mauve square are from the late Pleistocene at Vale Boi. Their very large size probably reflects the cold environment in accordance with Bergmann's rule. Aurochsen from Mesolithic and a single probable aurochs from the Chalcolithic are enclosed in green rectangles. The Neolithic cattle from Lameiras are enclosed in a grey oval and are presumed to have belonged to domestic cattle, although of course the large one could also have belonged to an aurochs. Domestic cattle from Chalcolithic to 13th century AD are enclosed in a red rectangle. Cattle from the 14th/15th century onwards appear to be slightly larger and are enclosed in a brown rectangle and probably reflect Christian improvements of this animal after the reconquista (see also Figure 1). The lack of aurochs metacarpals from Chalcolithic sites (there may only be one from São Pedro, Redondo) makes it difficult to see the Mesolithic - Chalcolithic size increase observable in the astragali (see figure 8).

Fig. 11: Chronological changes in the size of Bos (aurochs and cattle) in Portugal modified from figure 5 in Davis *et al*. (2018). These are stacked histograms of measurements of the greatest lateral lengths (GLl) of astragali. "N" refers to sample size. The Solutrean (late Pleistocene) specimen enclosed in the mauve square is from Vale Boi. Its very large size probably reflects the cold environment in accordance with Bergmann's rule. Aurochsen from Mesolithic and Chalcolithic sites are enclosed in green rectangles. These, it is speculated, show decrease in size during the Mesolithic, and a subsequent small recovery of larger size after the Neolithic as indicated here by an arrow. These Mesolithic to Chalcolithic variations in size may reflect the degree of hunting pressure. Presumed domestic cattle (from the Neolithic to Muslim times) are enclosed in a red rectangle and cattle from post-Muslim times are enclosed in a brown rectangle. These appear to be slightly larger and probably reflect Christian improvements of this animal after the *reconquista* (see also figure 1).

weight of Norwegian red deer, Langvatn and Albon (1986) concluded that these reflect clines in the productivity and quality of plants. Some studies suggest both temperature and resource availability are important factors. And according to Martin *et al.* (2018); a "negative relationship between body mass and global temperature may reflect underlying relationships between body size and net primary production as well as heat loads."

Today many mammals like the wolf, fox, black backed jackal, ermine, hare, rabbit, moose, wild boar, bison, and even humans, to name just a few, are known to be larger in colder regions and smaller in warmer ones (Hall 1951; Schreider 1964; Harrison 1972: 385-397; Davis 1981; 2019; Klein and Cruz-Uribe 1984; Sand *et al.* 1995; Katzmarzyk and Leonard 1998; Ruff 2002; Foster and Collard 2013; Martin *et al.* 2018). Some studies also demonstrate a chronological variation of size possibly due to the same factor(s). For example Klein and Scott (1989) studied hyaena remains from caves in Britain as well as modern African hyaenas. They note that during glacial maxima *Crocuta* in Britain was larger than during inter-glacial times. In Africa today this animal's carnassial length (an indicator of its body size) increases with latitude. Both these trends, they suggest, are examples of the inverse relation between body-size and temperature predicted by Bergmann's rule. Dwarfing of many lineages of fossil mammals and birds at the end of the Pleistocene was probably world-wide. Martin *et al.* (2018) studied bison size via the lengths of 849 calcanea from 60 late Pleistocene to modern sites in North America and show that this animal decreased substantially in size at the end of the Pleistocene.

Thus while an inverse correlation between body size and environmental temperature is well known in many species of homeotherms (Ashton *et al.* 2000), the explanation remains unclear. While many of these studies may reflect thermoregulatory selection on body size; few have attempted to test this against other potential drivers of the observed trends, such as nutritional factors. I too have reservations about a direct link between temperature and body size (see Davis 1981). Whether the large size of Portuguese late Pleistocene aurochsen, like contemporary red deer and rabbits (Davis 2019), reflects higher carrying capacity or simply the need to maintain

body warmth remains to be tested. Grigson (1969) noted that post-glacial Hungarian aurochsen were slightly smaller than aurochsen from Britain and Denmark which she suggested might be an example of Bergmann's rule. In their study of the geographic variation of aurochsen in Europe, Wright and Viner-Daniels (2015) also noted that aurochsen apparently obey Bergmann's rule: Italian aurochsen from MIS 9 were smaller than contemporary English ones and southern European early Holocene aurochsen were smaller than contemporary aurochsen from northern regions.

THE WILD VERSUS DOMESTIC DISTINCTION

That domesticated animals differ in size from their wild ancestors/cousins is well known (Darwin 1885). Cattle, pigs, goats and sheep are all smaller than their wild progenitors – aurochsen, wild boar, wild goats and mouflon respectively. And domestic rabbits are larger than wild ones. But why should this be? For animals like cattle and pigs Boessneck and Driesch (1978) suggested that diminution was due to early peoples' preference for large numbers of small and perhaps therefore more easily managed animals over a few large intractable ones. In their initial attempts at capturing and taming wild mammals like the boar and aurochs, people may have preferred to select smaller individuals. Another possible reason may simply have to do with size being linked (perhaps genetically) with a factor or factors that early people purposefully selected for. In Novosibirsk in the 1950s, Dmitry Belyaev and Lyudmila Trut began their now famous "fox breeding experiment" (Trut 1999; Dugatkin and Trut 2017). They selected for one character only – docility. After a mere 15 – 20 generations they succeeded in obtaining docile foxes. Besides this change of behaviour they also noticed that these animals were smaller.

Size is probably the most widely used means of separating bones of domestic animals from those of their wild relatives (for cattle versus aurochs see Grigson 1969). One example of this in zooarchaeology is Higham's (1968) study of cattle and pigs in Swiss and Danish sites. He demonstrated significant size differences between bones of the domesticated forms of these two animals and those of their wild ancestors.

Figure 11 shows more clearly the extent to which it may be possible to distinguish metrically between Holocene aurochs and cattle, thanks to the large sample of astragalus measurements from Chalcolithic Zambujal published by Driesch and Boessneck (1976). If we look closely at the plots for the Zambujal astragali they form two quite distinct peaks with no apparent overlap between them. The 11 large specimens that presumably belonged to aurochsen, and the 150 smaller ones presumed to have belonged to the domesticated form of this animal, are quite separate. There is, for this measurement of this bone, a clear gap between the two peaks. As Driesch and Boessneck (1976) suggested, in their 'Diagramm 2', astragali with GLl greater than 75 mm belonged to aurochsen, and those less than 75 mm, belonged to cattle. In her figure 11, Grigson (1969) also demonstrates a gap in the distribution of astragalus lengths between, on the one hand, two English Neolithic sites and, on the other hand, post-glacial aurochs from northern Europe. As a general rule however, the *Bos taurus* v *B. primigenius* distinction is less clear cut and there is often some overlap of the measurements of these two forms. It may therefore be dangerous to rely on a single measurement to make a definite identification 'wild' or 'domestic'.

The four metacarpals from Neolithic Lameiras [in the grey ellipse] and five astragali also from Neolithic Lameiras are, on average, small and similar to Iron Age and Roman cattle and presumably most or all belonged to domesticated *Bos* – perhaps the earliest known from Portugal. Of these, two astragali are from the Early Neolithic, and a metacarpal also is from the Early Neolithic of Lameiras. They are all too small to have belonged to aurochs. Thus we can be fairly sure that domestic cattle were already being herded in Portugal around 5450 years BC – the ^{14}C date obtained for several sheep bones from the same stratum (Davis *et al.* 2018).

THE SURVIVING AUROCHSEN AND THEIR EVENTUAL EXTINCTION

Note (fig. 10) that in the Chalcolithic there is a single large metacarpal [in the green square] that probably belonged to a surviving aurochs. After the Chalcolithic the distribution of the metacarpal distal widths and the astragali lengths (fig. 11) are similar to the distributions of plots of the smaller-sized specimens (the presumed domestic cattle) at Chalcolithic Zambujal. They all presumably belonged to domestic cattle and the absence of any large outliers undoubtedly signifies the absence of aurochsen and therefore the possible local extinction of this animal during or soon after the Chalcolithic, even though aurochsen were present elsewhere like 17th century Poland. Zooarchaeologists should however be on the lookout for surprises and who knows whether aurochsen did indeed survive, even if in small numbers, into later times.

AUROCHS SIZE CHANGES DURING THE MESOLITHIC AND CHALCOLITHIC

When we look closely, especially in the case of the astragalus measurements, at the plots of the lengths of this bone from the Mesolithic and Chalcolithic, it is possible to discern two small but extremely interesting trends that prompt speculation concerning a possible size reduction of the aurochsen during the Mesolithic followed by a small size increase of aurochsen during the Chalcolithic. The reduction during the Mesolithic may be demonstrated by the larger size of the three early Mesolithic specimens and the smaller size of the 22 late Mesolithic specimens (for more details see Davis *et al.* 2018). One possible interpretation of this decrease of size during the Mesolithic is that it was caused by increasingly intense hunting of the aurochsen during this period due to an increase in the human population – an increase that would eventually force people to change their relationship with the natural world and begin domesticating food animals and plants. This was followed after the Mesolithic and presumably during the Chalcolithic by a partial restoration of the aurochs' former size by an amount that is statistically significant. This was due to a relaxation of the intense hunting pressure of the Mesolithic (Davis and Mataloto 2012; Davis and Detry 2013). With domesticated animals now being close to hand, this new secure source of animal protein brought about a relaxation of hunting pressure upon the large mammals like aurochsen allowing their size to partially recover. Note the small peak of 11 astragali (presumed aurochsen [enclosed at the bottom of the upper green rectangle in figure 11]) at Zambujal which are slightly larger on average than their Mesolithic predecessors. (This of course assumes
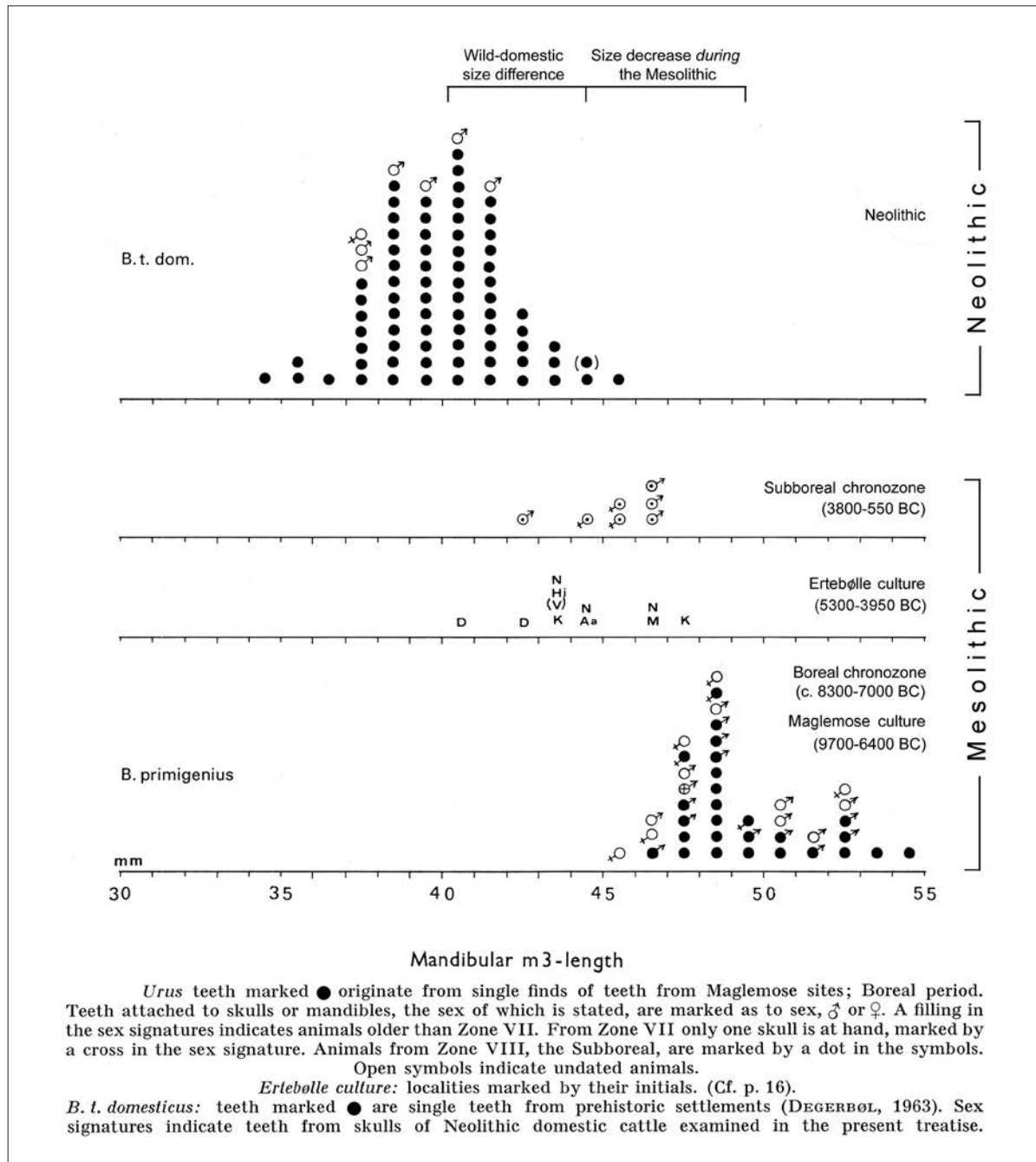
Fig. 12: The lengths of Danish aurochsen and cattle lower third molar teeth in Denmark. A modified version of Magnus Degerbøl's figure 17 (in Degerbøl & Fredskild 1970) showing that aurochsen in Denmark underwent a decline in size during the Mesolithic. I have transferred the aurochs M3s from the Subboreal chronozone onto a separate axis and are similar in size to the Ertebølle (late Mesolithic) specimens. Both these Subboreal and Ertebølle ones are smaller than those from the Boreal chronozone (early Mesolithic, Maglemose culture). Thus aurochsen lower third molar teeth in the early Mesolithic are larger than those from the late Mesolithic. The dates have been revised by Ola Magnell (pers. comm.). The original legend is also reproduced at the bottom. Note the possibility that some of the Ertebølle teeth may have belonged to cattle (Gotfredsen, pers. comm.).

that the 75 mm dividing line correctly separates wild from domestic forms!) Note the approximate increase in the mean value of astragalus GLl from *c.* 79 mm in the Late Mesolithic to *c.* 83 mm in the Chalcolithic of Zambujal – the latter value being the average GLl of the 11 presumed aurochsen at that site. A similar pattern of size reduction followed by a partial restoration of the size of aurochs is now recognised in the eastern Mediterranean (work in progress). Admittedly there are too few specimens to draw any definitive conclusions, but they do beg the question – does this reflect size decrease of aurochsen during the Mesolithic? It is also interesting to look closely at figure 17 of Degerbøl and Fredskild´s (1970) graph of lower third molar tooth measurements of aurochsen from the Boreal/Maglemose versus those from Subboreal/Ertebølle (i.e., Early versus Late Mesolithic). A redrafted version of their graph is reproduced here as figure 12. They too show a small decrease in size during the Mesolithic. Note that the specimens from the Maglemose culture (Early Mesolithic) and Boreal chronozone dated to 9,700-6,400 BC are larger than those from the Ertebølle culture and Subboreal chronozone dated to 5,300-550 BC. Anne Birgitte Gotfredsen of the Copenhagen Natural History Museum tells me that since Degerbøl's work was published, many of the Ertebølle shell-midden specimens have been found to be derived from domestic rather than wild animals. However Degerbøl's sexed Subboreal aurochsen deriving from Jutland (the Danish mainland, and in contact with the European mainland) are indeed smaller than the Boreal (Maglemosean) aurochsen. Clearly the subject of Mesolithic aurochsen requires new studies but Degerbøl's results are presented here as a possible parallel example of what could have been happening in Portugal.

It is therefore possible that over a period of several millennia the aurochsen both in Denmark and here in Portugal underwent a gradual size decrease due to overhunting and subsequently (in Portugal at least) recovered some of their former size. Confirmation of intense predation leading to a reduction of body size in the course of time is difficult to find in the literature. There are, however, a small number of studies that demonstrate overhunting leading to body size reduction in modern mammals. It is possible to envisage that hunters select the largest animals with their more impressive trophies and/or greater amount of meat, leaving the smaller ones to transmit their genes to subsequent generations (Miłkowski and Wójjcik 1984; Coltman *et al.* 2003). One could then explain the partial return of aurochs large size during the Chalcolithic as reflecting an 'inverse' selection by predators such as wolves and big cats who may have selected out the smaller individuals.

POST-MEDIEVAL IMPROVEMENT OF CATTLE

Note (fig. 10 and 11) that the Chalcolithic to 13th century astragali and metacarpals [enclosed in the red rectangles] are small and of similar size to the Neolithic specimens. These are all presumed to have belonged to domestic *Bos*. However, specimens from the 14th/15th centuries to modern times [in the brown rectangles] tend to be slightly larger. This, as mentioned above (and see fig. 6), probably reflects improvements by Christians after the *reconquista*.

Instead of considering specific measurements of individual bones such as Metacarpal BFd and Astragalus GLl, measurements of several bones from various Moslem period sites were compared with measurements of several bones from various post-*reconquista* sites in Portugal using the seven female Barrosãs as a baseline. The logarithm of the ratio between a measurement and its standard, given in fig. 5, was calculated. This is the "log ratio method" of George Gaylord Simpson (Simpson *et al.* 1960: 356-358). For example if an archaeological *Bos* astragalus Bd measures 39,2 the $\log_{10}$ ratio is the log of the result of dividing 39,2 by the Barrosã standard which for this measurement is 41,8. Thus the $\log_{10}$ ratio is -0,028. Log ratios of numerous measurements can then be pooled and portrayed on a graph. Figure 13 shows separate treatments of length measurements (on the left) and width measurements (on the right) of humerus, metacarpal, tibia, metatarsal, astragalus and calcaneum. This separate consideration of lengths and widths was done because, in sheep at least, measurements taken along the same axis – length, width or depth – are quite highly correlated, but measurements taken along different axes tend to show lower correlation (Davis 1996). The measurements taken are: for lengths – metacarpal-GL, astragalus-Dl, metatarsal-GL, and calcaneum-GL. And for widths: humerus-BT, metacarpal-SD and BFd, tibia-Bd, astragalus-Bd, and metatarsal-SD and BFd. The
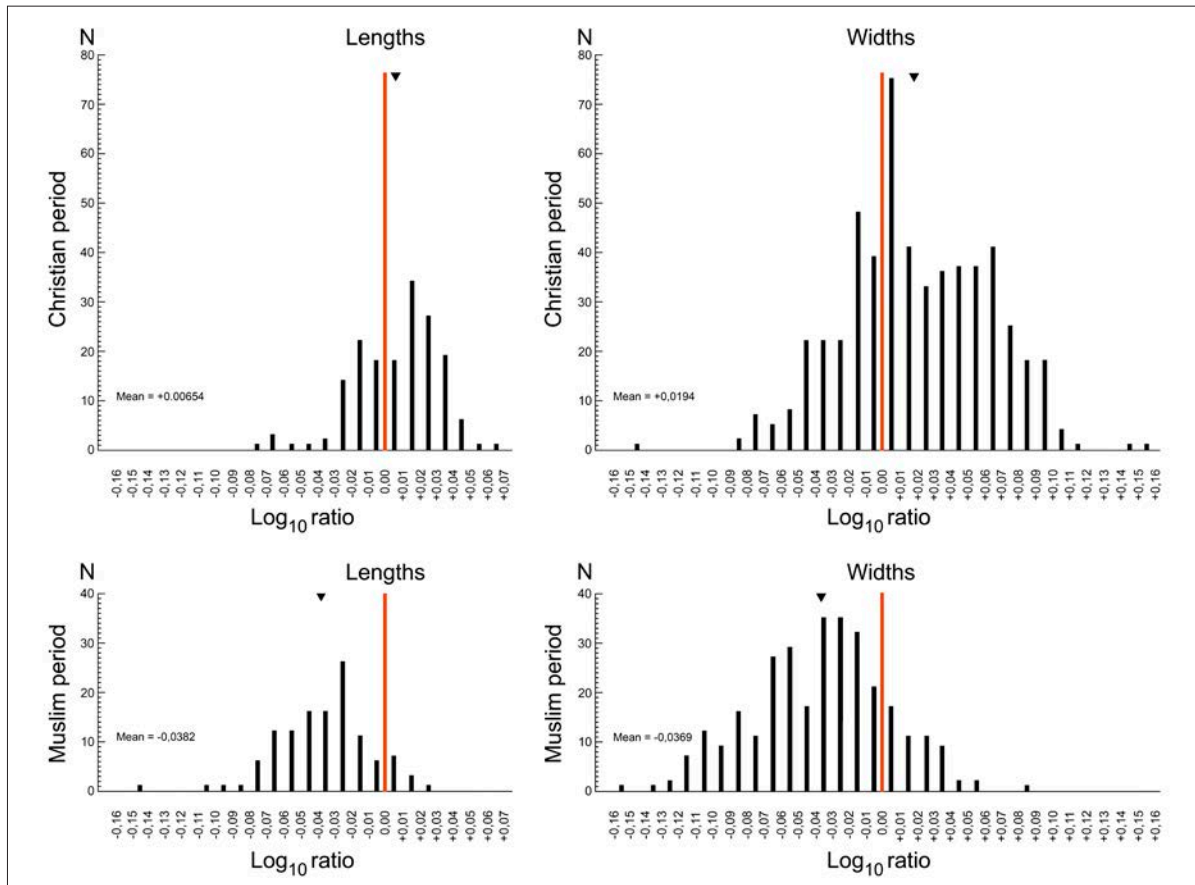
Fig. 13: Log ratio diagrams to show the size increase of Portuguese cattle between the Moslem and Christian periods. Widths are pooled and treated separately from pooled length measurements in an attempt to discern whether cattle simply became more robust only, or taller only or both. The vertical red line – the "0.00" line - is the average value for the seven female Barrosã – our baseline. Measurements are pooled as follows. 1. Lengths – metacarpal-GL, astragalus-Dl, metatarsal-GL, and calcaneum-GL. 2. Widths - humerus-BT, metacarpal-SD and BFd, tibia-Bd, astragalus-Bd, and metatarsal-SD and BFd. Mean values are shown as inverted triangles.

pooled results indicate quite clearly that both bone lengths and bone widths increased between Moslem and Christian times. There is some evidence that widths increased to a slightly greater extent than lengths; 0,056 versus 0,045.

The question we need to ask is why did the Christians of Portugal improve their cattle? What happened between the Muslim occupation of Portugal and the Christian *reconquista*? It is well known that within the Muslim world mutton is highly regarded, a preference that explains why sheep in Portugal were improved under the Muslims (Davis 2008). Glick (1979: 103) suggests that once the Christians took over southern Portugal, a shift in emphasis

from mutton to wool occurred. Klein (1920: 25) too, writing about Christian Spain, noted that the consumption of mutton became uncommon. He provides two explanations. First, the seasonal migrations of the *merinos* made their meat tough and this sheep was regarded as being more valuable for its wool. Second, in place of mutton much pork was eaten – this due to its high quality because of the abundance of acorn fodder, and its consumption removed suspicions of Judaism. In her history of Iberian husbandry, Gerbet (2000) emphasises how wool production really took off in the Iberian Peninsula in medieval times. Indeed in 1273, Alfonso el Sabio (1221-1284) established the Mesta, the powerful association of

sheep holders, in Castile (Klein 1920). In other words Christianity provided the impulse for breeding cattle (as well as pigs) with heavier carcasses with greater meat yields. Today at least, the famous meat breeds of cattle, in contrast to the dairy breeds, are characterized by their wide limb-bones (see for example Guintard 1998). With the establishment of the new Christian kingdom of Portugal, it is plausible that the Crusaders, many of whom came from the north, introduced new and bigger breeding stock from their homelands. The father of D. Afonso Henriques (1111-1185), first King of Portugal, hailed from Burgundy.

One other speculation is that for the Christians cattle were a source of power (and perhaps a symbol of status too!) for ploughing the now enlarged estates (due to the demographic losses incurred during the terrible pestilences of the 14th and 15th centuries). Hence the Christians bred larger and therefore more powerful animals. Indeed, de Oliveira Marques (1968) wrote that although known in earlier times, the 'Arado Quadrangular or Charrua (Quadrangular, or Chariot plough), which was pulled by oxen or cows, became widespread in Portugal in the 14th, 15th and especially the 16th centuries. This plough, of Nordic origin, was more complex and stronger than its predecessors and well adapted to wet and heavy soils.

In many parts of Europe there is now substantial zooarchaeological evidence indicating that livestock and even fowl were improved in later Medieval and post-Medieval times (Albarella and Davis 1996; Audoin-Rouzeau 1997; Clavel et al. 1996; Davis and Beckett 1999; Matolsci 1970). A pre-15th century AD date for improved cattle in Portugal is indeed somewhat early in comparison and may indicate an advanced state of farming here at that time. However, more recent zooarchaeological investigations by Thomas (2005) are revealing evidence for agricultural changes as early as the 14th century in England as Dyer (1981) had found in his studies of the documentary evidence. Like Dyer, Thomas links these 14th century improvements with the Black Death (1348-1350) and the resulting demographic decline, and suggests that the demand to feed an expanding population had dissipated and the market in grain crashed. Animal husbandry became a viable alternative being less labour intensive but requiring more land. And land became plentiful following the effect of the Black Death. A possible chain of explanations

for these 14th century changes in England which these authors propose include a downward social distribution of access to land and the tendency for peasants to become landowners. Peasants who were in more ''intimate contact'' with animals were better able to take ''technological initiatives''. A similar 14th century crisis and disease induced demographic decline in Portugal (de Oliveira Marques 1980: 27-28) can be cited here to explain the apparent improvement of Portuguese cattle. According to Gerbet (2000: 306): *La crise de la deuxième moitié du XIVe s. et du début XVe s. entraîna une diminution du sol cultivé et une croissance de l'élevage et des pâturages*. Such a line of reasoning, although very speculative, does at least provide a link between the demographic crisis and an improvement of cattle.

In sum, the measurements of *Bos* bones from late Pleistocene to recent Portugal fall into five different size-groups as shown in figures 10 and 11. Each group is enclosed in coloured rectangles as follows:

1) Late Pleistocene aurochsen: very large (mauve box).

2) Mesolithic aurochsen: considerably smaller than late Pleistocene aurochsen. They may have become smaller during this period (green rectangle).

3) Chalcolithic aurochsen: still considerably smaller than late Pleistocene aurochsen but slightly larger than their Mesolithic ancestors (another green rectangle above the former).

4) Neolithic to Muslim period cattle: even smaller than Mesolithic aurochsen (red rectangle).

5) Post-Muslim period (i.e., following the Christian *reconquista*) cattle: slightly larger than Medieval-Muslim period cattle but never as large as aurochsen (brown rectangle).

6. SOME FINAL WORDS

Late Pleistocene aurochsen were considerably larger than their Holocene descendents. The Pleistocene-Holocene size reduction occurred at the same time as other mammals both here in Portugal and elsewhere in accordance with Bergmann's rule. Whether this was due to a direct effect of the temperature with larger body size and hence relatively less surface area being an advantage in cold Ice Age conditions or whether it simply reflects a greater abundance

of resources in the late Pleistocene, remains to be tested. During the Mesolithic aurochsen may have undergone a further reduction of body size (as they appear to have done in Denmark) which, we speculate, reflects overhunting. The evidence is slim as we still have very few data. By Early Neolithic times (*c.* 5450 cal. BC) even smaller bones of *Bos* evidence the presence of cattle (i.e., domestic aurochs) in southern Portugal. Cattle bones remained, on average, approximately similar in size through to Medieval times. The Chalcolithic aurochs, probably the last survivors of this magnificent beast in Portugal, were slightly larger than their Mesolithic ancestors. This, we speculate, reflects a relaxation of the overhunting that they had been subjected to in Mesolithic times due to the increased numbers of people. The subsequent relaxation of predation was due to the arrival in Neolithic Portugal of a reliable source of meat in the form of domestic food animals. After the *reconquista*, it seems cattle became more robust and our small collection of Barrosã skeletons shows an even greater robustness. These cattle were improved – they underwent selection for great carcass weight and increased power for ploughing and transport.

This study is a preliminary version of part of a long term one of the large mammals of late Pleistocene to modern Portugal and adjacent parts of Spain to be undertaken by various zooarchaeologists. Besides aurochsen/cattle, it is planned to include taxa such as red deer, goats (wild and domestic), sheep and wild boar/pig. As it is geographically fairly restricted to the south-western part of the Iberian Peninsula, we shall be able to control any geographical variation of these taxa hence leaving chronological variation. As we demonstrate here, it should be possible to discern the effects of several different selective forces that have played their roles in affecting the size of large mammals during the last 30,000 years. For those taxa that were domesticated like *Bos*, *Capra* and *Sus* it should also be possible to discern when their domestication occurred here or (more probably) when their domesticated forms were introduced.

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