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Osteometric study of the metapodials of Amsterdam Island feral cattle

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The analysis of fossil and sub-fossil bones of wild *Bos primigenius* Bojanus, 1827 and domestic cattle *Bos taurus* Linnaeus, 1758 has been handicapped by the absence of modern comparative material. The feral cattle of Amsterdam Island have lived in the wild since 1871 and have been free from artificial selection since that period. We give here a complete description of metapodial bones of this population in order to offer archaeologists a modern comparative material with patterns of sexual dimorphism and extent of intra- and inter-individual variability. This work is based on the measurements of 90 sets of 4 metapodials belonging to 48 adult females and 42 adult males. We show that the cattle of Amsterdam Island are morphologically homogeneous, thus probably forming a single breed. Sexual dimorphism is important and was studied by univariate comparisons and ordination techniques. A discriminant analysis revealed that differences in depth of diaphysis alone could correctly classify 96.7% of individuals as far as metacarpal bones are concerned, whereas differences in breath of distal end alone could correctly classify 91.1% of individuals when metatarsal bones were measured. Inclusion of two more variables increased the accuracy to 98.8% and 97.8% of individuals correctly classified for metacarpal and metatarsal bones, respectively. Allometric relations within sexes are described and should prove to be usefull to archaelogists who work with fragmentary material and wish to estimate lacking measurements. Comparisons of size and shape of metapodial bones with data from the literature reveal that the feral cattle of Amsterdam Island are smaller than aurochs and recent breeds of domestic cattle, but that they compare well with old breeds of domestic cattle and also recent breeds of *Bos indicus* living in Africa.

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Introduction

Considerable difficulties exist in the differentiation of the bones of aurochs and domestic cattle (Kobryń and Lasota-Moskalewska 1989). This problem is of essential significance for the determination of the earliest date of cattle domestication, since bones found in archaeological sites of a given period can not always be classified on the basis of size either as aurochs or as any of the forms of domestic cattle. According to Lasota-Moskalewska and Kobryń (1989), this has often been

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interpreted as the effect of sexual dimorphism or variability in individual specimens. For example, Higham (1969) discussed the possibility that certain animals only may have been raised on a high plane of nutrition at prehistoric settlements, leading to increased sample heterogeneity.

Among the bones used by archaeozoologists, metapodials are often used because they are usually found well conserved in archaeological excavations, and they seem to be more promising than other limb bones for sexing cattle from archaeological sites (Grigson 1982). These bones have been used to study sexual dimorphism of aurochs (e.g. von Leithner 1927, Degerbøl 1942, Zalkin 1960) and domestic cattle (e.g. Dottrens 1947, Boessneck 1956, Coble *et al.* 1971, Grigson 1982). However, the analysis of heterogeneous samples of bovine bones displaying bi- or tri-modal distributions (when castrates are present) has been handicapped by the absence of modern comparative material (Higham 1969) and detailed statistical analyses of measurements of these particular bones was highly recommended by Higham (1969). Any data collection giving the extent of intra- and inter-individual variability in dimension of these bones is thus of essential significance in interpreting findings.

The population of feral cattle of Amsterdam Island (37°40'S, 77°35'E) in the Southern Indian Ocean, represents one of the very few feral herds of *Bos taurus* Linnaeus, 1758 anywhere in the world (Berteaux and Micol 1992, Berteaux 1993). They have lived in the wild since 1871 and have been free from artificial selection since that period. They are descendants of french stocks present on La Réunion island (west Indian Ocean) which at that time comprised the following breeds: Jersey, Tarentaise, Grey Alpine, Breton Black Pied. Petit (1977) suggested that some individuals of the species *Bos indicus* may also have been introduced on the island, although this could never be confirmed. The population numbered aproximately 2000 at the beginning of 1988, but about half of the herd was removed in 1988 and 1989 in order to preserve the ecosystem of the island from cattle grazing and trampling. This removal offered a unique opportunity to analyse a large collection of bones belonging to individuals of known sex and age.

Our objective in this paper is to give a complete description of metapodial bones of Amsterdam Island cattle in order to offer archaeologists modern comparative material with patterns of sexual dimorphism and extent of intra- and inter-individual variability. Such documentation is valuable because it may serve to orient investigators or enlarge discussion of collected data when sex and degree of artificial selection of individuals is unknown.

Materials and methods

The study population has been described by Lésel (1969), Petit (1977), Guintard (1991), Berteaux and Micol (1992), Berteaux (1993) and Guintard and Tardy (1994). In 1871 the herd initially numbered 5 individuals which had been imported from La Réunion by a settler, who released them on Amsterdam Island. They are small bodied (adult male: 390 kg, adult female: 290 kg, Berteaux and

Micol 1992) and have horns of medium length. Many different patterns of colour are present including one reminescent of the ancestral aurochs (Olson 1980, Guintard 1988) which is common among males. They never received neither supplemental food nor veterinary care. Cattle numbered 2000 at the beginning of 1988 (Berteaux 1993), and inhabited a total surface of 3000 ha. Prompted by evidence of pernicious influence of Amsterdam Cattle on the flora and fauna of the island, a fence was erected accross the island in 1987 (Decante *et al.* 1987), and all the cattle located south of the fence (n = 1050; Berteaux and Micol 1992) were culled at the beginning of 1988 and 1989. This provided the material used in this study.

We collected in 1989 and 1990 the 4 metapodials of 90 adult individuals (48 females and 42 males ≥ 5 years old). The material thus comprised 180 metacarpal bones (90 left-side Mc III+IV and 90 right-side Mc III+IV) and 180 metatarsal bones (90 left-side Mt III+IV and 90 right-side Mt III+IV). The age of dead animals was determined from the chronology of eruption of permanent incisors (Steenkamp 1970). Bones were collected after they had remained at least 1 year in the field, so that most of them were already clean when sampled.

Five measures (1–5) were obtained on each bone according to von den Driesch (1976), while two (6–7) conform to Schild (1962) (Fig. 1)*. Abbreviations following the definitions (see bellow) correspond to measures taken on left Metacarpal (Mcl), right Metacarpal (Mcr), left Metatarsal (Mtl), and right Metatarsal (Mtr):

1. greatest length (MclGL, McrGL, MtlGL, MtrGL),
2. breath of proximal end (MclBp, McrBp, MtlBp, MtrBp),
3. breath of distal end (MclBd, McrBd, MtlBd, MtrBd),
4. depth of proximal end (MclDp, McrDp, MtlDp, MtrDp),
5. depth of distal end (MclDd, McrDd, MtlDd, MtrDd),
6. breath of diaphysis (Mcld, Mcrd, Mtld, Mtrd),
7. depth of diaphysis (Mcle, Mcre, Mtle, Mtre).

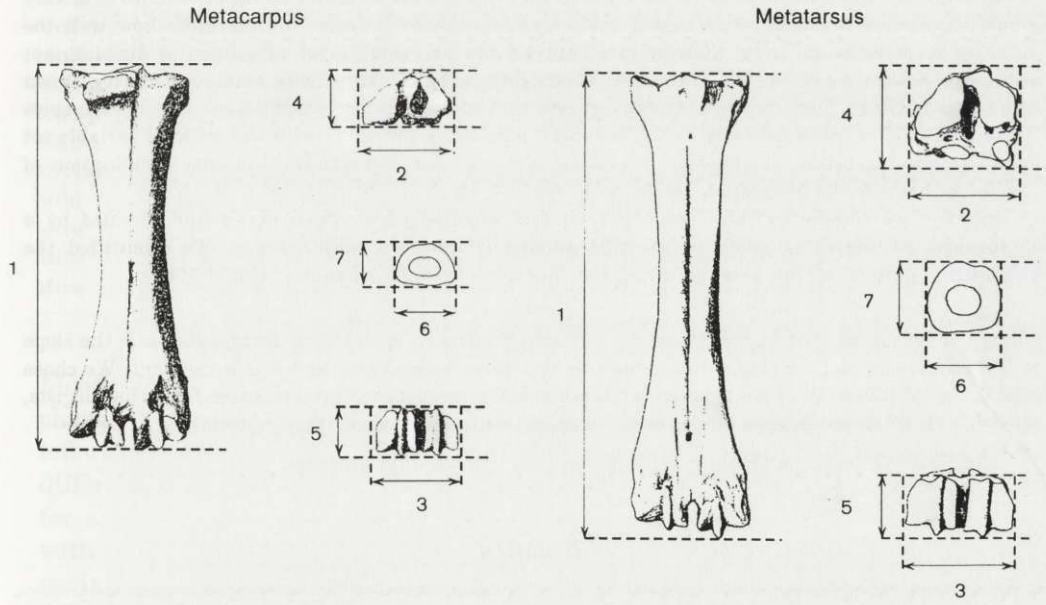

Fig. 1. Description of metapodial characters measured. Explanations of numbers in the text.

* A detailed catalogue of individual measurements is available from the authors.

Osteometric features were analysed for each of the 360 metapodials, except for the left metatarsal of one male that presented abnormal pathological characteristcs. Thus 48 measures of each variable were analysed for females, while 42 measures were analysed for males (except for MtlGL, MtlBp, MtlDp, Mtld and Mtle for which only 41 measurements could be made). Measures were made to the nearest 0.1 mm with a calliper rule.

In order to test for the homogeneity of the population, the normality of each of the 28 data sets was tested with the Kolmogorov-Smirnov one-sample test of goodness of fit (Lilliefors 1967). We assumed before using this test that every variable had a continuous distribution, since the Kolmogorov-Smirnov test is properly applied to continuous frequency distributions only (Sokal and Rohlf 1981). The significance of univariate differences among means of variables was tested with an analysis of variance, and simultaneous post-hoc comparisons were made using Fisher's least-significant difference. A coefficient of difference (C.D.) was calculated in order to assess the extent to which bone dimensions are dimorphic (Kurteń 1955):

$$\text{C.D.} = \frac{X_1 - X_2}{SD_1 + SD_2}$$

where X_1 and X_2 are mean dimensions for males and females, respectively, and SD_1 and SD_2 are standard deviations of dimensions for males and females, respectively.

A principal component analysis (PCA) was used subsequently to determine extent of sexual dimorphism and/or presence of several breeds differing in bone dimensions. The aim of a PCA is to transform the original variables into new variables that have zero inter-correlation, so that the new axes define an independent pattern of variation that is not necessarily obvious in the original data (Wiig 1985). Principal components were extracted from the correlation matrix of osteometric data. In this type of analysis, the correlation matrix is first obtained from the standardized centered data matrix, so that all the variances are equalized before axis rotation (the analysis itself) is carried out (Pielou 1984). Factors were subjected to a Quartimax rotation (Harman 1976).

Because the categorization of bones found in excavation sites as either males or females is of very great importance, we next performed a discriminant analysis in order to determine how well the different measurements could discriminate between the two sexes. The advantage of discriminant ordination is that it permits the differences among data to be displayed with maximum clarity. It can also potentially provide a means to assign any new case into the group which it most closely resembles (Pielou 1984). Observation scores on the canonical axis were correlated with the original variable set to aid in interpretation. A stepwise procedure was used for determining the best combination of variables that allowed separation according to sex.

Finally, we completed this comparison of size dimensions between males and females by a comparison of shape, in order to describe allometric relations within sexes. We quantified the allometric relations within sexes by using the equation of simple allometry (Gould 1966):

$$y = bx^{\alpha},$$

where y = MclGL or MtlGL, x represents a different dimension of the same metapodial, α is the slope of the rectilinear plot for original variables on logarithm coordinates, and b is a constant. We chose MclGL and MtlGL as the y value because GL is one of the most important dimension for archaeologists, but which is often not avaible due to people working with only fragmentary material.

The SYSTAT program (Wilkinson 1989) was used for all data analyses.

Results

The observed distributions of data (Table 1) were not significantly different from normality ($p > 0.05$) for every variable, except for MtlGL ($p = 0.020$), Mtrd ($p = 0.027$) and Mtle ($p = 0.046$) measured for females and Mcld ($p = 0.015$) and

Table 1. Variation of cattle metapodial bones in males and females. Number of metapodials examined (n), mean value of each measurement ($\bar{x}$), standard deviation, minimum-maximum range, coefficient of variation, and coefficient of difference between sexes are given.

	Males						Females						CD
	n	$\bar{x}$	SD	Min	Max	CV	n	$\bar{x}$	SD	Min	Max	CV	
MclGL	42	205.4	7.7	181.2	220.3	3.7	48	203.1	5.8	190.6	214.2	2.9	0.17
McrGL	42	205.6	7.6	182.4	220.7	3.7	48	203.5	5.5	191.6	213.7	2.7	0.16
MclBp	42	60.9	2.4	55.4	66.0	3.9	48	54.6	2.0	50.8	59.3	3.7	1.43
McrBp	42	60.9	2.5	54.7	65.9	4.1	48	54.1	2.0	50.5	58.6	3.7	1.51
MclBd	42	62.7	2.7	56.3	68.2	4.3	48	55.1	1.9	50.9	59.0	3.4	1.70
McrBd	42	62.7	2.7	56.5	68.2	4.3	48	55.2	1.7	51.7	58.6	3.1	1.70
MclDp	42	38.9	1.8	34.9	42.7	4.6	48	34.8	1.2	32.5	37.5	3.4	1.37
McrDp	42	38.9	1.9	35.0	42.9	4.9	48	34.9	1.2	32.6	37.5	3.4	1.29
MclDd	42	33.3	1.3	30.9	36.4	3.9	48	30.7	0.9	28.6	32.4	2.9	1.14
McrDd	42	33.3	1.4	30.2	36.1	4.2	48	30.8	0.8	29.2	32.5	2.6	1.14
Mcld	42	34.8	2.1	31.2	39.6	6.0	48	29.0	1.4	25.7	33.2	4.8	1.66
Mcrd	42	34.7	2.1	31.0	39.8	6.1	48	28.9	1.4	25.9	32.8	4.8	1.66
Mcle	42	26.0	1.2	23.2	28.7	4.6	48	22.5	0.9	20.4	24.3	4.0	1.67
Mcre	42	26.1	1.3	22.9	28.4	5.0	48	22.5	0.9	20.7	24.2	4.0	1.64
MtlGL	41	233.3	8.8	206.3	250.3	3.8	48	231.9	6.6	217.6	243.1	2.8	0.09
MtrGL	42	233.0	8.8	206.5	250.4	3.8	48	231.8	6.5	217.5	243.7	2.8	0.08
MtlBp	41	50.0	2.0	46.9	54.8	4.0	48	45.3	1.5	41.1	48.2	3.3	1.34
MtrBp	42	50.6	1.9	47.2	53.8	3.8	48	45.3	1.5	41.0	48.6	3.3	1.56
MtlBd	42	57.7	2.2	53.3	62.7	3.8	48	51.4	1.7	47.0	54.7	3.3	1.62
MtrBd	42	57.8	2.4	53.6	63.3	4.2	48	51.5	1.6	48.2	55.2	3.1	1.57
MtlDp	41	48.0	1.7	44.1	52.3	3.5	48	43.5	1.3	40.8	46.3	3.0	1.50
MtrDp	42	47.9	1.7	43.8	51.9	3.5	48	43.6	1.2	41.4	46.1	2.8	1.48
MtlDd	42	32.7	1.3	29.5	35.0	4.0	48	30.6	0.8	29.1	32.4	2.6	1.00
MtrDd	42	32.7	1.3	29.9	34.9	4.0	48	30.6	0.9	28.5	32.3	2.9	0.95
Mtld	41	29.6	1.6	27.5	33.5	5.4	48	26.2	1.2	23.4	28.9	4.6	1.21
Mtrd	42	29.6	1.7	27.1	33.9	5.7	48	26.3	1.3	23.8	29.6	4.9	1.10
Mtle	41	29.5	1.4	26.4	31.9	4.7	48	26.0	1.2	23.2	28.2	4.6	1.35
Mtre	42	29.7	1.3	27.1	32.3	4.4	48	25.9	1.1	23.6	28.5	4.2	1.58

Mcrd ($p = 0.014$) measured for males. Analyses of variance were used to test each character for differences between sexes and sides (left *versus* right). No significant left-right differences were found for any character ($p > 0.05$). However, significant differences were found for every character when sexes were compared ($p < 0.01$ for each character except GL for which $p < 0.05$). This last result is consistent with the fact that coefficients of difference between sexes were > 1 for every variable except for GL for which it was < 0.2 (Table 1).

When the character of one side was compared to the same character of the other side, the means were always within 1% and the correlation was always very high ($0.97 < r < 0.99$). Therefore the correlation matrix was only computed for the

Table 2. Correlation matrix (Pearson's coefficients) of variables measured on cattle metacarpal and metatarsal bones of the left side.

	Metacarpus								Metatarsus							
	GL	Bp	Dp	d	e	Bd	Dd		GL	Bp	Dp	d	e	Bd	Dd
GL	1							GL	1						
Bp	0.44	1						Bp	0.27	1					
Dp	0.36	0.84	1					Dp	0.27	0.89	1				
d	0.29	0.88	0.82	1				d	0.31	0.87	0.82	1			
e	0.34	0.88	0.87	0.91	1			e	0.23	0.88	0.83	0.89	1		
Bd	0.41	0.92	0.88	0.88	0.89	1		Bd	0.28	0.89	0.86	0.84	0.84	1	
Dd	0.45	0.86	0.84	0.83	0.82	0.91	1	Dd	0.40	0.82	0.78	0.78	0.73	0.85	1

Table 3. Character loadings calculated from a principal component analysis of 28 dimensions of cattle metapodials (components extracted from the correlation matrix).

	PC1	PC2	PC3
MclGL	0.40	0.89	0.04
McrGL	0.39	0.90	0.03
MclBp	0.93	0.08	0.02
McrBp	0.94	0.09	−0.02
MclBd	0.96	0.02	0.10
McrBd	0.95	0.04	0.08
MclDp	0.92	0.02	0.01
McrDp	0.91	0.01	0.01
MclDd	0.92	0.07	0.30
McrDd	0.92	0.10	0.27
Mcld	0.94	0.02	−0.16
Mcrd	0.95	−0.02	−0.16
Mcle	0.96	0.05	0.17
Mcre	0.94	0.04	−0.22
MtlGL	0.31	0.93	−0.03
MtrGL	0.30	0.93	−0.01
MtlBp	0.95	0.03	−0.01
MtrBp	0.95	0.02	−0.02
MtlBd	0.95	−0.02	0.10
MtrBd	0.95	−0.02	0.11
MtlDp	0.93	0.02	0.04
MtrDp	0.92	0.04	0.11
MtlDd	0.88	0.15	0.36
MtrDd	0.88	0.14	0.35
Mtld	0.92	0.08	−0.22
Mtrd	0.91	0.08	−0.20
Mtle	0.92	0.02	−0.26
Mtre	0.93	0.03	−0.25

Table 4. Discriminant function analysis of metapodial dimensions. Coef – standardized discriminant function coefficients, r – correlation with canonical variable, p – probability value for univariate F-tests.

	Coef	r	p
MclGL	−0.325	0.063	0.102
McrGL	0.306	0.063	0.105
MclBp	−0.385	0.504	0.000
McrBp	0.177	0.536	0.000
MclBd	0.051	0.580	0.000
McrBd	0.661	0.598	0.000
MclDp	0.466	0.485	0.000
McrDp	−0.332	0.451	0.000
MclDd	−0.550	0.409	0.000
McrDd	0.378	0.404	0.000
Mcld	0.806	0.589	0.000
Mcrd	0.173	0.601	0.000
Mcle	0.366	0.607	0.000
Mcre	0.085	0.587	0.000
MtlGL	−0.461	0.031	0.415
MtrGL	0.005	0.032	0.411
MtlBp	−0.153	0.548	0.000
MtrBp	0.494	0.545	0.000
MtlBd	0.541	0.575	0.000
MtrBd	−0.510	0.559	0.000
MtlDp	0.766	0.535	0.000
MtrDp	−0.727	0.516	0.000
MtlDd	0.182	0.337	0.000
MtrDd	−0.147	0.342	0.000
Mtld	0.276	0.434	0.000
Mtrd	−1.451	0.411	0.000
Mtle	−1.133	0.505	0.000
Mtre	1.131	0.554	0.000

left Mc and Mt. Two groups of variables clearly appear. On one hand, GL is poorly correlated with the other variables ($0.23 < r < 0.45$), whereas all the other variables are highly correlated with each other ($0.73 < r < 0.92$) (Table 2).

The results of the PCA reveal that the first three components account for 91.4% of the total variance of osteometric measurements. The first PC makes 76.3% of the variance, the second 12.2%, and the third 2.9%. Thus we consider that the space of factors formed by the axes of the first three components is sufficient to characterize the distribution of the analysed set of data.

The first component (PC1) has all positive loadings (Table 3). However, the loadings for the total length are comprised between 0.30 and 0.40 whereas the loadings for all other characters are ≥ 0.88. Thus PC1 mostly represents variation in width and breadth of metapodials. The second component (PC2) almost entirely represents variation in total length of the metapodials, as loadings for this character are > 0.89 whereas loadings for other characters are ≤ 0.15.

Figure 2 shows the plots of the scores on the first and second principal components. PC1 allows to separate nearly completly the males from the females, since all 48 females have scores < 0 and 40 out of 42 males have scores > 0.

One-dimensional ordination of individuals as determined by the discriminant function analysis allowed to separate completly males from females except for one individual (Fig. 3). The functions resulting from the analysis (Table 4) were used to identify the bone dimensions that separated better males from females. As far as metacarpal bones are concerned, differences in depth of diaphysis (e) alone could correctly classify 96.7% (87 out of 90) of individuals (Table 5). Inclusion of breath of distal end (Bd) and greatest length (GL) increased the accuracy to 98.8% of individuals correctly classified. The formula for the first discriminant function is: CVI = 0.30Gl − 2.45e − 1.18Bd + 67.57 (where CVI is the first canonical

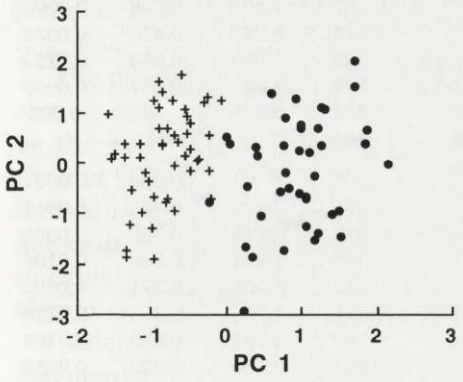

Fig. 2. Position of individual cattle in the coordinate system of the first and second principal components (component scores standardized to a zero mean, standard deviation = 1). + – females, ● – males.

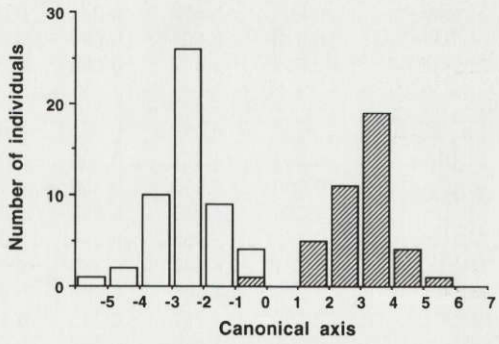

Fig. 3. One-dimensional ordination of individuals as determined by discriminant function analysis. Open bars – females, lined bars – males.

Table 5. Number and percentage of individuals correctly classified according to the different dimensions measured on metacarpal and metatarsal bones. *n* (%) – number (and percentage) of individuals correctly classified.

Metacarpus		Metatarsus	
Variable	*n* (%)	Variable	*n* (%)
e	87 (96.7)	Bd	82 (91.1)
d	86 (95.6)	Bp	82 (91.1)
Bd	85 (94.4)	Dp	82 (91.1)
Bp	81 (90.0)	e	81 (90.0)
Dp	81 (90.0)	d	79 (87.8)
Dd	80 (88.9)	Dd	74 (82.2)
GL	51 (56.7)	GL	44 (48.9)

Table 6. Coefficients of allometry calculated for each variable with respect to MclGL (a) or MtlGL (b). MclGl (or MtlGL) = bx^{α}, *r* – partial correlation coefficient.

	Males				Females			
	α	*b*	*r*	*p*	α	*b*	*r*	*p*
(a)								
McrGL	1.019	-0.101	0.991	0.0001	1.041	-0.222	0.979	0.0001
MclBp	0.477	3.366	0.493	0.0009	0.380	3.793	0.494	0.0004
McrBp	0.468	3.403	0.506	0.0006	0.443	3.546	0.558	0.0001
MclDp	0.255	4.390	0.310	0.0461	0.401	3.891	0.488	0.0004
McrDp	0.200	4.594	0.261	0.0949	0.431	3.784	0.502	0.0003
Mcld	0.180	4.687	0.282	0.07	0.147	4.819	0.247	0.0905
Mcrd	0.164	4.742	0.254	0.1046	0.156	4.788	0.252	0.0846
Mcle	0.255	4.493	0.297	0.056	0.360	4.192	0.513	0.0002
Mcre	0.184	4.724	0.240	0.1256	0.357	4.202	0.508	0.0002
MclBd	0.481	3.332	0.552	0.0002	0.343	3.939	0.415	0.0034
McrBd	0.595	2.862	0.671	0.0001	0.329	3.993	0.359	0.0123
MclDd	0.519	3.504	0.547	0.0002	0.376	4.025	0.387	0.0066
McrDd	0.557	3.372	0.603	0.0001	0.440	3.805	0.399	0.005
(b)								
MtrGL	0.990	0.054	0.995	0.0001	1.007	-0.036	0.986	0.0001
MtlBp	0.304	4.261	0.309	0.0496	0.395	3.942	0.445	0.0015
MtrBp	0.330	4.155	0.336	0.0315	0.323	4.215	0.385	0.0069
MtlDp	0.356	4.073	0.333	0.0336	0.354	4.111	0.366	0.0106
MtrDp	0.387	3.956	0.374	0.0161	0.381	4.008	0.371	0.0093
Mtld	0.281	4.501	0.380	0.0142	0.211	4.755	0.353	0.0138
Mtrd	0.273	4.526	0.398	0.0099	0.200	4.791	0.339	0.0185
Mtle	0.193	4.797	0.242	0.1282	0.204	4.780	0.323	0.0252
Mtre	0.231	4.669	0.267	0.0921	0.265	4.583	0.410	0.0038
MtlBd	0.500	3.423	0.512	0.0006	0.212	4.612	0.240	0.0997
MtrBd	0.410	3.789	0.439	0.0041	0.259	4.424	0.285	0.0499
MtlDd	0.484	3.763	0.525	0.0004	0.417	4.019	0.389	0.0062
MtrDd	0.478	3.785	0.513	0.0006	0.313	4.376	0.314	0.0299

variable). As far as metatarsal bones are concerned, differences in breath of distal end (Bd) alone could correctly classify 91.1% (82 out of 90) of individuals (Table 5), and inclusion of depth of proximal end (Dp) and greatest length (GL) allowed to correctly classify 97.8% of individuals. The formula for the first discriminant function is: CVI = 0.21Gl – 1.41Dp – 1.42Bd + 91.43.

Table 6 gives the coefficients of allometry (b and α) calculated for each variable with respect to MclGL and MtlGL, together with a measure of fit (partial correlation coefficient) of each expression to point squatters. Closest fit was obtained for Bd, Dd and Bp for males, and Bp, Dp and e for females.

Discussion

Most of the variables measured in males and females showed a normal distribution. This indicates that the Amsterdam Island cattle population is morphologically homogeneous, and suggests that it should not be considered as an admixture of different breeds, despite of the great variability of colour patterns observed (Petit 1977).

Sexual dimorphism was evident when data were analysed with PCA, because very little overlap existed between sexes. We used 28 variables per individual in our analysis, however, results were not different when only the 7 variables of one metapodial bone were used. This is due to the very high correlation of each variable with the same variables measured on other metapodial bones of the same individual, which is often observed on cattle bones (Costiou *et al.* 1988). The observed sexual dimorphism is consistent with results described by many other authors (e.g. Suess *et al.* 1969, Higham 1969, Wilson *et al.* 1977). We showed that there is much less sexual difference in the length than in the breadth of metapodials, which is not different from results of other studies on modern cattle bones (e.g. Fock (1966) who studied the German "Schwarzbunte").

The discriminant analysis gave important information on which measurements can be used to sex the bones with highest accuracy. e, Bd and GL was found to be the combination most appropriate for sexing metacarpal bones, whereas Bd, Dp and GL was found to be the best combination for sexing metatarsal bones. One individual could not be classified correctly when ordination of individuals was determined by the discriminant function analysis (Fig. 3). This pattern remains unexplained to us, and a mistake during identification of the bones in the field should not be excluded.

Allometric relations between variables are important, especially when only fragments of bones are found. Allometry within sexes differs between males and females. We have given the equation of simple allometry that allows to predict MclGL and MtlGL from each of the other variables, in the hope that it will prove to be usefull for archaeologists. However, one must keep in mind that the fit between the actual data and the predictions derived from the equations differs

Table 7. Greatest length (GL) of metapodials (expressed in percentage of greatest length of metapodials of Amsterdam Island cattle) and slenderness index (SI = 100 × Bp / GL) calculated for several populations of aurochs and domestic cattle. *n* in parentheses. [(1)] metatarsal bone, [(2)] metacarpal bone, [(3)] calculations based on measurements of metapodials of 50 adult males and 50 adult females collected in different slaughter-houses of western France.

	Males		Females		References
	Mt[1]	Mc[2]	Mt[1]	Mc[2]	
Wild cattle					
Bos primigenius					
Pleistocene	126.6/24.5 (13)	126.4/34.7 (21)	121.5/21.5 (39)	122.7/30.0 (39)	Brugal (1985)
Holocene	124.5/23.6 (20)	123.3/33.2 (22)	119.0/20.4 (7)	118.3/29.1 (13)	Degerbøl and Fredskild (1970)
Domestic cattle					
Bos taurus					
Neolithic	99.5/23.5 (1)	–	99.6/22.1 (2)	98.6/28.6 (8)	Matolcsi (1970)
3500–2500 B.C.	102.9/22.0 (8)	97.2/32.0 (12)	92.0/21.2 (5)	98.2/28.3 (9)	Lasota-Moskalewska (1980)
2500–1500 B.C.	96.0/22.9 (24)	95.2/31.8 (25)	95.2/20.4 (10)	94.3/28.3 (9)	Lasota-Moskalewska (1980)
Bronze age	92.8/22.8 (2)	94.2/35.1 (6)	91.7/20.1 (20)	91.7/29.2 (28)	Haimovici (1963)
1500–500 B.C.	79.1/25.1 (12)	84.9/32.2 (15)	89.8/20.6 (23)	87.6/28.6 (35)	Lasota-Moskalewska (1980)
Roman period	99.5/23.1 (4)	97.3/32.1 (6)	100.8/21.2 (7)	97.8/28.1 (10)	Matolcsi (1970)
500 B.C.–500 A.D.	82.5/23.2 (5)	85.6/31.9 (19)	86.3/20.6 (36)	85.9/27.6 (30)	Lasota-Moskalewska (1980)
Middle Age	87.9/23.2 (1)	85.3/32.0 (5)	91.0/20.3 (11)	90.8/27.8 (7)	Grenouilloux (1989)
5th–9th centuries	89.5/23.1 (1)	97.1/30.4 (2)	94.9/21.1 (5)	98.4/28.6 (4)	Matolcsi (1970)
9th–15th centuries	–	91.5/30.8 (1)	91.0/19.7 (6)	87.2/26.9 (12)	Matolcsi (1970)
15th–18th centuries	98.3/22.9 (3)	–	94.0/20.5 (11)	93.9/28.6 (3)	Matolcsi (1970)
Recent breeds					
German Fleckvieh	104.5/27.8 (16)	108.1/34.9 (16)	107.5/26.1 (100)	109.4/33.5 (100)	Fock (1966)
German Schwarzbunte	105.6/27.1 (11)	106.8/35.8 (11)	104.4/25.6 (33)	105.2/32.7 (33)	Fock (1966)
Angler Rind	104.9/26.5 (8)	105.6/35.2 (8)	104.6/24.9 (10)	106.4/31.7 (10)	Fock (1966)
Charolais	107.3/31.3 (52)	109.9/41.1 (52)	107.9/26.7 (51)	108.9/35.0 (51)	C. Guintard (pers. obs.)[3]
French friesian	116.9/27.3 (10)	116.0/36.8 (10)	106.7/24.6 (51)	106.9/32.3 (51)	Pierre (1988), Costiou *et al.* (1988)
Hungarian Steppe	108.9/24.8 (4)	108.2/34.3 (4)	110.1/21.4 (66)	109.6/29.0 (67)	Matolcsi (1970)
Bos indicus					
African recent breed	101.6/19.8 (3)	99.7/28.1 (3)	99.2/17.9 (6)	98.1/25.1 (5)	Brugal (1987)
Amsterdam	100/21.6 (42)	100/29.6 (42)	100/19.5 (48)	100/26.8 (48)	this study

greatly in quality according to the variable considered. One has thus to be carefull when estimating GL from other variables.

The coefficients of variation for bone dimensions ranged from 2.6 to 6.1, with 51 out of 56 values ranging from 2.6 to 4.9. For each variable considered, C.V. is smaller for females (3.49) than for males (4.35). These results are highly consistent with those given by Higham (1969) on 3 modern breeds (Aberdeen Angus, Red Danish and Kalmyk breed) for several limb bone dimensions. Thus it is suggested that the release of artificial selection 120 years ago did not lead to an increased variability in metapodial dimensions. One major consequence of these results is that a much higher variability found in prehistoric samples would suggest admixture of breed or sex (Higham 1969).

Several authors (e.g. Fock 1966, Matolcsi 1970) have estimated withers height (WH) of animals by transforming the length of metapodials. These estimates are of great value in prehistory and agricultural science (Jewell 1962, Audoin-Rouzeau 1991). Matolcsi (1970) proposed that WH = McGL × 6.03 (or WH = MtGL × 5.33) for females, and WH = McGL × 6.33 (or WH = MtGL × 5.62) for males. We estimated WH for Amsterdam Island cattle using these coefficients and compared the results with the measurements given in Petit (1977). The estimates based on Matolcsi's coefficients give WH values of 1.30 m (1.31 m) for males and 1.22 m (1.24 m) for females (numbers in parentheses are estimates from metatarsal bones). These estimates are very close to the measurements of Petit (1977), namely 1.30 m for males and 1.17 m for females, suggesting that these coefficients may be valid for a wide range of different breeds.

We compared the greatest length of the metapodial bones of our study population with data published for several other breeds or species. The data from the literature have been transformed in percentage of the greatest length observed on Amsterdam Island cattle to permit easy comparison (Table 7). Cattle of Amsterdam Island appear to be much smaller in length than aurochs and recent breeds of domestic cattle, but compare well with old breeds of domestic cattle and also *Bos indicus*. However, pleistocene aurochs used in our comparison were not the direct ancestors of domestic cattle and were bigger than holocene aurochs (A. Lasota-Moskalewska, pers. com., see Degerbøl and Fredskild 1970).

Metapodial bones of different breeds or species have also been compared by several authors (e.g. Haimovici 1963) by using coefficients such as the "slenderness index" (SI = 100 × Bp / GL). Different values of SI calculated for several populations of aurochs or cattle are reviewd in Table 7. Comparison with our study population shows that the cattle of Amsterdam Island have very slender metapodials, even when compared with old breeds of domestic cattle. Although it is difficult to propose an explanation for this trend, differences in genotype or phenomenon of inbreeding (island effect) might have occured (A. Lasota-Moskalewska, pers. com.).

In conclusion, the present work has shown that the cattle of Amsterdam Island can be considered as an homogeneous breed with respect to morphology. We described the degree of variation for several variables, both within and between

sexes, thus providing a reference set of data of importance to archaezoologists. This population, free from artificial selection and containing a large number of individuals, might offer a good model to study key questions about age or sex determination of fossil or subfossil bone remains of cattle.

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