

Horses from Pleistocene Sites in the Rhineland, Germany

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ABSTRACT: This paper deals with the size variability of caballine horses (*Equus ferus* in a broad sense) from Middle and Upper Pleistocene sites in the Rhineland. Osteometrical (Variability Size Indices) and oxygen isotope ($\delta^{18}\text{O}$) data show the variability in the size of *Equus ferus* living under different climatic and environmental conditions: horses of warmer climates were larger than those of colder climates, which is in contradiction to Bergmann's rule.

KEYWORDS: CABALLINE HORSES, CLIMATE, BODY SIZE, SIZE INDEX, OXYGEN ISOTOPES

RESUMEN: Este trabajo se ocupa de la variación en la talla del caballo (*Equus ferus* en el sentido amplio del término) en el área del río Rin durante el Pleistoceno medio y superior. Los datos osteométricos (Variability Size Indices) e isotópicos ($\delta^{18}\text{O}$) demuestran el efecto de las condiciones climáticas y ambientales en la variación de *Equus ferus*: caballos de climas más cálidos son de mayor tamaño que aquellos de climas fríos, lo cual contradice la muy citada regla de Bergmann.

PALABRAS CLAVE: ÉQUIDOS CABALLINOS, CLIMA, TAMAÑO, ÍNDICES DE TALLA, ISÓTOPOS DE OXÍGENO

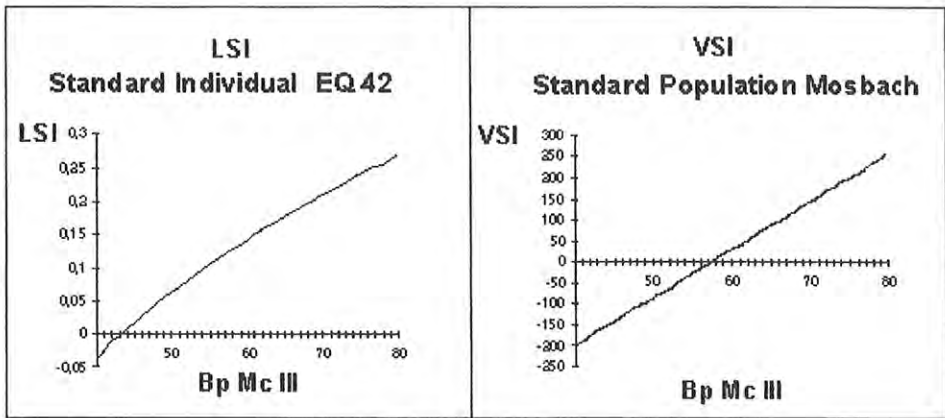
INTRODUCTION

Osteometrical data from archaeozoological samples are routinely used for a number of different purposes: in investigations of animal domestication (e.g. Davis, 1981; Meadow, 1984; Uerpmann, 1979, 1990), taxonomic determinations (e.g. Eisenmann & Beckouche, 1986; Forsten 1991), or to distinguish between sexes in dimorphic taxa (e.g. Weinstock, 1998). In the present study, osteometric data are used to examine the effects of the

climatic changes during the Pleistocene on the morphology of caballine horses and on the isotopic composition of their bone remains¹. Whereas the relationship of climate and body size is an old topic of discussion, the analysis of isotopes in this context is fairly new.

In this paper, we concentrate on the correlation between the body size changes of caballine horses in the Rhine valley and the climatic changes which took place during the Middle and Upper Pleistocene. The Rhineland was chosen because it is a

¹ The present report is part of a larger project dealing with the effects of climatic change on the morphology and isotopic composition of large mammal remains. Initial work is limited to two species: *Rangifer tarandus* (Weinstock 1997b, 1998) and *Equus ferus*.



FIGURES 1 & 2

LSI and VSI distribution in correlation to the standard.

relatively small area containing significant collections of well dated *Equus* remains.

MATERIAL AND METHOD

The oxygen isotope ratios in animal bone tissue depend on the global oxygen cycle. The oxygen isotope ratios ($^{18}\text{O}/^{16}\text{O}$) in the drinking water of mammals change as a function of temperature, humidity, and other related effects. Animals in different habitats have an uptake of drinking water with different oxygen isotope ratios. This ratio is changed by fractionation in the body in a characteristic way for certain species and independent of environmental temperature until the oxygen isotopes are incorporated in the hydroxyapatite of the bones. Investigations of recent animals show a linear relationship between the oxygen isotope ratios of drinking water and bone phosphate (Longinelli, 1984; Luz & Kolodny, 1985). Because of this linear relationship and because of the diagenetic stability of phosphate, the $\delta^{18}\text{O}$ values of animal bones reflect the isotopic composition of the drinking water at the time of the formation of the hydroxyapatite. Therefore it is possible to draw conclusions about palaeoenvironments on the basis of the oxygen isotope ratios of bone phosphate (Ayliffe & Chivas, 1990; Luz *et al.*, 1990).

Oxygen isotope compositions were measured exclusively on phosphate of the bone apatite. The sample preparation and analysis followed a modified version of the method described by O'Neil *et*

al. (1994) and Stephan (1999). The $^{18}\text{O}/^{16}\text{O}$ ratios are expressed in the δ -notation relative to USMOW.

It is important to mention that the osteometric studies reported here do not include skulls or teeth, but only postcranial bones. While teeth are certainly useful for taxonomic purposes, their relationship to body size is problematic, since they are part of the nutritional system and much more stable genetically than the postcranial skeleton (Clutton-Brock, 1987).

In this study, body size is used in the sense of "body mass" and not height. Therefore, length measurements of long bones were also excluded. The length of a limb bone represents mostly the height of an animal which depends on other criteria of selection than the whole body mass. The weight of an animal, which directly reflects the body mass, is expressed mainly in breadth and depth measurements of the long bones and all measurements of the small bones in the appendicular skeleton. The measurements were taken to the nearest 0.1 mm generally following the definitions of von den Driesch (1976) and Eisenmann *et al.* (1981).

For the purpose of comparing the size of horses - or any other animals - from different sites and/or periods, it is of great importance that samples be as large as possible. Here, the size index methods are very useful, because through these methods all skeletal elements can be compared simultaneously. Size indices are defined as measures for the deviation of a particular dimension from the respective dimension in a standard. This standard can either be a single individual (Iceland-

ic pony EQ 42, comparative collection, University of Tübingen), if the index is calculated with the Logarithmic Size Index method (LSI; Uerpman, 1990), or it can be a standard population, when using the Variability Size Index (VSI; Uerpman, 1982).

The LSI method has the advantage that it is very simple to calculate according to the formula:

$$LSI_{(x)} = \log_x - \log_m$$

where "x" is the dimension of the archaeological specimen while "m" is the corresponding dimension in the standard individual. The disadvantages of this method reside in its exponential nature and therefore the unequal treatment of small and large dimensions (Figure 1).

The VSI has better mathematical properties. It is calculated according to the following formula:

$$VSI = \frac{x-m}{2 \cdot s_m} \cdot 50$$

where "x" is again the dimension of the archaeological specimen while "m" in this case is the mean of the corresponding dimension in the standard population, and "s_m" is its standard deviation. The standard population should be as homogeneous as possible, because strongly deviating individuals will influence the standard deviation. As can be seen from the formula, the VSI attains a value of ± 50 for values of x that are two standard deviations larger or smaller than the mean. It is thus scaled according to the variability of each measurement in the standard population. In mathematical terms it is linear and its increments do not depend on the magnitude of the respective bone dimension (Figure 2). The resulting VSI is positive, if the measured animal was bigger than the mean of the standard population. It will take negative values, if it is smaller. If more than one measurement can be taken on a particular specimen the arithmetic mean is calculated, resulting in a "mean VSI" of the bone. The mean VSI values for all bones of a particular collection form a body of numbers whose statistical parameters characterise the respective sample. The mathematical results can be displayed graphically as "box-and-whisker" plots or as histograms.

Despite the clear advantages of the VSI method over the LSI method, it had not been utilised for horses until now because of a lack of an adequate

standard population. The newly available osteometrical data from the site of Mosbach (Brüning, 1978; Koenigswald & Tobien, 1987) allow now the application of the VSI method in the investigation of caballine equids. At the Mosbach site, near Wiesbaden in the Rhine valley, a large number of horse remains were collected over many years. The finds come from fluviatile sands, dating to a temperate phase at the beginning of the Middle Pleistocene, probably Oxygen Isotopic Stage 13 or 15.

The collection is not only rich but also shows a high level of biological homogeneity, which makes it the ideal choice as a standard population. Thus, the size indices used here are based on this horse population. The VSI-distribution of the Mosbach horses approaches a normal distribution, reflecting size homogeneity within the population.

The sites compared to Mosbach in this paper are: Tönchesberg, Wannan, Ariendorf, and Schweinskopf in the Neuwied basin, Wallertheim near Mainz, Mauer near Heidelberg, Achenheim near Strasbourg (France) and - for comparative purposes although not in the Rhine Valley - Vogelherd in the Swabian Alb (see also Table 1).

- Mauer (Beinhauer & Wagner, 1992) - well known because of the *Homo erectus heidelbergensis* - is like Mosbach dated to the Cromerian (OIS 15 (?); Hambach *et al.*, 1992). - Mauer and Mosbach are therefore the only early Middle Pleistocene sites dealt with here. All the others are younger, dating to the end of the Middle Pleistocene and the Upper Pleistocene.

- Neuwied basin: Wannan (Justus, 1987; Turner, 1990), Tönchesberg 1A (Conard, 1992; Turner, 1990), Ariendorf (Turner, 1990), and Schweinskopf (Turner, 1990) are well dated to OIS 6, which is the end of the Middle Pleistocene. From Wannan there is an additional sample of Late Pleistocene bones (Frechen, 1995).

- Wallertheim belongs to OIS 5 (Conard, 1995). For this paper the horse remains from layer F, probably OIS 5c, are analysed.

- Achenheim (Wernert, 1956) has a relatively long sequence, spanning isotopic stages 6 to 2. The results for Achenheim are preliminary, since not all of the material has yet been evaluated. The stratigraphy of this site is complicated and it is not easy to define the transitions between stages.

- Vogelherd (Lehmann, 1954 a+b). Since no adequate sites from the colder parts of the Upper Pleistocene in the Rhineland are at present avail-

Site	Geographical Location	Age	OIS
Mosbach	Wiesbaden	Cromer Complex	13 or 15
Mauer	Heidelberg	Cromer Complex	13 or 15
Toenchesberg IA	Neuwied basin	Younger Riss/Saale	6
Wannen	Neuwied basin	Younger Riss/Saale	6 (+2)
Ariendorf	Neuwied basin	Younger Riss/Saale	6
Schweinskopf	Neuwied basin	Younger Riss/Saale	6
Wallertheim F	Mainz	Early Würm/Weichsel	5c
Achenheim	Strasbourg	Riss to Würm	6-2
Vogelherd	Lonetal, Ulm	Würm	4-3

TABLE 1
List of sites

able to us, this period must be covered by a site in the Swabian Alb. For the purposes of this study, Middle Palaeolithic (Mousterian) material from Layer VII (probably OIS 4) and Upper Palaeolithic (Aurignacian) bones from Layers IV + V (probably OIS 3) of this cave were used.

RESULTS AND DISCUSSION

The main goal of our work is to investigate possible correlations between climatic and environmental changes during the Pleistocene and the body size of *Equus ferus* in Central Europe. Figure 4 shows the VSI values of the measured bone complexes. The black bar in the middle of each plot indicates the mean \pm 1 standard deviation. The box contains the middle quartiles and has the median marked at its outside. The two 'whiskers' represent minimum and maximum.

The box-and-whiskers plots show a smaller size decrease from the Cromer Complex - Mosbach and Mauer - to the younger Middle Pleistocene sites, and a stronger decrease towards the end of the Pleistocene. It would seem as if the extreme climatic changes which occurred during the very long time span of the Middle Pleistocene had no significant influence on the body size of horses. However, when considering the isotopic signals of the bones in detail (Table 2), it can be recognised that the available faunal remains do not actually reflect the climatic changes. Obviously, none of

the Middle Pleistocene collections included here come from really cold periods of the glacial cycles.

It seems possible that - if horses from cold periods were available - the plot would show stronger fluctuations in the size of Middle and Upper Pleistocene *Equus* instead of a fairly continuous size decrease. This is indicated by the temperature related size decrease during the Upper Pleistocene. There are several sites where the horse remains from overlaying strata are significantly smaller than those from the Middle Pleistocene layers. Histograms of the VSI-distributions of all horse bones from these sites are shown in Figure 5.

For instance, at Mauer two metapodials were found which clearly do not belong to the same population as the rest of the horse bones. Their VSI values are much smaller²; stratigraphically, they come from loess deposits belonging to a cold phase, perhaps to the penultimate or - more probably - to the last glaciation.

In Wannen, again, it is obvious that two different size classes of horses are represented. The majority of the bones come from fairly large horses, but 29 specimens point to a similar body size as that of the smaller horses from Mauer. An ESR date for a molar of the small horses from Wannen gives an age of c. 14.5 ka BP, while a ¹⁴C-date on a bone gave 22.2 ka BP³. Apparently, these bones were deposited during the cold period around the last Glacial Maximum.

² VSI-values are calculated independently for the proximal and distal end of complete long bones. Therefore there are four size indexes for two complete metapodials.

³ Thanks are due to Prof. Dr. A. Mangini and Dr. B. Kromer, Heidelberg, for making these dates available.

Site	Sample N°	VSI	$\delta^{18}\text{O}(\text{‰})$
Mosbach	EQ-MOS 282	8.9	17.3
	EQ-MOS 283	-31.2	16.5
	EQ-MOS 284	12.5	16.7
	EQ-MOS 285	-4.3	16.6
	EQ-MOS 286	-16.9	16.7
	EQ-MOS 287	8.0	16.8
	EQ-MOS 288	-5.5	17.7
	EQ-MOS 289	43.4	17.2
	EQ-MOS 290	-13.7	17.1
	EQ-MOS 291	19.4	17.1
	EQ-MOS 332	-37.3	16.3
	EQ-MOS 333	26.0	18.6
	EQ-MOS 334	41.2	16.8
	Mauer, large horses	EQ-MAU 279	-31.2
EQ-MAU 280		-12.6	17.4
EQ-MAU 281		-23.7	16.7
Mauer, small horses	EQ-MAU 277	-92.8	16.0
	EQ-MAU 278	-133.3	16.4
Wannen, large horses	EQ-WAN 339	-8.1	16.3
	EQ-WAN 346	-19.6	16.6
	EQ-WAN 347	-44.0	16.6
Wannen, small horses	EQ-WAN 341	-105.9	16.4
	EQ-WAN 344	-129.0	16.0
	EQ-WAN 345	-84.0	15.0
	EQ-WAN 348	-95.4	14.7
	EQ-WAN 349	-123.3	15.9
Schweinskopf	EQ-SWK 336	-49.6	16.4
	EQ-SWK 337	-45.4	16.9
	EQ-SWK 338	-28.2	17.2
Ariendorf 2	EQ-ARI 335	-46.5	16.9
Toennesberg I A	EQ-TOE 92	-67.7	15.6
Toennesberg I B	EQ-TOE 93	-83.7	16.2
Wallertheim, Layer F	EQ-WALF 71	-35.3	17.1
	EQ-WALF 72	-55.9	17.3
	EQ-WALF 73	-47.0	17.7
	EQ-WALF 74	-44.0	17.3
	EQ-WALF 75	-53.3	17.2
	EQ-WALF 76	-53.0	16.6
	EQ-WALF 80	-37.5	16.7
Vogelherd IV	EQ-VGH 263	-104.1	15.6
	EQ-VGH 264	-109.4	14.4
	EQ-VGH 265	-141.6	14.8
	EQ-VGH 266	-156.3	14.6
	EQ-VGH 270	-106.6	15.3
Vogelherd V	EQ-VGH 271	-126.0	15.7
Vogelherd VII	EQ-VGH 275	-23.1	15.9
	EQ-VGH 276	-57.1	16.0

TABLE 2

List of bone samples which yielded VSI and $\delta^{18}\text{O}$ values

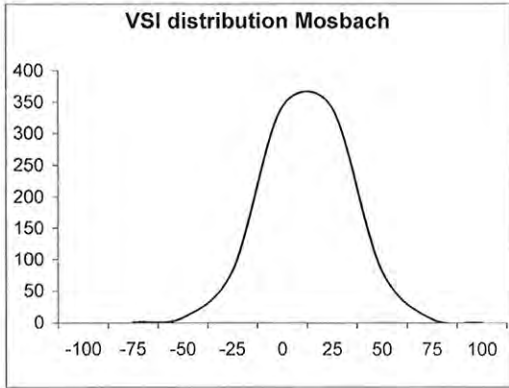


FIGURE 3

VSI distribution of the Mosbach Standard Population. By definition the mean value of the distribution is zero.

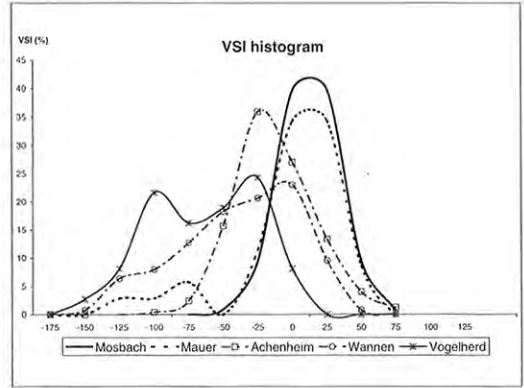


FIGURE 5

VSI distributions for sites with large and small horses in comparison to Mosbach.

The osteometrical evaluation of the horses from Achenheim has not been finished yet. However, it is already clear that beside large individuals there are also some with very small size indices. Unfortunately, no reliable absolute dates for these horses are yet available, and the isotopic analysis of this material is still to be carried out. It seems probable - as was the case in Wannen - that the smaller equids belong to a younger, presumably colder period.

In the case of Vogelherd the two size classes are very well marked in the histogram. The small horses from layers IV+V belong to a colder period of the last glaciation (as indicated by the $\delta^{18}\text{O}$ -values, see below).

The rest of the sites (Wallertheim, Tönchesberg, Schweinskopf, Ariendorf) show a relatively homogeneous population of Equids within the range between the larger Wannan horses and the horses of Vogelherd layer VII.

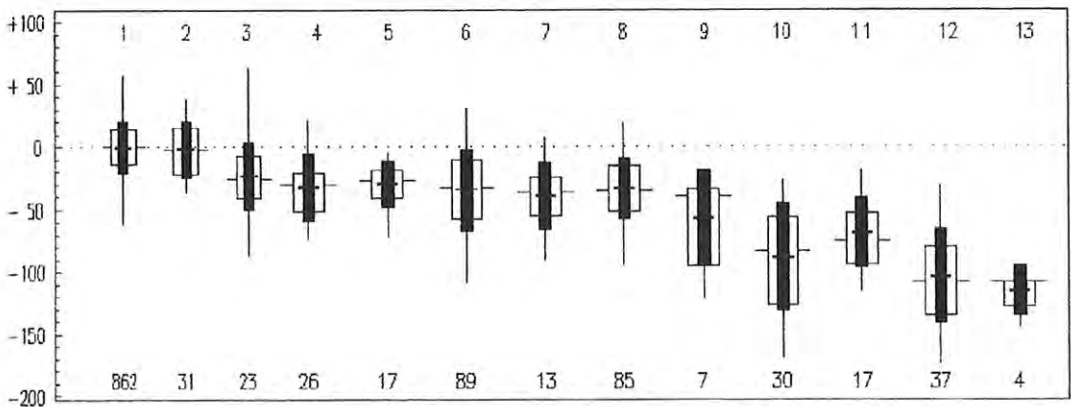


FIGURE 4

VSI-distributions of horses from Middle and Upper Pleistocene. Sites are arranged in chronological order from older (left) to younger (right). The chronological position of the small horses from Mauer is unclear.

- | | | |
|----------------------|-------------------|-----------------------|
| 1 - Mosbach | 6 - Wannan, large | 10 - Vogelherd IV/V |
| 2 - Mauer, large | 7 - Tönchesberg | 11 - Achenheim, small |
| 3 - Achenheim, large | 8 - Wallertheim | 12 - Wannan, small |
| 4 - Schweinskopf | 9 - Vogelherd VII | 13 - Mauer, small |
| 5 - Ariendorf | | |

How can the size variability of the horses in the Rhine valley during the Pleistocene be explained? In order to test the hypothesis that the size fluctuations of *Equus ferus* are a response to changes in climatic and environmental conditions, bone samples from the different sites were analysed for their $^{18}\text{O}/^{16}\text{O}$ ratios.

Figure 6 shows the relation between the VSIs and corresponding $\delta^{18}\text{O}$ values for all specimens which yielded a sample for chemical analysis. The individual values are listed in Table 2.

The small horses from Wannen (OIS 2) have definitely lower levels of VSI and $\delta^{18}\text{O}$ values than the larger horses of the same site (OIS 6). The same is the case in Vogelherd IV/V in contrast to Vogelherd VII. This result demonstrates that the smaller horses were not contemporaneous to the larger horses and lived under very different environmental conditions.

The relationship between climatic/environmental conditions and body size has been discussed at least since the 19th century (e.g. Bergmann, 1847; Allen, 1877), with the result that a number of so-called "ecogeographical rules" were postulated. One of the best known is Bergmann's rule, which - as reformulated by Mayr (1970) - states that, in species of warm blooded animals, races from colder climates tend to be larger than races of the same species living under warmer conditions. The basic idea is that with an increase in body mass the surface of the body does not increase at the same rate. Therefore the loss of heat per unit of weight is

larger in a small than in a large animal of the same species. Bergmann's rule has been used in a number of studies to explain variations of the body size in different species in the past (e.g. Davis, 1981; Klein, 1964; Klein & Scott, 1989).

In recent decades, however, the validity of Bergmann's rule has been questioned by some scholars (e.g. Dayan *et al.*, 1991; Geist, 1987; McNab, 1971; Scholander, 1955, 1956). Geist (1987), for example, argues that the rule would only apply if "all other things are equal". Since thermoregulation in homiotherm vertebrates is a complex physiological system (e.g. Schmidt-Nielsen, 1975), and since it is but one of many requirements of an individual, it cannot be expected that a single factor - temperature - would determine the correlation between body size and environment. Instead, a number of different factors are involved. On the one hand there are ontogenetical factors such as age and sex (in case of sexually dimorphic species), which can be - up to a point - controlled by the investigator. On the other hand are climatic factors such as temperature and precipitation but also "bio-ecological" ones, like population density and food availability (Weinstock, 1997a, 1998). Of course, climatic and "bio-ecological" factors are interrelated.

The results presented here are in contradiction to Bergmann's rule: Large horses lived during warmer periods and smaller horses during colder ones. As VSI-values are calculated mainly from breadth- and depth-measurements they closely reflect the body weight, which is a direct expression of body mass. Therefore the positive overall correlation between VSI and ^{18}O is clear-cut mathematical evidence against the validity Bergmann's rule in the wild horses which existed in Central Europe during the Middle and Upper Pleistocene. A similar phenomenon was observed for Upper Pleistocene reindeer, *Rangifer tarandus*: the smallest reindeer in the Périgord region (south-western France) occurred during the glacial maximum, ca. 18 ka BP (Weinstock, 1997a+b).

The isotopic investigations are extremely useful to draw conclusions about the temperature regime - and perhaps the degree of continentality - under which a given population lived, but many other climatic parameters which may influence body size remain unknown. At the moment it is not possible to offer a detailed explanation for the size variations in the caballine horses of the Middle and Upper Pleistocene. Research will be continued

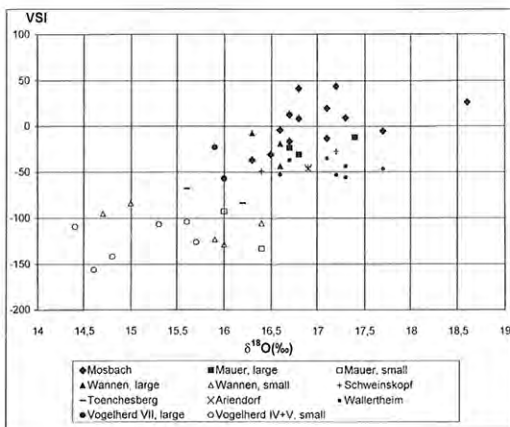


FIGURE 6

VSI versus O (‰) values for Pleistocene horse bones. $\delta^{18}\text{O}$ values taken from Stephan (1999).

and its geographical frame broadened. In particular it is necessary to measure more bones from contexts belonging to really cold phases of earlier glacial cycles.

The investigations into the development of body size in equids might have repercussions for the taxonomy of this genus. Size has been often used as a criterion to define horse species such as *Equus mosbachensis*, *Equus achenheimensis*, or *Equus solutreensis* (Musil, 1969; Nobis, 1971). Our preliminary results suggest that the size of caballine horses varied repeatedly in response to environmental fluctuations. There seems to be no need to assign horses from different periods at different sites to different species. Instead, it can be postulated that a single species of caballine horse (i.e. *Equus ferus*), with a high degree of phenotypic plasticity, existed during the whole of the Middle and Upper Pleistocene in Central Europe. Statistical parameters for their body size (for instance in the form of VSI distributions) will be more valuable for the geographical and stratigraphical discrimination of populations than any bi- or trinomial taxonomy can ever be.

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