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* Manuscript

REVISED SUBMISSION TO *QUATERNARY INTERNATIONAL*

INTEGRATING TAPHONOMY INTO THE PRACTICE OF ZOOARCHAEOLOGY IN CHINA

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ABSTRACT:

With the study of faunal remains (zooarchaeology) emerging as an increasingly prominent component of archaeological studies in China, the importance of studying processes of assemblage formation and preservation (taphonomy) is becoming evident. Remains of animals recovered from an archaeological site are a biased sample of the assemblage that was originally deposited because certain animal parts preserve better than others. Important characteristics of faunal assemblages, such as skeletal element representation and age profiles, can be affected by differential preservation caused by taphonomic agents – cultural or natural. One primary goal of taphonomic studies is to provide an understanding of differential preservation of bone elements, allowing archaeologists to make more accurate assessments concerning the exploitation of different animal species by past peoples. Recent studies of the faunal assemblages from the Early Paleolithic site of Xujiayao and the Neolithic site of Taosi, both in Shanxi province, provide examples of the effects that differential preservation can have on archaeological interpretations of skeletal element representation and age profiles, respectively. These examples illustrate how an understanding of taphonomy is critical to the future practice of zooarchaeology in China.

Keywords: bone density, faunal analysis, Taosi, Xujiayao

1. **Introduction**

Over the past decade, the analysis of animal remains from archaeological sites (zooarchaeology) has become increasingly important to the study of prehistoric and early state societies of China, providing information concerning the subsistence and ritual behavior of early Chinese peoples (Yuan, 2002; Yuan and Flad, 2005). This development has recently been accompanied by recognition of the importance of taphonomy, the study of the processes that affect the preservation of an organism's remains after death (Norton and Gao, 2008a, 2008b; Zhang, 2008). Paleontologists and zooarchaeologists have long recognized that the faunal remains recovered from a site are typically a small, biased sample of what was originally deposited. A faunal assemblage may undergo significant modification through time as it becomes subject to many different biological, chemical, geological, and cultural processes before recovery by archaeologists. As investigators strive to reconstruct aspects of the behavior of past peoples, they have devoted greater effort to understanding how the differential preservation of different parts of the animal skeleton may affect their interpretations of the faunal record.

The importance of taphonomy can be illustrated from the perspective of the "life history" of a faunal assemblage. Table 1 shows the general similarity in how different researchers have defined the stages of this life history. The inverted triangle indicating sample size represents the loss of bones (i.e., data) from one stage to the next as an assemblage progresses from the animals that are potentially exploitable by the inhabitants of a site (Stage A) to the data eventually published from the study of that assemblage (Stage H). Zooarchaeologists are most interested in how ancient people selected and obtained the animals that they used (B) from all of the species available to them (A) and how the remains of these animals (C) reflect the manner in which they were used. Taphonomic studies have focused on determining how to reconstruct the death assemblage (B) from the preserved fossil assemblage (D). As it progresses through each stage, the assemblage, in its different manifestations, becomes smaller and smaller, and each stage of the assemblage may or may not be representative of the one that preceded it.

An important consideration, made explicit by researchers such as Meadow (1980) and Davis (1987), is that archaeologists play a role in shaping the life history of a faunal assemblage, making the decisions that determine the nature of each stage from E (bones in excavated volume) to H (published data). Archaeologists decide how a site is excavated (e.g., where to place excavation units), how bones are recovered from the excavated volume (e.g., the size of the mesh used for sieving), which of the recovered bones are recorded (e.g., how much time is spent in identifying a bone fragment), and what types of faunal data and what level of detail are presented in the eventual publication, if any. In the context of zooarchaeology, the role of taphonomy is to identify biases that affect the interpretation of the faunal record so that these can be discussed when presenting the results of an analysis. Taphonomic factors need to be taken into consideration in order to understand patterns documented in the faunal data and to assess how accurately these patterns represent the originally deposited faunal assemblage.

Archaeologists have long recognized that certain parts of the skeleton preserve better than others, and taphonomic studies have attempted to address this issue. In one of the most influential works in this field, *The Hunters or the Hunted: An Introduction to African Cave Taphonomy*, C. K. Brain reported on the collection and modification of bones by different species of prey animals (Brain, 1981). He also observed how pastoralists butchered animals and how their dogs consumed the discarded bones. They noted that the damage to and survival of different parts of the skeleton appeared to reflect their relative density. Some bone elements were denser, and therefore survived more frequently, than others. In addition, certain parts of a given element preserved better than other parts of the same element.

The remainder of this paper focuses on the effects of differential preservation on archaeological faunal assemblages by addressing the following questions:

1) Which bones are most likely to be lost in the archaeological record (specifically, between Stage B and Stage D)?
2) How does the differential preservation of bones affect our interpretation of the archaeological record?
3) How may zooarchaeologists adapt their analytical methodology, during the recovery (F) and recording (G) of bone specimens, to deal with differential preservation?

The Early Paleolithic site of Xujiayao and the Neolithic site of Taosi, both in Shanxi province (Figure 1), are used as examples to address these questions and to demonstrate the potential significance of taphonomic analyses in Chinese zooarchaeology.

2. Bone Density

In examining which bones are most likely to be lost in the archaeological record, the variable that has received the most attention has been bone density. Following initial studies by Binford and Bertram (1977) and Brain (1981), other researchers have measured the bone density of the entire skeleton of several different species of animals (e.g., Kreutzer, 1992; Lyman, 1994; Lam et al., 1999; Stahl, 1999) in different ways. Unfortunately, these sets of density data vary tremendously in accuracy, reflecting the different methods used to derive them (Lam & Pearson, 2005). In addition, because of the difficulty, expense, and effort involved in deriving density measurements, the sample sizes involved in all density studies have been small. As a result, we do not have enough data on how bone density varies within a species (e.g., between individuals of different sexes, ages, and/or diets) and between different species. Nevertheless, it remains evident that the density of a bone element (or parts thereof) plays an important role in determining the likelihood of that element (or parts thereof) preserving in the archaeological record.

Within an individual skeleton, bone density varies between and within different skeletal elements. Such variation appears similar not only among individuals of the same species but among animals with a similar skeletal structure. Comparisons of bone density data derived using computed tomography (CT) found that species of bovid, cervid, and equid all show similar patterns in bone density across the skeleton (Lam et al., 1999). In these species, the densest elements of the cranium are the teeth and the petrous bone; among the post-crania, the middle shaft portions of the long bones are the densest.

3. Interpreting Archaeological Faunal Assemblages

The differential preservation of faunal remains, whether due to differences in bone density or other factors, may have a significant effect on the interpretation of faunal assemblages. Here we examine the potential influence of biased preservation on two important lines of zooarchaeological evidence – skeletal element representation and age profiles – using examples from two archaeological sites in China.

3.1 Skeletal Element Representation

Skeletal element representation has been used to infer the hunting behavior of prehistoric peoples. In examining the relative abundance of different bone elements, zooarchaeologists rely heavily on the concept of bone “utility” developed by Binford (1978), in which he estimated the nutritional value represented by each skeletal part. High-utility elements are associated with a large amount of meat, marrow, and grease, while low-utility elements have little food value. In ungulates, the femur, which bears a high amount of meat and marrow, represents a high-utility element, while the metapodials

(metacarpals and metatarsals), which contain some marrow but bear little meat, are considered to be of low-utility, as are cranial elements, carpals, tarsals, and phalanges.

Patterns of skeletal element representation at Palaeolithic residential sites have been examined by zooarchaeologists in order to determine how Palaeolithic peoples acquired and used animals. In these studies, interpretations have been based largely upon the utility index – the relative abundance of high-utility and low-utility skeletal elements. When many low-utility bones are found at such sites, researchers infer that the humans at the site engaged in scavenging – obtaining only the left-over parts of prey animals that had been killed and consumed by other predators. Conversely, the occurrence of high-utility bones at a Palaeolithic site is typically interpreted to represent the result of hunting activities, indicating that ancient people killed the animals and brought the most valuable parts of the carcass back to the site (e.g., Marean and Kim, 1998).

The quantification and subsequent interpretation of skeletal element abundance can be affected by differences in bone density within the skeleton. In particular, the most accurate bone density data have shown the middle shaft portions of long bones to be much denser and, therefore, more likely to preserve than their epiphyses (Lam et al., 1998, 1999). Most long bone epiphyses are composed largely of cancellous bone, which, when compared to cortical bone, is both less resistant to destruction and more likely to be consumed by humans or carnivores for the grease it holds. Long bone shafts may be broken for access to bone marrow, but the resulting fragments of cortical bone are extremely durable and thus likely to preserve in the archaeological record. Traditional methods of long bone quantification have focused on counting epiphyses because they are much more easily identified to element and to taxon than are shaft fragments. However, taphonomic research has demonstrated that if bone counts are based on epiphyses, the number of long bones present is underestimated. More importantly, counts based on epiphyses may not record the correct *proportion* of long bones. This is because the epiphyses of some long bones (e.g., the metapodials) are denser than the epiphyses of others (Lam et al., 1998, 1999). If bone quantification is based on epiphyses, then metapodials (the low-utility long bones) may be over-represented compared to the other long bones. Using the traditional method of basing long bone counts on epiphyses, studies of many archaeological faunal assemblages have found low numbers of high-utility long bones when compared to metapodials and cranial elements (i.e., a scavenging pattern). When long bone counts are based on shaft fragments, the relative proportion of high-utility long bones may increase dramatically.

The faunal assemblage from Xujiayao, a well-known Early Palaeolithic site in Yanggao county, Shanxi province, provides an example of this observation. Excavated in the late 1970s by the Institute of Vertebrate Paleontology and Palaeoanthropology under the direction of Professor Jia Lanpo (Jia and Wei, 1976; Jia et al., 1979; cited in Norton and Gao, 2008a), Xujiayao has produced a faunal assemblage dominated by bones attributed to horse (*Equus prezwlaskii*). While sieving was not conducted during the excavation, an effort was made to recover small bone fragments (Norton and Gao, 2008a). Norton and Gao (2008a) conducted a detailed taphonomic study of this assemblage and identified 889 specimens of equid long bone. They found that, for all long bones, the shaft portions were much more abundant than the epiphyses (Figure 2). The traditional method of counting epiphyses would have severely underestimated the numbers of long bones present and would also have found the low-utility metapodials to be the most abundant long bones. When shaft fragments are identified to element and counted, a much larger number of long bones are recorded, with the most abundant element being the tibia, a high-utility bone. The survival of these different long bone portions is highly correlated with their bone density (r_s=0.811, $p < 0.001$) (equid bone density values from Lam et al., 1999; see Lam and Pearson, 2005, for the assumptions required for such correlation analysis).

This example illustrates two points. First, variables such as bone density will determine how likely a bone specimen will survive in the fossil record (Table 1: Stages B to D). Second, the choices made by zooarchaeologists with regards to bones recovered (Stage F) and bones recorded (Stage G) can have a significant influence over the eventual interpretation of a faunal assemblage. The sieving of excavated sediments will recover diagnostic shaft fragments of macromammal long bones, and greater attention during laboratory analysis to such fragments will affect the quantification of skeletal element representation. While such efforts are likely to increase the accuracy of bone counts, this focus on shaft portions does have two practical shortcomings: identifying shaft fragments is extremely time-consuming and may not be practical for many studies, and it is often difficult to identify such fragments to species. As a result, such studies usually can draw conclusions based only on animal size classes.

In the case of Xujiayao, different methods of recording bones would have led to contrasting interpretations of how the assemblage of horse remains was accumulated. If only epiphyses were counted, metapodials would appear to dominate the assemblage. This predominance of low-utility elements could result in the interpretation that the ancient inhabitants of Xujiayao were primarily scavengers – that they had access to the remains of horses only after the original predators had consumed the more desirable parts of the carcasses. However, by identifying and counting shaft specimens, Norton and Gao (2008a) found a much higher relative abundance of other long bones, producing a pattern of skeletal element representation that is consistent with hunting. This distinction between scavenged and hunted faunal assemblages is relevant primarily to early Palaeolithic sites, but taphonomic processes also influence the preservation and interpretation of more recent faunal assemblages, as illustrated in the following example from the Late Neolithic site of Taosi.

3.2 Age Profiles

Archaeological age profiles for certain mammal species provide evidence for the herd management and hunting practices of prehistoric peoples. Age determinations are based typically on tooth eruption and wear, epiphyseal fusion, and incremental structures such as cementum bands in teeth. At Neolithic sites, the relative proportion of animals of different sexes and ages provide insight into whether a particular species was domesticated and if that species was exploited by humans for meat or for other products (e.g., Zeder and Hesse, 2000). At Palaeolithic sites, the predominance of very young and very old individuals representing large mammal species may indicate that the people living at these sites were not able to hunt healthy individuals in their prime (Klein and Cruz-Uribe, 1984). On the other hand, Palaeolithic faunal assemblages dominated by the remains of prime-aged large mammals have been interpreted to reflect effective hunting strategies on the part of the site occupants (Stiner, 1994; Gaudzinski and Roebroeks, 2000). For the Late Paleolithic site of Zhoukoudian Upper Cave, Norton and Gao (2008b) reconstructed the age profiles of the deer species based on tooth eruption and wear. They found mostly young and prime-aged deer, with very few old individuals, and concluded that this age profile was consistent with the activities of ambush hunters such as humans or large cats.

One important taphonomic issue is whether the bones and teeth of adult animals preserve better than those of juvenile animals. As the bones of juvenile animals are still developing, it seems reasonable to expect that they are less dense than those of adults, but the density studies that have addressed this issue are few and inconclusive (e.g., Symmons, 2005). Age profiles are often constructed on the basis of tooth eruption and wear, but it has been long been suspected that juvenile teeth do not preserve as well as adult teeth (Klein and Cruz-Uribe, 1984; Marean, 1995). This likely reflects not differences in density between juvenile and adult teeth but the fact that juvenile teeth are smaller and more likely to fall out of the mandible and maxilla. In addition, the mandibles of young deer (under 6 months of age) appear to be less dense than those of adult deer, providing less protection for juvenile teeth (Munson

and Garniewicz, 2003). While it appears that juvenile bones and teeth are more vulnerable to destruction compared to those of adults, the degree to which juvenile bones are more likely to survive in the archaeological record than juvenile teeth remains to be determined (see also Pike-Tay et al., 2004).

Another taphonomic issue concerns the relative under-representation of teeth due to cultural behavior. In many depositional environments, teeth will preserve extremely well because of their enamel, which is primarily mineral and much denser than bone. However, teeth may be rare in certain contexts, such as Paleolithic residential sites, because the Paleolithic hunters may have chosen not to transport (low-utility) cranial elements, particularly those of large animals, back to the site (e.g., Assefa, 2006).

The faunal assemblage from the Late Neolithic site of Taosi in Xiangfen county, Shanxi province, illustrates the complexities involved in interpreting age profiles. The excavation of this assemblage was conducted in 2004 by the Shanxi Archaeology Team of the Institute of Archaeology, Chinese Academy of Social Sciences, under the direction of Dr. He Nu. As at Xujiayao, the excavation sediment was not screened, and bones were collected by hand. Brunson's (2008) analysis of the Taosi assemblage identified taphonomic biases in kill-off patterns for pig (*Sus* sp.). For sheep (*Ovis aries*) remains from Taosi, the age profile derived from tooth eruption and wear is consistent with the profile derived from the pattern of epiphyseal fusion of appendicular elements. These profiles both show that most sheep were killed when they were old, suggesting that the residents of the site had kept sheep for secondary (antemortem) products such as wool.

For pig, however, the data from tooth eruption and wear produced a different age profile than that based on epiphyseal fusion. The tooth data show that most pigs were killed when young, a pattern that is consistent with their being used for meat.[1] However, the epiphyseal fusion data show a different pattern, indicating that a large proportion of pigs had survived into adulthood (Figure 3). This discrepancy may reflect the fact that epiphyseal fusion is not an effective way of ageing pig bones (Bull and Payne, 1982). It may also reflect biased preservation or biased recovery against juvenile pig post-crania. Because shafts without epiphyses could not be aged, the destruction of juvenile long bone epiphyses (even if the shaft portions had survived) would result in a recording bias toward older individuals. For both pig and sheep, late-fusing epiphyseal portions, such as the proximal humerus and the distal radius, are poorly represented in the Taosi assemblage (Brunson, 2008: her Table 4.10). As late fusion corresponds with low bone density (e.g., Brain, 1981: his Table 7), the relative paucity of these long bone epiphyses suggests that they had been subjected to a higher degree of destruction by taphonomic processes. In addition, the proportions of small elements such as phalanges and metapodials are low in the overall Taosi faunal assemblage. This suggests that small bones, including the relatively smaller bones of juvenile individuals, may not have been systematically collected. It is possible that sieving of the excavation sediment might have resulted in the recovery of a larger number of post-cranial elements.

[1] In the Taosi collections analyzed by Brunson, the sex of most pig specimens could not be determined; therefore, sex was not included in the analysis of *Sus* age profiles. Consideration of sex may play a part in determining the culling strategies for pigs, and one might expect that males would be killed earlier than females. However, considering that female pigs can reproduce before one year of age and produce large litters, it is not necessary to keep even most female pigs alive much longer than 12 months or so (Redding and Rosenberg, 1998). Because it is particularly difficult to determine sex from the bones of infants and young juveniles, it may not be possible to ascertain the role of selection based on sex in cases of the extensive kill-off of young individuals.

4. Conclusion

In pursuing zooarchaeological studies in China, as elsewhere, it is critical to take into account the effects of taphonomic processes – in particular, the differential preservation of skeletal elements. Bone density is an important factor in bone survival, and accurate bone density values (such as those obtained using CT) have shown the importance of counting the shaft fragments of long bones. Shaft represent the densest portions of the post-cranial skeleton. If they are not collected and counted, the number of long bones in a faunal assemblage will likely be underestimated. Some research has suggested that, in certain conditions, the bones and teeth of young animals do not survive as well as those of adults and may be under-represented in faunal assemblages. In constructing age profiles, it is therefore important to compare data from teeth to those from post-crania. The examples from Xujiayao and Taosi illustrate how the choice of recovery methods, analytical techniques, and the lines of evidence that are examined may influence the interpretations of an archaeological faunal assemblage. Understanding the taphonomic biases shaping these lines of evidence represents an essential foundation to the practice of zooarchaeology.

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FIGURE CAPTIONS

Figure 1: Map showing the location of Xujiayao and Taosi, after Liu (2004: her Figure 1.1).

Figure 2: Equid long bone representation by portion at Xujiayao, based on data from Norton and Gao (2008: Table 10). When they are based on epiphyseal portions, the counts of long bones are low, with metapodials (low-utility elements) being most abundant. When they are based on shaft portions, the counts of long bones are much higher, with tibia (a high-utility element) being most abundant.

Figure 3: *Sus* (pig) survivorship curves at Taosi, based on data from Brunson (2008: her Tables 4.10 and 4.11). Epiphyseal fusion: 1 year: n=93; 2 years: n=43; 3 years: n=12. Tooth eruption and wear: 0-6 months: n=23; 6-12 months: n=25; 18-24 months: n=14; over 24 months: n=2. Tooth eruption and wear stages were defined according to Hongo and Meadow (1998) and Ervynck et al. (2001). Epiphyseal fusion stages were defined following Silver (1969) and Hongo and Meadow (1998).

Table

Table 1: The different stages in the life history of a faunal assemblage.

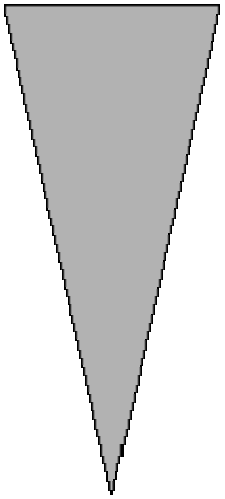
Sample Size	Stage	Clark and Kietzke (1967)	Lawrence (1968)	Meadow (1980)	Klein and Cruz-Uribe (1984)	Davis (1987)
LARGER  SMALLER	A	life assemblage	birth		life assemblage	animals living around the site
	B	death assemblage	death	potential bone population	death assemblage	dead animals and parts brought to the site
	C		final burial	deposited fraction	deposited assemblage	buried bones
	D	total fossil assemblage		preserved fraction	fossil assemblage	preserved bones
	E		discovery	bones in excavated volume		bones in excavation area
	F	collection		bones recovered	sample assemblage	bones recovered
	G			bones recorded		bones recorded
	H			published data		published data

Figure 1

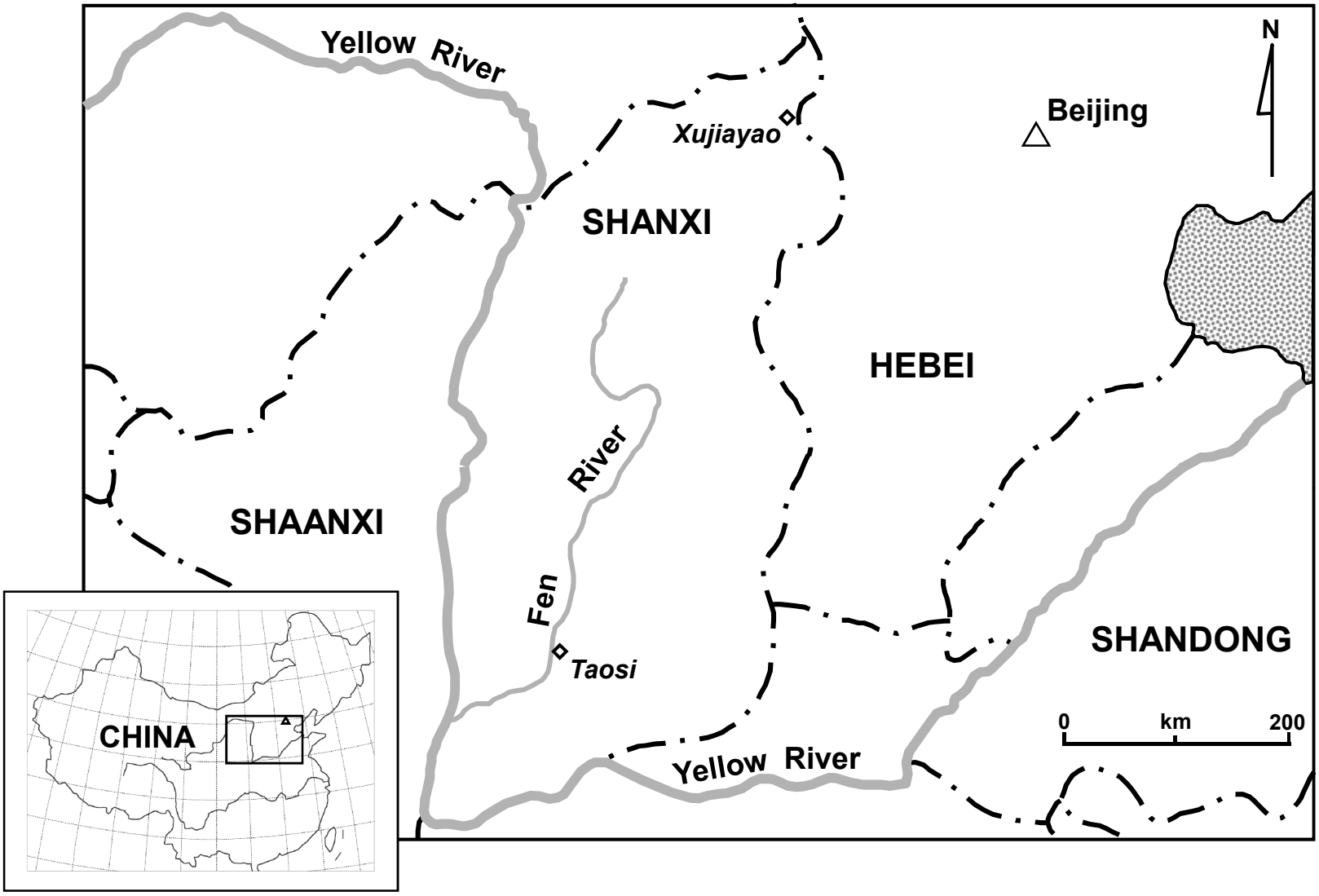

Yellow River
Xujiayao
Beijing
N
SHANXI
HEBEI
Fen River
SHAANXI
Taosi
SHANDONG
CHINA
0
km
200
Yellow River

Figure 2

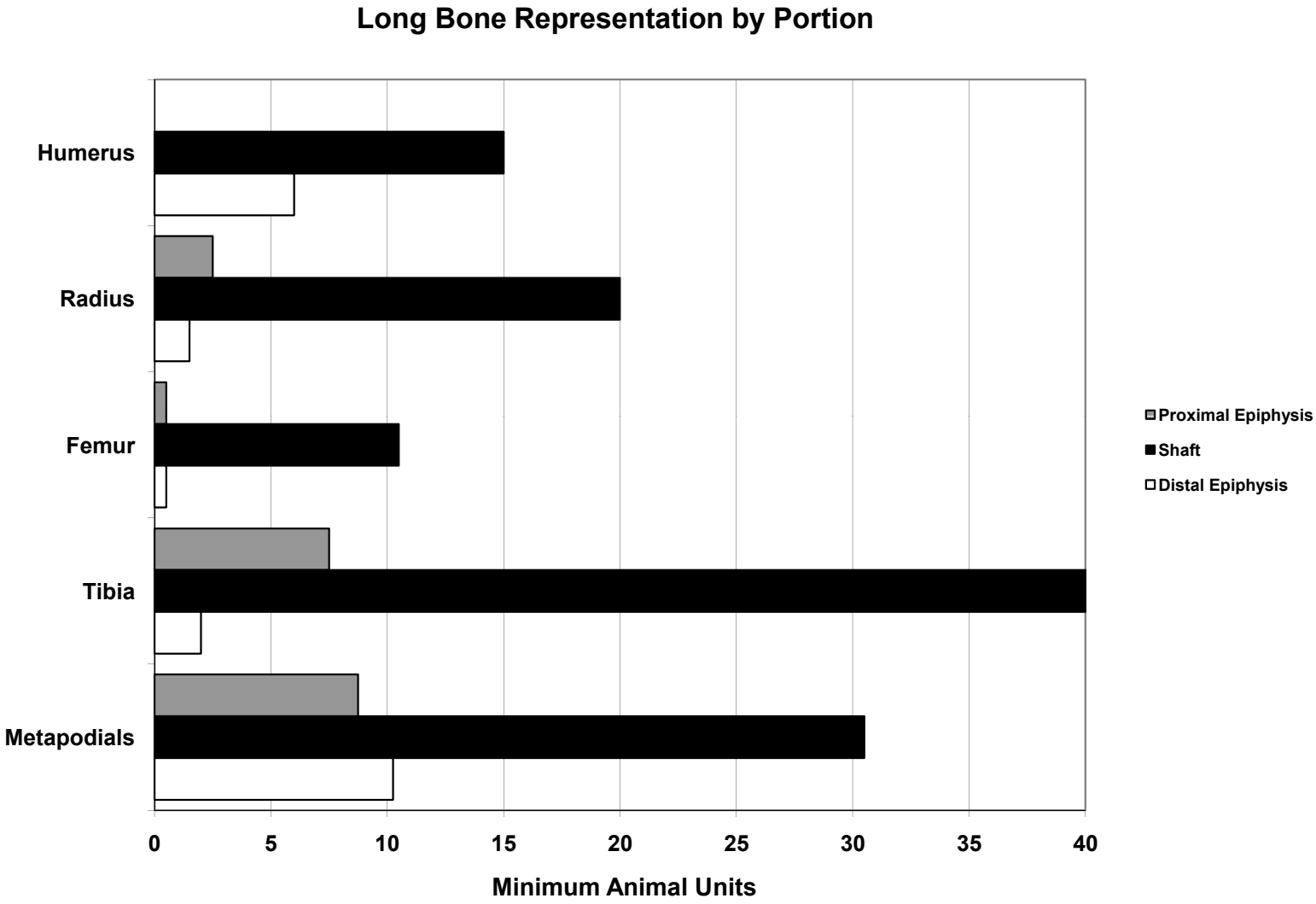
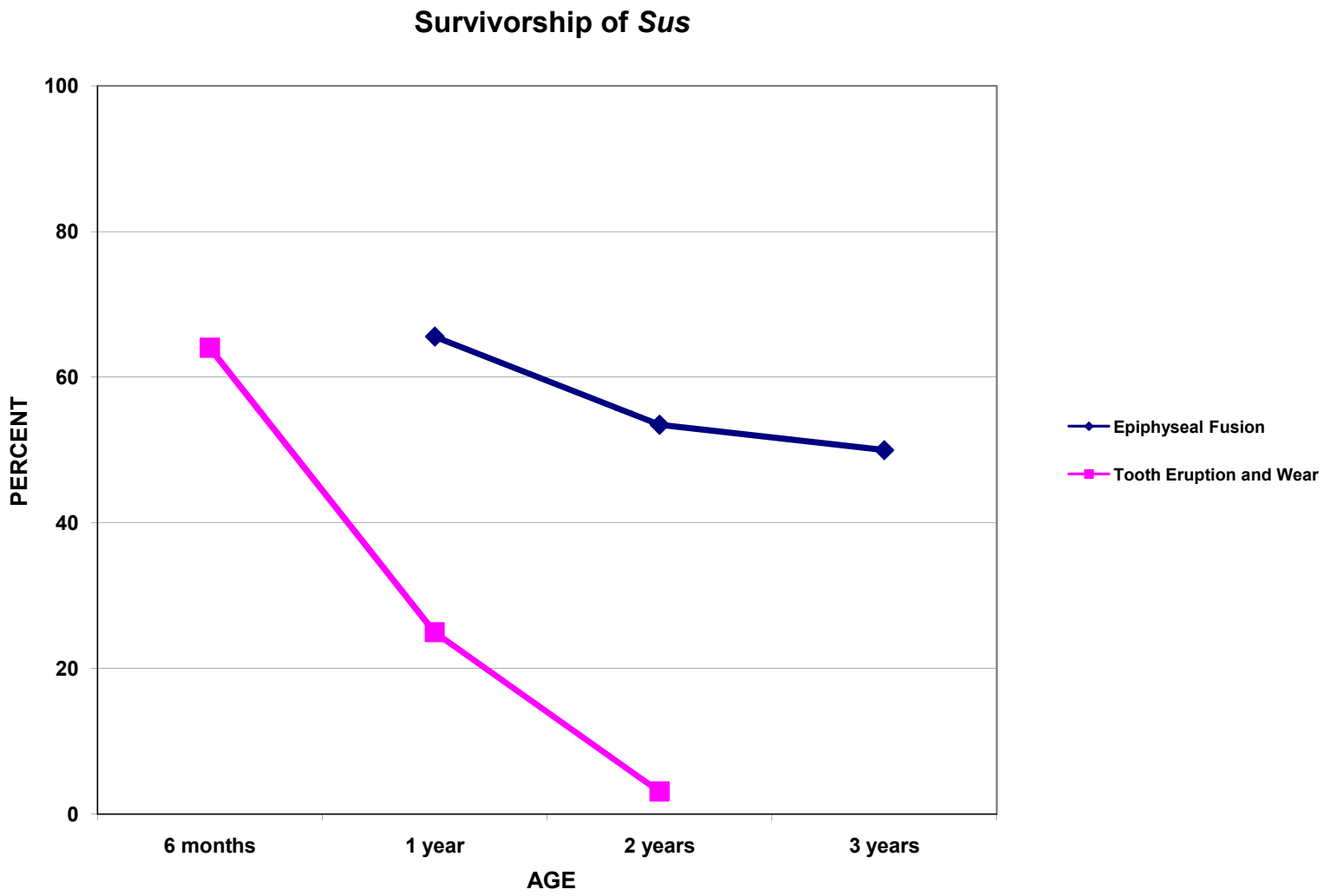

Long Bone Representation by Portion
Humerus
Radius
Femur
Tibia
Metapodials
0
5
10
15
20
25
30
35
40
Minimum Animal Units
Proximal Epiphysis
Shaft
Distal Epiphysis

Figure 3


Survivorship of *Sus*
100
80
60
40
20
0
PERCENT
6 months
1 year
2 years
3 years
AGE
Epiphyseal Fusion
Tooth Eruption and Wear