



# A Metrical Analysis of a Collection of Modern Goats (*Capra hircus aegargus* and *C. h. hircus*) from Iran and Iraq: Implications for the Study of Caprine Domestication

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(Received 14 September 1999, revised manuscript accepted 14 February 2000)

A critical comparison of two commonly used markers of initial animal domestication, size reduction and demographic profiling, is presented. A metrical analysis of a large collection of modern wild and domestic goats (*Capra hircus aegargus* and *C. h. hircus*) from Iran and Iraq clearly demonstrates that sex is by far the most significant factor affecting size in goats. In all post-cranial bones examined, those of males, even the unfused bones of males over 1 year of age, are absolutely larger than the bones of females. Region also plays a significant role in the size of these animals, but domestic status seems to have little impact. Similarly, a re-analysis of archaeological assemblages from Upland Sites the eastern fertile crescent shows no evidence of population-wide size reduction over a period that encompasses the transition from hunting to herding goats in the region, from the Middle Palaeolithic to the Early Neolithic. The apparent rapid reduction in the size of caprines during the early phases of domestication noted in earlier studies is likely attributable to a shift in the sex ratio of the adult breeding population of managed herds towards female domination, plus the differential destruction and loss of the bones of male animals killed at younger ages, as well as biases introduced by standard methodological practices. Building on the earlier work of Hesse, and using the empirical understanding of the factors influencing size in modern goats gained in this study, a new approach is proposed that combines both size and long-bone fusion data to construct high resolution, sex-specific age profiles of male and female goats that can be used to detect the hunting to herd management transition which marks the initial stages of the domestication process.

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**Keywords:** DOMESTICATION, SIZE REDUCTION, DEMOGRAPHIC PROFILING, *CAPRA HIRCUS*, NEAR EAST.

## Introduction

For more than 50 years the origin of animal domestication has been a major topic of archaeological investigation in the Near East. Literally hundreds of tightly focused to broadly synthetic studies devoted to this topic have appeared in the archaeological literature over the years. But while these scholarly efforts have provided a general outline of the process of domestication for the region's primary livestock species (goat, sheep, pigs, and cattle), there are still no conclusive answers to fundamental questions about the causes, cultural and environmental context, and the exact timing and sequence of the domestication of these four "founder" species. Of obvious central importance to answering these basic questions, of course, is being able to identify the initial stages of animal domestication in the archaeological record. As a result, it is not surprising that considerable attention has focused on the identification of "markers" of domestic status in animals and the development of methods that allow domesticated animals to be

distinguished from wild ones in archaeological assemblages of animal bones. Three quite different such methods and markers for recognizing the initial appearance of domesticated animals in the archaeological record have been proposed and widely employed by archaeologists: species abundance, morphological change, and demographic profiling. Each of these three methods has different strengths and limitations, as well as different proponents and sceptics (e.g. Meadow, 1989; Davis, 1987; Hesse, 1982; Legge, 1996).

Of these three methods, the one with the greatest number of shortcomings and the most limited utility is based on a simple recognition of an increase in the relative abundance of a species in the archaeofaunal record of a region. The "increased species abundance" marker (or, in some cases, even the simple presence/absence of a species) can work well in recognizing the initial appearance of a domesticate in areas that are well beyond the known geographical range of its wild ancestor. But this method is of little value in documenting the early history of a domesticate in regions close to, or within, the range of distribution of its wild

progenitor. In this general geographical zone—the likely ground zero for initial domestication—it would be difficult to either accurately define the exact boundary of a wild species' range thousands of years ago, or to say if an observed increased representation of a species, in fact, marked the initial management of domesticated herds, or simply signalled an increased reliance on hunting of wild populations.

The other two commonly used markers of animal domestication, in contrast, can be clearly and appropriately applied in looking for evidence of initial domestication of a species within this ground-zero zone. This is because both of these markers can be directly linked in a cause-and-effect relationship to the intervention of humans in the breeding behaviour of managed herds, which lies at the core of the process of domestication. Both of these markers and the methods used to identify their presence, however, are subject to different limitations and sources of potential bias.

The use of size reduction or other changes in skeletal morphology, which comprise the widely employed “morphological change” marker category for initial animal domestication, is complicated by the number of diverse factors that can and do influence size and morphology in wild animals. Wild animal species can potentially exhibit considerable morphological variation across the full extent of their geographical range, depending upon habitat heterogeneity and the species' sensitivity to such environmental change. Age and sex, too, are obvious factors that can influence the size and shape of various skeletal elements, particularly for those species in which sexual dimorphism is pronounced. Many wild species have also undergone a reduction in size since the end of the Pleistocene, further complicating the use of morphological change as a marker of initial domestication in animal species (Uerpmann, 1978; Davis, 1981; Ducos & Kolska Horwitz, 1997). Clearly, any effort to employ morphological changes as a marker of initial domestication would need to be able to rule out a role for any of these other potential factors—age, sex, time, and environment—before deeming such change evidence of domestication. Moreover, while Zohary *et al.* (1998) present the most cogent discussion to date of why a diverse array of proposed nutritional and selective factors might lead to size reduction and other morphological changes in animals under human management, the proposed causal pathway between human management and morphological change has yet to be convincingly, empirically demonstrated.

In addition, it is not at all clear how rapidly morphological changes actually appear once humans begin the active management and control of reproduction in domesticated herds. Changes in the horn form of early domestic goats, for example, seem to have happened gradually and are not clearly evident in archaeological assemblages until well after other markers indicate the transition to herding had occurred (as in Hole *et al.*, 1969 and Hesse, 1998). On the other hand, Bökönyi

(1976) and others (e.g. Uerpmann, 1978; Meadow, 1989) propose that size reduction in managed herds can occur quite rapidly, in less than a century. Other researchers, however, suggest that size reduction, like changes in horn form, may be a more delayed marker of domestic status (Zohary *et al.*, 1998; Davis, 1987).

The third commonly used marker of initial animal domestication in the archaeological record is based on the predicted differences in age and sex profiles between faunal assemblages resulting from the hunting of wild populations, as opposed to the controlled harvesting of managed, domesticated herds. Modelling such profiles requires baseline knowledge of the population dynamics and age and sex composition of both wild and domesticated herds, and the range of possible hunting and management strategies that were followed by early hunters and herders. The primary obstacle to the effective use of demographic profiling to detect initial animal domestication centres on the limited resolution of current techniques for establishing the age and sex of individual skeletal elements recovered from archaeological contexts. The challenges encountered in ageing and sexing individual bones can be even further complicated if two closely related species having similar morphology are both represented in a faunal assemblage. Goat and sheep, for example, both frequently occur in Near Eastern faunal assemblages and it is often difficult to distinguish between the two species. As a result, many researchers compile combined “caprine” demographic profiles, even though kill-off patterns for these two species may differ, especially if one is kept as a managed animal and the other hunted in the wild. Without the ability to reconstruct separate age profiles for both male and female animals of tightly drawn taxonomic groups, it may be difficult to distinguish between the demographic patterns of managed herds from those that result from specialized hunting practices.

In this article I present a critical comparison of the relative merits of morphological change (specifically size reduction) versus age and sex profiling in marking the initial domestication of the goat—arguably the earliest domesticated livestock species in the Near East. Central to this assessment of these proposed markers of initial animal domestication is an intensive metrical analysis of a large collection of modern goats from Iran and Iraq designed to establish the impact of various factors on the size of these animals. This empirically grounded understanding of the morphological variation in a well-documented collection of modern goats is then applied to the development of a new approach for monitoring the transition from hunting to herding in the Early Holocene of highland Iran.

## The FMNH Goat Collection

The Field Museum of Natural History (FMNH) curates what is likely the largest skeletal collection of

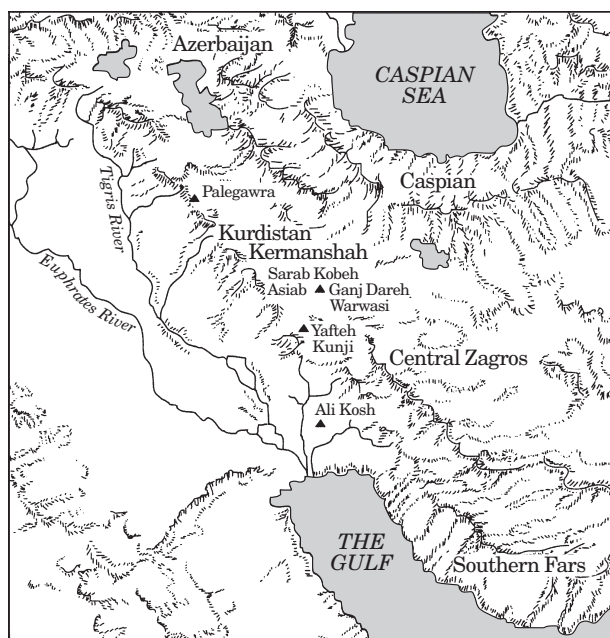


Figure 1. Map of Iraq and Iran showing six collecting localities of the modern FMNH goat specimens and archaeological assemblages analysed.

Near Eastern wild and domestic caprines in the world—specimens collected during the Street Expeditions to Iran of the 1960s (Lay, 1967; Street *et al.*, 1986), and by Charles Reed while assisting in archaeological investigations in Iraqi Kurdistan and northwestern Iran in the 1950s and 1960s. The Field Museum houses the post-cranial skeletons of 40 modern goats from Iran and Iraq (*Capra hircus*, following Wilson & Reeder, 1993). Of these, 36 are wild (*Capra hircus aegargus*) and four are domesticated livestock (*C. h. hircus*). The sex and collecting locality of all specimens is included in the FMNH catalogue records. Collecting localities can be divided into six general regions (Figure 1): *Caspian*, including animals taken in the Elburz Mountains rimming the Caspian Sea north of Tehran (two ♂ and four ♀); *Azerbaijan*, in the far northwest portion of Iran (two ♂ and one ♀); *Iraqi Kurdistan*, in northeastern Iraq (five ♂ and four ♀); *Kermanshah*, in western highland Iran (two ♂ and four ♀); the *Central Zagros* region, east and north of Isfahan (four ♂ and two ♀); and *Southern Fars*, which includes the southern highlands of Iran extending up to the narrow, southern coastal region of the Persian Gulf (six ♂ and four ♀).

The age of the specimens in the FMNH collection was determined for this study by examination of post-cranial long-bone fusion patterns of complete skeletons. Age classes presented here are based on Silver's (1963) fusion data compiled as the mean ages of fusion from a number of "scrub" crossbreed domestic European sheep. Silver is the standard reference employed by researchers to assign goat bones to age classes. The FMNH collections were grouped into

five general age classes: *Class A*, defined by the fusion of the proximal radius and distal humerus, which according to Silver takes place within the first year of life (three ♂ and two ♀); *Class B*, capped by the fusion of the metapodials and the distal tibia, which takes place in the second year (eight ♂ and one ♀); *Class C*, defined by the fusion of the calcaneus and distal radius set at between 2 and 3 years (four ♂ and three ♀); *Class D*, in which there is fusion of the proximal and distal femur, the proximal tibia and the proximal humerus, between about 3 and 4 years (four ♂ and 12 ♀); and *Class E*, marked by the fusion of all post-cranial elements, set at over 4 years of age (one ♂ and one ♀).

For the most part, post-cranial elements were measured using the metric standards developed by von den Driesch (1976) as a basic guide (Table 1). The metrical analysis of this large collection of modern goats was aimed at addressing four basic questions:

- (1) What is the degree of regional variation in the size of these animals?
- (2) What role does age play in size variation?
- (3) What is the degree of sexual dimorphism in these populations?
- (4) Are the domestic specimens in this collection distinguishable from the wild specimens on the basis of size?

#### Region and size

Figure 2 presents data on the distal breadth of the metacarpals of the FMNH goats by region and by sex within three general regions: the Northern Zagros, including the Caspian, Azerbaijan, and Kurdistan collecting localities; the Central Zagros, including the Kermanshah and Isfahan collecting localities; and the Southern Zagros, comprised primarily of goats collected in the Southern Fars coastal region. Departing from standard practice, which limits metrical analysis to fused specimens (see von den Driesch, 1976: 4), all bones in this study were measured if the standard landmarks for measurement were preserved, regardless of their state of fusion.

There is a clear, statistically significant trend toward reduction in the size of the goats in the FMNH collection as one moves south from the Elburz Mountains in northern Iran down the spine of the Zagros Mountains toward the Persian Gulf. This pattern is consistently manifested not only in the breadth of the distal metacarpals shown in Figure 2, but in all bones and in all dimensions measured. Two-sample Student's *t*-tests, based on separate variance using the largest of the two metacarpal distal breadth measurements of each individual, show a significant difference when males in the Northern Zagros group (Figure 2(a)) are compared to males in both the Central Zagros group (Figure 2(b)) ( $t=4.509$ ,  $df=7.1$ ,  $P=0.003$ ) and the Southern Zagros group (Figure 2(c)) ( $t=5.546$ ,  $df=7.4$ ,  $P>0.001$ ). The regional

Table 1. Dimensions (mm) of modern goat skeletons, excluding animals younger than 1 year and animals from the Southern Zagros, largest specimen for each individual skeleton

Bone	Measurement*	Sex	N	Minimum	Maximum	Mean	Median	s.d.	CV (%)
Humerus	Dd	Both	23	24.71	34.22	28.98	28.13	3.10	10.7
		Male	12	28.13	34.22	31.38	31.81	2.28	7.3
		Female	11	24.71	27.69	26.37	26.55	0.97	3.7
1st phalanx†	GL	Both	41	36.01	49.52	41.95	41.29	3.62	8.6
		Male	22	40.29	49.52	44.55	44.27	2.72	6.1
		Female	19	36.01	42.32	38.94	38.50	1.65	4.2
1st phalanx	Bp	Both	42	11.12	16.78	13.86	13.74	1.47	10.6
		Male	22	12.58	16.78	14.81	14.75	1.13	7.7
		Female	20	11.12	15.03	12.81	12.86	1.02	7.9
2nd phalanx	GL	Both	32	24.77	32.82	28.50	28.00	2.21	7.8
		Male	17	26.60	32.82	30.07	30.31	1.77	5.9
		Female	15	24.77	28.10	26.73	27.01	0.98	3.7
2nd phalanx	Bp	Both	35	10.66	16.52	13.13	13.18	1.49	11.3
		Male	19	11.98	16.52	13.93	13.42	1.32	9.5
		Female	16	10.66	13.90	12.19	12.17	1.08	8.8
Metacarpal	Bd	Both	24	25.29	36.07	30.50	29.69	3.51	11.7
		Male	12	30.09	36.07	33.18	33.55	1.72	5.2
		Female	12	25.29	29.29	26.92	27.05	1.20	4.5
Metatarsal	Bd	Both	24	23.11	31.47	26.42	25.84	2.91	11.0
		Male	12	25.73	31.47	28.87	29.19	1.93	6.7
		Female	12	23.11	26.27	23.96	23.89	0.91	3.8
Tibia	Bd	Both	22	24.35	31.82	27.34	27.31	2.20	8.1
		Male	11	27.23	31.82	29.11	28.35	1.57	5.4
		Female	11	24.35	27.39	25.57	25.33	0.90	3.5
Calcaneus	Bp	Both	23	20.75	26.97	23.65	23.08	1.64	6.9
		Male	12	22.74	26.97	24.85	24.76	1.26	5.1
		Female	11	20.75	23.32	22.34	22.36	0.72	3.2
Radius	Bd	Both	23	27.62	38.92	31.61	30.56	3.29	10.4
		Male	12	29.31	38.92	33.82	34.51	3.03	9.0
		Female	11	27.62	31.12	29.19	29.03	1.17	4.0

\*Measurements taken from von den Driesch (1977), except for calcaneus proximal breadth.

†Phalanx measurements shown include both fore and hind limbs.

variation among the female goats in the sample is more subtle and does not become significant at better than a 0.05 probability level until the Northern females (Figure 5(a)) are compared to those from Southern Fars (Figure 5(c)) ( $t=5.197$ ,  $df=9.7$ ,  $P<0.001$ ). It is possible that the trend toward decreasing size in the more southerly populations is a manifestation of Bergmann's (1847) rule that predicts a decrease in the size of animals with increasing temperatures. It is also possible, however, that this decrease is linked not so much to temperature as it is to decreasing quality of pasturage in these increasingly more arid regions.

#### Age and size

Figure 3 partitions breadth measurements of the distal metatarsal by age, as estimated by long-bone fusion. While the young males in age class A (Figure 3(d)) (less than 1 year) are larger than females in the same age group, the size of these young male and female animals is quite similar, and the two sexes could not be easily differentiated from one another if the sex were not known.

Male animals show a remarkable increase in size after age class A, essentially attaining their full adult

size within the age group B, (Figure 3(c)) at 1 to 2 years. Females, in contrast, do not show the same dramatic jump in size. In fact, the size of females remains fairly consistent over the more than 4-year span of time displayed, suggesting that the two very young females in age class A were already reaching adult size when collected. Once males are older than age class A, they are absolutely larger than all females regardless of age or region of origin. Even the unfused bones of younger males in age class B ( $\approx 1$  to 2 years) are significantly larger than the fully fused bones of adult females in the oldest age classes D and E (Figure 3(a)) (at least 3–4+ years) ( $t=9.771$ ,  $df=14$ ,  $P<0.001$ ). This pattern is seen in all dimensions of the post-cranial bones measured, lending support to Davis's (1996: 599) conjecture that caprines undergo very rapid osteological development, so that joint dimensions, like the breadth of the distal metapodials, reach their full size before full fusion is attained.

#### Sex and size

Figure 4 presents the combined samples of all the age classes and all regions for four different long bones (see also Table 1). Male and female animals show almost



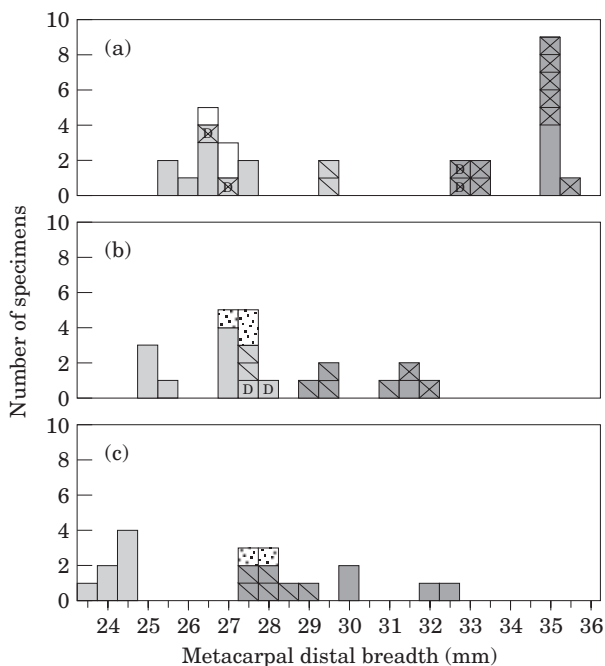


Figure 2. Metacarpal distal breadth measurements for modern FMNH goat specimens by region. Females shown in light grey bars, males in dark grey bars, fused bones in solid bars, fusing bones noted by a single hatch mark, unfused bones by a double hatch. Female animals in age class A shown in white, unshaded bars and males in age class A in stippled bars. Domestic specimens indicated by a "D". (a) Northern Zagros, individuals ( $i$ )=17, specimens ( $s$ )=32; (b) Central Zagros,  $i$ =12,  $s$ =22; (c) Southern Zagros,  $i$ =12,  $s$ =22.

complete size separation for all elements. Even where there is some overlap between males and females (as in the radius and calcaneus measurements), Student's  $t$ -tests indicate a highly significant difference between males and females at greater than the 0.001 level of probability. With the exception of the young animals in age class A, the measurements of the male elements (regardless of state of fusion) are distinctly larger than those belonging to females. Thus, while the bones of very young males fall into the size range of the female population, there is almost no overlap between the size of the bones of males and females in the older age classes.

There is also a remarkable consistency in the distribution of the male and female population in each element examined. When the distributions of the different elements are stacked as in Figure 4, it becomes quite clear that the point of separation between males and females occurs in about the same place in each graph. For every skeletal element, the range of variation in the female elements accounts for about 40% of the total range of variation for that bone, while the males contribute around 60% to the total variability. When a normal curve is fitted to the measurements of male and female distributions for each measurement, in all cases the female curve is quite sharply peaked and narrow, while the male curve in comparison is low and broad.

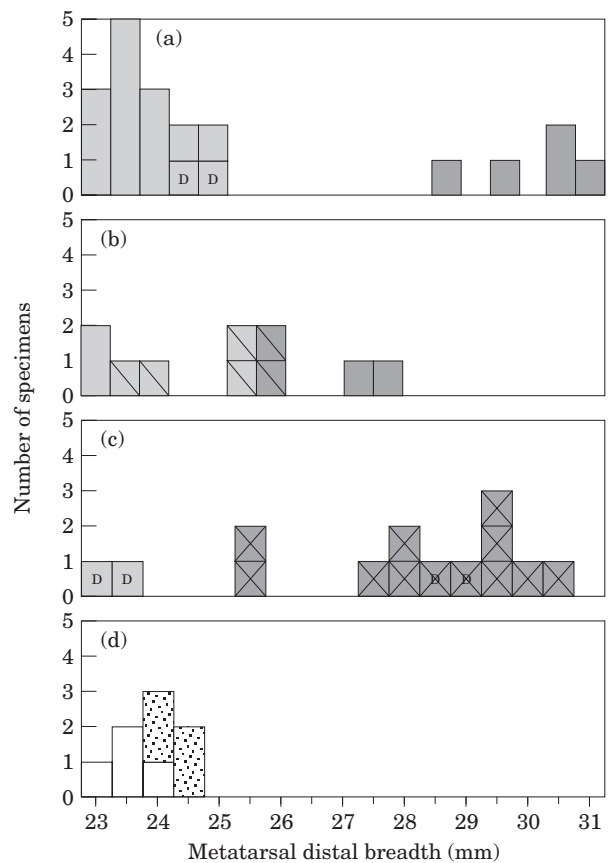


Figure 3. Metatarsal distal breadth measurements for modern FMNH goat specimens by age class; Southern Fars specimens excluded. (a) Age classes D and E,  $i$ =11,  $s$ =20; (b) Age class C,  $i$ =6,  $s$ =12; (c) Age class B,  $i$ =8,  $s$ =14; (d) Age class A,  $i$ =4,  $s$ =8.

This visual assessment of the shape of the distributions of the male and female measurements is consistent with their statistical assessment using the coefficient of variation (CV—the standard deviation expressed as a percentage of the mean) of the various male and female elements measured (Table 1). The CVs of female elements range from 3.2–4.7%, indicating limited variability and a relatively tight, narrow distribution around the mean. These CV values are consistent with those reported by Davis (1996) in his metrical study of female domestic Shetland sheep, which generally range from 3–5%. The similarity in the distributions of the female goat joint measurements in this study is also in line with Davis' (1996: 606) observation that measurements taken on the same axis tend to be highly correlated. The CVs of the wild male goat elements, in contrast, range from 5.4–9%, and are consistently about 2–4% greater than the CVs of corresponding female elements. The greater variability of male measurements is not likely to be an artefact of a different age or regional distributions for males versus females. CVs for males and females within regions resemble those found in the population as a whole, and the joint measurements of males and

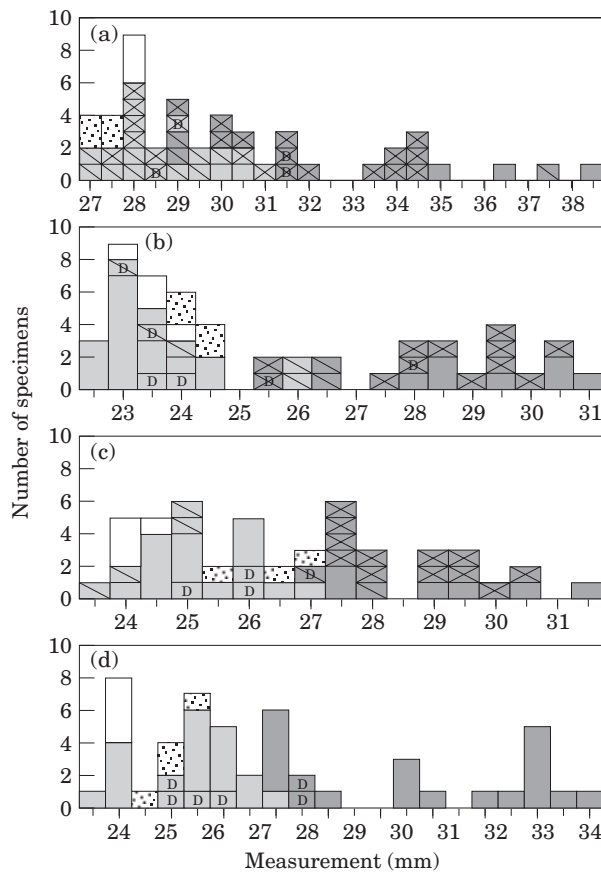


Figure 4. Size distribution of four long bones of modern FMNH goats; Southern Fars specimens excluded. (a) Radius Bd,  $i=28$ ,  $s=52$ ; (b) Metatarsal Bd,  $i=25$ ,  $s=46$ ; (c) Tibia Bd,  $i=24$ ,  $s=43$ ; (d) Humerus Dd,  $i=28$ ,  $s=54$ .

females change little after the first year of life. Instead, CV values, like the visual inspection of the distribution of male and female measurements, indicate that male elements show a consistently greater range and degree of variability than females.

This pattern extends to the phalanges, which can prove problematical in metrical analysis because of size differences both between morphologically similar front and hind limb phalanges, and to some extent between phalanges on the lateral and medial sides of each limb. Figure 5 shows, however, that the impact of these factors seem less strongly felt in some measurements than in others. Specifically, while the upper limit of the length measurements in both males and females is a bit greater in fore limb 1st phalanges than in hind limb phalanges (Figure 5(a),(b)), the area of overlap between the lengths of male and female animals in fore and hind elements tends to be quite narrow (mostly attributable to regional size differences), and falls at about the same place in both the fore and hind limb sample. In fact, the distributions of lengths of male fore and hind limb phalanges are statistically indistinguishable from one another ( $t=1.208$ ,  $df=19.9$ ,

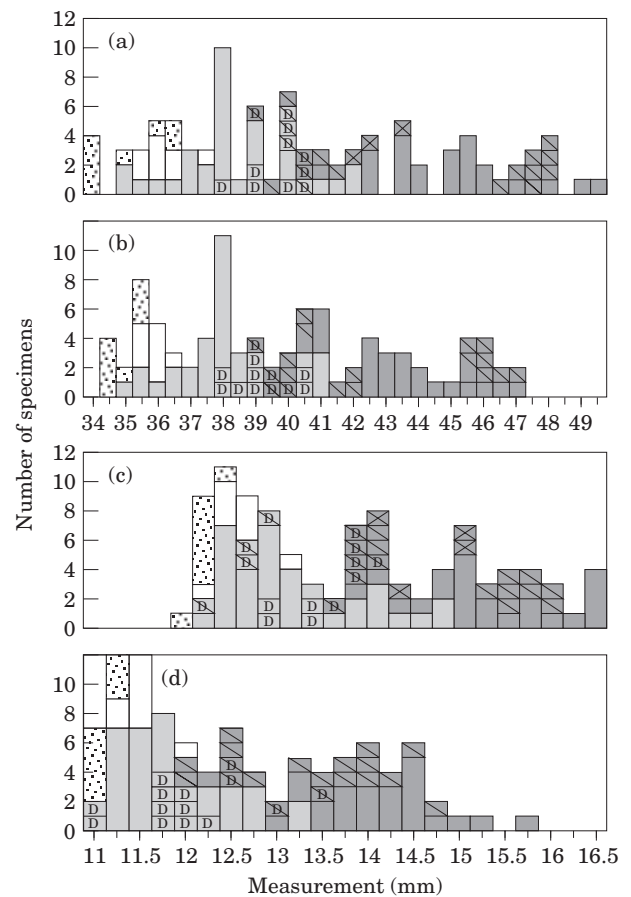


Figure 5. Size distribution of two dimensions of the first phalanx, greatest length (GL) and proximal breadth (Bp) for fore and hind limb phalanges; Southern Fars specimens excluded. (a) 1st phalanx GL: Forelimbs,  $s=26$ ,  $s=99$ ; (b) Hindlimbs,  $i=26$ ,  $s=96$ ; (c) Bp: Forelimbs,  $i=26$ ,  $s=102$ ; (d) Bp: Hindlimbs,  $i=26$ ,  $s=100$ .

$P=0.241$ ), as are the female fore and hind limb phalanges ( $t=0.661$ ,  $df=17$ ,  $P=0.518$ ). However, even in a mixed population of fore and hind limb phalanges, the differences between the distributions of male and female greatest length measurements is highly significant ( $t=-9.101$ ,  $df=35.3$ ,  $P<0.001$ ). In contrast, there is a much greater area of overlap between the proximal breadth measurements of male and female fore and hind limbs (Figure 5(c),(d)). In a mixed sample, the proximal breadth of female fore limb phalanges would be impossible to distinguish from male hind limb elements, and the area of overlap between males and females would account for approximately 50% of the total size range. This same pattern is evident in an examination of 2nd phalanges (Table 1). Thus, while phalanx breadth measurements may not be as reliable in distinguishing between males and females in a mixed sample, length measurements of these elements provide as strong and clear a reflection of the marked dimorphism in the size of male and female goats as any of the other post-cranial measurements. Moreover, the proportional relationship in the ranges of the male and

female length measurements in both the 1st and 2nd phalanges is consistent with that seen in other bones, as is the relationship between the CVs of male and female elements (Table 1).

#### *Domestication and size*

Since the sample of domesticated goats is so small (two females, one complete and one incomplete male, marked with a “D” in Figures 2–5), no final conclusions can be drawn about the impact of domestic status on the size of goats from the Zagros region. However, it is interesting to note that in all measurements the female domesticates fall well within the size range of the wild females. Moreover, although the bones of the more complete domestic male usually fall within the small end of the distribution of wild males, they are often somewhat larger than other wild males in the sample, and are almost always larger than all the females. The single metatarsal from the incomplete domesticated male also falls within the wild male range.

Uerpmann (pers. comm., July 1998) has suggested that comparisons between modern wild and domestic caprines are invalid models for ancient populations, due to recent forces that have caused size reduction in wild caprines, along with improved breeding and management practices that have caused size increase in domestic caprines. As demonstrated below, there is good evidence for size reduction in wild goats over the last 10,000 years. It would be difficult to argue, however, that the FMNH domestic specimens, which represent unimproved breeds from rural villages, were the beneficiaries of the kinds of targeted breeding and enhanced nutrition that might lead to substantial increase in size in these animals over wild animals from similar environmental settings. Moreover, it is curious that with all the size changes proposed by Uerpmann for wild and domestic goats, the modern FMNH domestic females still fall within the range of the wild females and the domestic males fall within that of the wild males. This consistency suggests that sex and environment remain the primary factors influencing size in all goats, both wild and domestic.

#### *Summary: discussion of size variation among modern goats*

There are then, four major conclusions one can draw from this analysis of the FMNH goats:

- (1) There is strong north to south cline in the size of goats, probably related to increasing temperatures and decreasing quality of forage as one moves southward.
- (2) The size distinction between males and females is clearly evident in animals older than 1 year of age, and is present even when comparing unfused bones of young males to fully fused bones of older females.

- (3) Marked and consistent sexual dimorphism of male and female goats is evident in the size of all post-cranial elements and in all dimensions.
- (4) Measurements of the limited sample of domesticated females fall squarely within the range of those of wild females. And while the domesticated males may fall within the smaller end of the size range of the male goats, they are still within the range of wild males, and are generally larger than both wild and domestic females.

Thus, of all the variables examined here (region, age, sex, and domestic status), the sex of an animal is the single most important factor determining size, followed by region, with age coming in a distant third. Finally, the limited sample of domestic animals examined here suggests that domestic status has little discernible influence on the size of these animals.

#### **Archaeological Collections of Goats**

The empirically grounded understanding of size variation in modern goats gained from the analysis of the FMNH collection allows us to take a new look at the methods used to track the transition from hunting to herding that took place in the eastern fertile crescent around 10,000 years ago. This discussion will focus primarily on the large assemblage of goats from the site of Ganj Dareh in the Kermanshah region of western highland Iran (Figure 1), originally studied by Brian Hesse (1978, 1982, 1984) in his breakthrough dissertation research, and re-analysed for the present study. New AMS dates obtained on collagen of goat bones from Ganj Dareh (Zeder & Hesse, 2000; Zeder, 1999) confirm that all five levels at this early village site represent a very brief occupation of about 100 years about 10,000 years ago. The Ganj Dareh goats are accepted as a domestic population by most zooarchaeologists working in the region. Hesse based his conclusion that these animals were domesticated on the basis of demographic patterns that showed an emphasis on young animals, especially males, a pattern consistent with the age profiles of managed domestic herds (Hesse, 1977). Proponents of size reduction as a marker of initial domestication point instead to an apparent reduction in the size of the Ganj Dareh goats when compared to wild Pleistocene benchmark populations as the primary supporting evidence for assigning them domestic status (Uerpmann, 1979; Helmer, 1989; Bar-Yosef & Meadow, 1995). The controversy over the primacy of the relative validity of these different markers of the domestic status of the Ganj Dareh goats, along with the very large size of this carefully collected, well-dated assemblage, makes it an ideal case study comparison of size reduction versus demographic profiling as markers of domestication in archaeological animal bone assemblages.

Table 2. Dimensions of Ganj Dareh goat bones (mm)

Bone	Measurement	Fusion	N	Minimum	Maximum	Mean	Median	S.D.	CV (%)
Humerus	Dd	Both	264	25.29	38.41	30.01	29.13	3.06	10.2
		Fused	226	25.29	38.41	30.16	29.15	3.10	10.3
		Unfused	38	25.57	34.62	29.12	28.73	2.65	9.1
1st phalanx	GL	Both	73	36.48	50.57	42.49	41.40	3.51	8.3
		Fused	55	36.48	49.25	41.79	41.01	3.05	7.3
		Unfused	18	37.50	50.57	44.62	44.49	4.05	9.1
1st phalanx	Bp	Both	133	11.32	17.30	14.04	13.83	1.53	10.9
		Fused	86	11.36	17.30	13.88	13.71	1.47	10.6
		Unfused	47	11.32	16.93	14.33	14.29	1.61	11.2
2nd phalanx	GL	Both	122	24.59	36.38	29.88	29.16	2.85	9.5
		Fused	102	24.59	36.38	29.69	28.87	2.83	9.5
		Unfused	20	25.60	35.92	30.87	31.04	2.78	9.0
2nd phalanx	Bp	Both	134	9.70	18.23	13.83	13.62	1.61	11.6
		Fused	108	9.70	18.23	13.87	13.63	1.66	12.0
		Unfused	26	11.58	16.27	13.69	13.28	1.41	10.3
Metacarpal	Bd	Both	158	24.71	40.78	30.68	29.54	3.58	11.7
		Fused	96	24.71	39.49	29.13	28.92	2.20	7.6
		Unfused	62	25.38	40.78	33.08	33.24	3.97	12.0
Metatarsal	Bd	Both	147	23.49	35.88	28.01	26.79	3.16	11.3
		Fused	87	23.68	32.63	26.50	26.26	1.69	6.4
		Unfused	60	23.49	35.88	30.19	30.99	3.50	11.6
Tibia	Bd	Both	81	24.48	32.72	28.81	28.93	2.21	7.7
		Fused	28	25.24	32.18	28.60	28.65	1.94	6.8
		Unfused	53	24.48	32.72	28.92	29.09	2.35	8.1
Calcaneus	Bp	Both	232	20.61	31.01	24.05	23.92	1.74	7.2
		Fused	74	20.71	26.18	23.67	23.67	1.22	5.2
		Unfused	158	20.61	31.01	24.27	24.02	1.90	7.8
Radius	Bd	Both	181	25.93	40.13	31.99	31.53	3.17	9.9
		Fused	31	29.18	34.72	31.89	31.91	1.44	4.5
		Unfused	150	25.93	40.13	32.01	31.27	3.42	10.7

*Size variation in ancient goat populations*

First let us consider the size of the Ganj Dareh goat assemblage relative to goats recovered from other archaeological sites in the region that bracket the key transitional period from the Late Pleistocene up into the Early Holocene (Figure 1). Collections stored at the Smithsonian's National Museum of Natural History and at the Field Museum that were examined for this study include five small Pleistocene-age cave assemblages: Warwasi, Kobeh, and Kunji caves (dating to the Mousterian/Middle Palaeolithic at c. 50,000 BP), Yafteh Cave (Upper Palaeolithic/Baradostian period c. 30,000 BP), and Palegawra Cave (Upper Palaeolithic/Zarzian c. 12,000 BP). Earlier analyses of these collections include those by Reed (1960, 1983), Turnbull & Reed (1974), Turnbull (1975), Stampfli (1983), and Marean & Kim (1998). These Palaeolithic upland collections have been widely acknowledged as representing wild animals.

The somewhat younger, Epipalaeolithic collection from the open-air site of Asiab, thought to date to about 10,000 years ago (Hole, 1987), was reported by Sandor Bökönyi to contain mostly large adult males, which he interpreted as representing a transitional culling pattern related to early domestication (Bökönyi, 1977). Other researchers, however, subsequently interpreted the size and age data from this site as representative of selective hunting of a wild

population (Hesse, 1984; Ducos & Helmer, 1981; Legge, 1996).

On the other side of the domestication divide is the collection of goats from the site of Ali Kosh, originally studied by Kent Flannery in the 1960s (Hole *et al.*, 1969), and re-analysed for this study. Ali Kosh is also widely accepted as being comprised of domesticated animals on the basis of three different criteria: (1) species abundance—the presence of goats outside their presumed natural range; (2) morphological change—changes in horn form; and (3) demographic data—an emphasis on the slaughter of young animals. Metric data for the Ali Kosh goats have not been available until this study. Ali Kosh makes for a particularly interesting comparison since, in contrast to Ganj Dareh and the other upland sites examined, it is located on the hot, arid Deh Luran Plain, well outside of the Zagros Mountains region. This comparison is also of interest since new AMS dates obtained for this study confirm that Ali Kosh was not occupied until about 500–1000 years later than Ganj Dareh (Zeder & Hesse, 2000; Zeder, 2000). Thus, Ali Kosh provides the opportunity to gain a slightly later glimpse of the ongoing process of goat domestication outside the highland natural habitat of wild goats.

Summary statistics for the Ganj Dareh goats and the goats from other Zagros sites examined in this study are presented in Tables 2 & 3. Figure 6 presents a



Table 3. Dimensions of archaeological goats from sites in the Zagros regions dating from the Middle Palaeolithic to the Early Neolithic (mm)

Bone	Measurement	Site	N fused	N unfused	Minimum	Maximum	Mean	Median	S.D.	CV (%)
Humerus	Dd	Palegawra	2	1	24·83	31·41	27·12	25·11	3·72	13·7
		Asiab	6	0	28·15	32·24	30·44	30·97	1·80	5·9
		Ali Kosh	67	5	22·17	34·98	27·74	26·77	3·02	10·9
1st phalanx	GL	Kunji	3	0	35·64	39·68	37·08	35·92	2·26	6·1
		Palegawra	5	1	35·01	44·36	38·34	37·52	3·58	9·3
		Yafteh	1	0	49·08	49·08	49·08	49·08	—	—
		Asiab	1	0	27·26	27·24	27·26	27·26	—	—
		Ali Kosh	117	4	29·50	46·45	38·39	37·57	3·13	8·2
1st phalanx	Bp	Warwasi	1	0	15·80	15·80	15·80	15·80	—	—
		Kobeh	2	0	12·03	14·87	13·45	13·45	2·01	14·9
		Kunji	3	0	11·81	13·05	12·43	12·43	6·20	5·0
		Palegawra	8	1	10·97	15·86	12·92	12·44	1·44	11·2
		Yafteh	9	2	12·51	18·25	14·45	13·77	1·77	12·2
		Asiab	4	1	12·04	16·76	13·91	14·13	1·91	13·7
		Ali Kosh	166	15	10·67	18·25	13·13	12·95	1·35	10·2
2nd phalanx	GL	Kobeh	1	0	33·92	33·92	33·92	33·92	—	—
		Kunji	1	0	26·45	26·45	26·45	26·45	—	—
		Palegawra	8	0	29·33	35·38	31·44	31·07	2·09	6·6
		Yafteh	10	0	25·99	33·15	29·49	29·42	2·60	8·8
		Asiab	7	0	26·48	32·67	30·07	30·70	2·57	8·5
		Ali Kosh	104	9	22·44	31·93	26·20	25·70	2·07	7·9
		Kobeh	1	0	17·78	17·78	17·78	17·78	—	—
2nd phalanx	Bp	Kunji	2	0	12·48	13·38	12·93	12·93	0·64	4·9
		Palegawra	8	0	14·29	18·42	16·03	15·81	1·60	10·0
		Yafteh	9	0	12·81	18·30	15·33	14·86	2·12	13·8
		Asiab	4	0	11·70	18·31	15·01	15·01	2·98	20·0
		Ali Kosh	99	11	10·71	16·56	12·80	12·70	1·36	10·7
		Palegawra	1	0	26·29	26·29	26·29	26·29	—	—
		Asiab	2	0	29·84	31·29	30·57	30·57	1·3	3·4
Metacarpal	Bd	Ali Kosh	26	8	24·82	35·89	27·98	27·01	2·88	10·3
		Kobeh	1	0	36·28	36·28	36·28	36·28	—	—
Metatarsal	Bd	Ali Kosh	29	12	21·52	32·85	24·72	23·78	2·69	10·9
		Kunji	1	0	28·65	28·65	28·65	28·65	—	—
Tibia	Bd	Asiab	2	0	27·57	31·78	29·68	29·68	2·98	10·0
		Ali Kosh	38	26	20·87	32·77	26·36	26·08	2·29	8·7
		Palegawra	1	1	19·18	21·71	20·46	20·46	1·81	8·8
Calcaneus	Bp	Asiab	0	1	23·71	23·71	23·71	23·71	—	—
		Ali Kosh	19	19	19·15	25·48	22·03	21·93	1·56	7·1
		Kunji	1	0	33·13	33·13	33·13	33·13	—	—
Radius	Bd	Palegawra	1	3	26·15	33·82	29·09	28·20	3·37	11·6
		Asiab	2	0	31·78	41·40	36·59	36·59	6·81	18·6
		Ali Kosh	9	53	24·47	29·77	30·35	30·00	3·36	11·1
		—	—	—	—	—	—	—	—	—

graphic comparison of the measurements of the second phalanx—a bone particularly well represented in all assemblages examined. It is clear that the wild goats from both the Pleistocene sites and the Epipalaeolithic hunting camp of Asiab all fall comfortably within the distribution of the larger sample of goats from Ganj Dareh. The means and the medians for all of the assemblages are almost identical. Student's *t*-test comparing these assemblages show, not surprisingly, no significant difference between them. Moreover, this pattern is consistently seen in all bones measured taken from upland sites (Tables 2 & 3). In all cases, the samples from these likely wild goat assemblages fall comfortably within the range of the Ganj Dareh assemblage, and when samples are large enough to compute more reliable summary statistics, or when Pleistocene sites are grouped together (Figure 6), there is no demonstrable difference in the range, mean, and

median between these wild highland assemblages and the Ganj Dareh goats. While the small sample size of the wild goat assemblages makes it difficult to draw any firm conclusions about the variability of these wild assemblages as measured by their CVs, the generally smaller Ganj Dareh CVs certainly do not indicate the comparatively greater degree of variability predicted by Uerpmann (1979) and others (Meadow, 1989) for a domestic population. Thus, contrary to earlier claims for size diminution of the Ganj Dareh goats (Uerpmann, 1979; Helmer, 1989; Bar-Yosef & Meadow, 1995), there is no evidence of size reduction in the Ganj Dareh collection when compared to assemblages of earlier and contemporary assemblages of wild goats from the same region. The reasons for the divergence of these results from earlier studies that argued for size reduction in the Ganj Dareh goats is explored below.

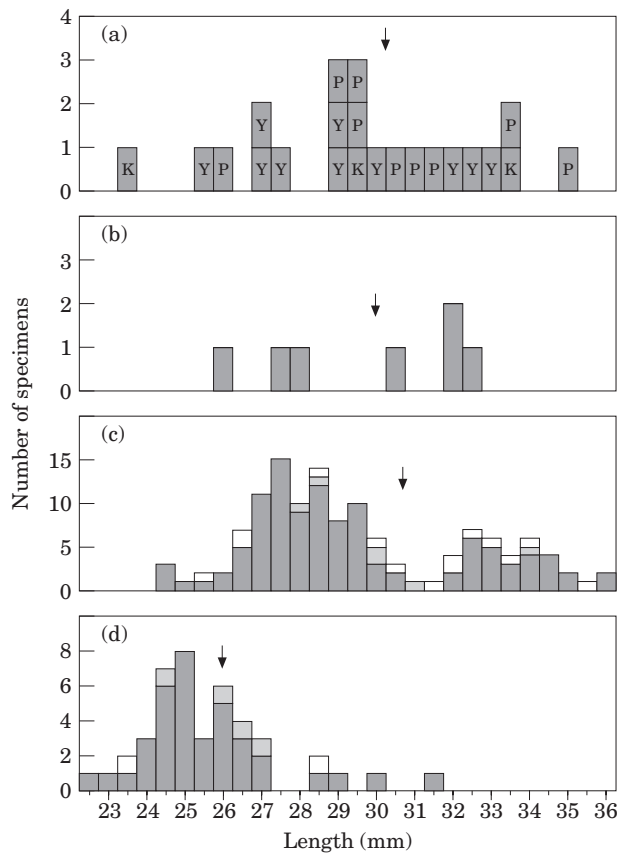


Figure 6. Comparison of the second phalanx greatest length (GL) for specimens from archaeological assemblages. Fused bones represented by dark grey bars, fusing bones in light grey shaded bars, and unfused bones by white, unshaded bars. Means are indicated by an arrow. Abbreviations for Pleistocene age sites: K: Kobeh, P: Palegawra, Y: Yafteh. (a) Pleistocene sites, number ( $N$ )=23; (b) Asiab,  $N$ =6; (c) Ganj Dareh,  $N$ =129; (d) Ali Kosh,  $N$ =43.

There is, however, a difference in the size of the lowland Ali Kosh goats from the initial Bus Mordheh levels of occupation when compared to highland collections. The Ali Kosh goats are distinctively smaller in their means, medians, and ranges, a difference that is significant at greater than a 0.001 level of probability in all cases. While it is possible that the change in the size of the Ali Kosh goats is an artefact of 500–1000 years of human management of goats, it is also useful to keep in mind the demonstrated impact of climatic and environmental conditions on size seen among the modern FMNH goats (Figure 2). Indeed, the difference in the size of the Ganj Dareh and Ali Kosh goats is quite comparable to the degree of difference between the modern Kermanshah and Southern Fars samples, which represent strong environmental parallels to the upland Ganj Dareh region and the arid Deh Luran Plain. The CVs of the Ali Kosh goats, however, are similar to those of the Ganj goats, indicating that, despite the change in size, there has been no change in the variability of the sample.

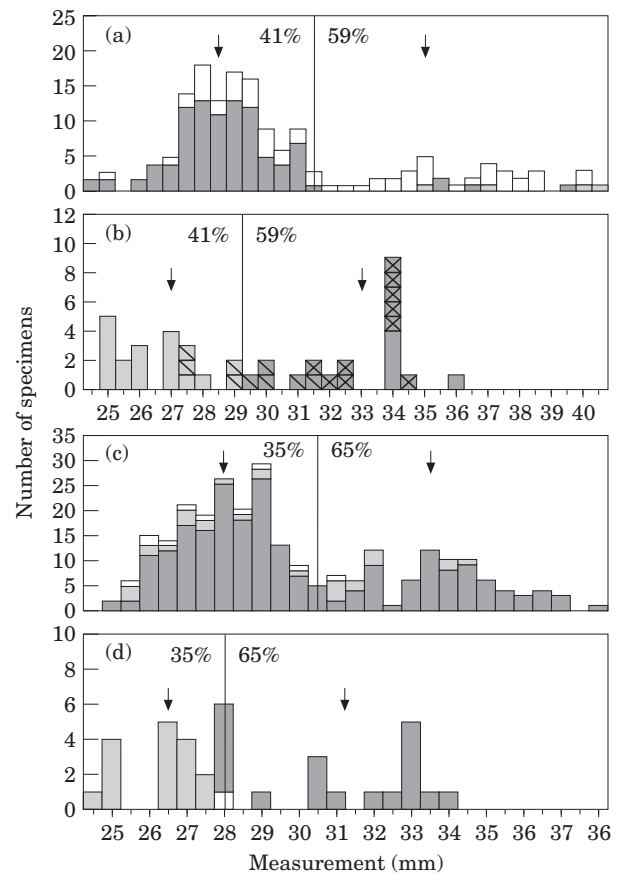


Figure 7. Comparison of the size distributions of modern FMNH goats and archaeological goats from Ganj Dareh for the distal breadth of the metacarpal and the distal breadth of the humerus; excluding goats from Southern Fars, animals in age class A, and domestics. The dividing line between the size range of males and females in the modern sample is marked by a bold vertical line and the proportional representation of each sex within the total range of variation noted on either side of the line. Arrows mark the mean and female sub-populations. (a) Metacarpal Bd: Ganj Dareh,  $N$ =157; (b) Metacarpal Bd: Modern,  $i$ =22,  $s$ =42; (c) Humerus Dd: Ganj Dareh,  $N$ =264; (d) Humerus Dd: Modern,  $i$ =21,  $s$ =41.

#### *Size variation from the Early Holocene to the modern era*

Figure 7 compares the measurements of two bones (the metacarpal and the humerus) of the modern Iranian goats to those of the 10,000-year-old highland Ganj Dareh goats. The modern sample displayed here is comprised solely of wild goats older than about 1 year of age from the five more northern collecting localities in the study region. The graphs in Figure 7 follow the conventions adopted in earlier figures of the modern and archaeological collections for designating males and females in the modern collections and for noting states of fusion in the modern and the archaeological assemblages.

It is clear that over the past 10 millennia there has been a substantial decrease in the average size of wild goats in the Zagros highlands. Yet this change is more

Table 4. Dimensions of Ganj Dareh goats by sex

Bone	Measurement	Cut-off	Sex	N	Minimum	Maximum	Mean	Median	S.D.	CV (%)
Humerus	Dd	29·88	Male	100	29·99	38·41	33·38	33·62	2·05	6·1
			Female	164	25·29	29·88	27·96	28·09	1·16	4·1
1st phalanx	GL	41·98	Male	30	42·04	50·57	46·01	46·30	2·56	5·6
			Female	43	36·48	41·98	40·04	40·10	1·28	3·2
2nd phalanx	GL	29·19	Male	61	29·25	36·38	32·17	32·51	2·11	6·6
			Female	61	24·59	29·06	27·60	27·81	1·12	4·1
Metacarpal	Bd	31·29	Male	42	31·36	40·78	35·85	35·81	2·48	6·9
			Female	116	24·71	31·28	28·81	28·90	1·40	4·9
Metatarsal	Bd	27·95	Male	50	28·03	35·88	31·84	32·20	2·21	6·9
			Female	97	23·49	27·91	26·03	26·17	1·03	3·9
Tibia	Bd	27·86	Male	51	28·02	32·72	30·25	30·45	1·30	4·3
			Female	30	24·48	27·82	26·37	26·37	0·85	3·2
Calcaneus	Bp	24·77	Male	101	24·79	31·01	26·16	25·81	1·13	4·3
			Female	194	20·61	24·77	23·20	23·30	1·07	4·6
Radius	Bd	31·61	Male	90	31·69	40·13	34·57	33·99	2·21	6·4
			Female	91	25·93	31·53	29·44	29·90	1·42	4·8

Table 5. Coefficient of variation for modern goats and ancient Ganj Dareh goats

Bone	Measurement	CV (all modern)	CV (all ancient)	CV (male modern)	CV (male ancient)	CV (female modern)	CV (female ancient)
Humerus	Dd	10·7	10·2	7·3	6·1	4·7	4·1
1st phalanx	GL	8·6	8·3	6·1	5·6	4·2	3·2
2nd phalanx	GL	7·8	9·5	5·9	6·6	3·7	4·1
Metacarpal	Bd	11·7	11·7	5·2	6·9	4·5	4·9
Metatarsal	Bd	11·0	11·3	6·7	6·9	3·8	3·9
Tibia	Bd	8·1	7·7	5·4	4·3	3·5	3·2
Calcaneus	Bp	6·9	7·2	5·1	4·3	3·2	4·6
Radius	Bd	10·4	9·9	9·0	6·4	4·0	4·8

complex than a simple downward shift in the size range of the goat population. Instead it seems that while the upper limits of the modern range, which includes the largest of the male animals, is considerably smaller than in the 10,000-year-old Ganj Dareh assemblage, the lower limit of the size range, the size of the smallest modern female goats, has remained relatively unchanged. Comparison of the population statistics for the ancient and modern goats in Tables 1 and 2 shows this pattern in all post-cranial bones measured. Whatever the factors that caused this change in the size of goats in this region over time, then, they seem to have affected males and female goats in different ways.

Given the demonstrated difference between the sizes of male and female goats in the modern sample, the marked bimodality in the archaeological goat bones displayed in Figure 7(a) and (c) can also, in all likelihood, be attributed to sexual dimorphism. Thus, the group of smaller specimens on the left-hand-side of the graph most likely consists primarily of females, while the larger specimens on the right represent males. Transposing the proportional dividing lines between modern males and females on to the ancient distributions, the vertical line in Figure 7, cleanly separates the larger and smaller modes of the ancient population.

When this is done for all the bones measured in the Ganj Dareh assemblage (Table 4), summary statistics for these proposed ancient male and female populations can be compared with those presented in Table 1 for the known males and females in the modern population.

In all bones examined there seems to have been little, if any, change over the last 10,000 years in the lower limit of the size range of females in these highland populations. However, there has been a fairly substantial downward shift in the upper size limit and the mean size of modern females, resulting in a contraction in the size range of modern wild females when compared to the ancient females. In wild males, on the other hand, there seems to have been a quite consistent downward displacement in both the lower and upper limits of their size range. However, not only are CVs for the total populations of ancient and modern goats almost identical in all bones (Table 5), there is also striking similarity between the CVs of the known male and female goats in the modern sample and those computed for the presumed male and female goats in the ancient sample. This consistency is all the more remarkable given the greater regional range of the modern sample, and the likelihood that the separation

between males and females in the ancient population is not entirely clean. Thus, it would seem that while the size range of modern goats has contracted over time, and while males and females have experienced this change in somewhat different ways, the overall nature and proportional relationships between the size distributions of male and female goats has remained unchanged. It is possible, then, to use the empirically demonstrated relationships between the sizes of modern male and female goats to differentiate between male and female individuals in these ancient bone assemblages where the sex of individuals is not directly known.

#### *The demography of the goats from Ganj Dareh*

The size distributions of seven different bones in the Ganj Dareh goat assemblage are presented in Figure 8. The bold vertical line in each represents the proportional cut-off between males and females extrapolated from the modern sample for each bone, and the arrows mark the means of the distributions of the presumed males and females. Bones are arranged in decreasing order of fusion, from the distal radius at the top (Figure 8(a), which Silver estimates to fuse at 36 months) to the distal humerus (Figure 8(g), whose fusion is set at 10 months). There are a number of patterns highlighted in this graph which have important bearing on the demography of the Ganj Dareh goat herd.

As was the case for the humerus and metacarpal, in the more clearly bimodal distributions included in Figure 8 (the metatarsal and the phalanges) the extrapolated cut-off between males and females separates the two modes in the archaeological population reasonably well. The distinction between the male and female size modes is less clearly marked, but still evident, in the greatest depth of the calcaneus and the distal breadth of the radius, two bones that showed a greater degree of overlap between males and females in the modern sample as well. Also as in the modern sample, the means of the ancient male and female samples in all bones fall proportionately in about the same place on each graph.

One of the most striking patterns in this figure is the steady increase in the proportion of unfused bones, especially in the larger, presumed male, mode of each graph. This visual pattern is numerically supported in Table 2 by the proportional increase in the number of unfused elements in bones that fuse at progressively older ages, and the tendency for these unfused elements to have a greater mean size than fused elements. This suggests that males in the sample were killed at younger ages than females.

Also noteworthy is the general under-representation of specimens included in the larger, male mode relative to the number of smaller specimens that fall into the female mode. Rather than an artefact of past human preference, this pattern is probably best attributed to

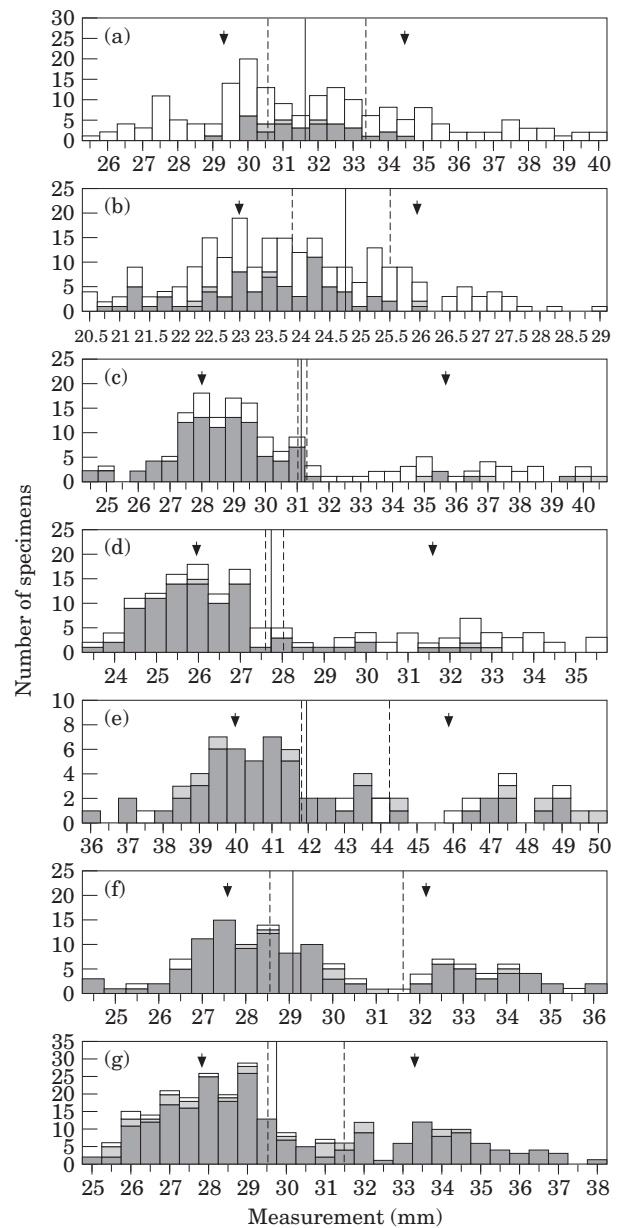


Figure 8. Size distribution of seven long bones from Ganj Dareh with male/female dividing lines based on modern collections transposed on to each bone. The dotted lines mark the 90% confidence interval for inclusion in the female or male groups, based on discriminant function analysis. Black arrows mark the mean of the male and female sub-populations. (a) Radius Bd,  $N=182$ , 36 months; (b) calcaneus Bp,  $N=237$ , 30 months; (c) metacarpal Bv,  $N=157$ , 24 months; (d) metatarsal Bd,  $N=146$ , 24 months; (e) 1st phalanx GL,  $N=73$ , 16 months; (f) 2nd phalanx GL,  $N=129$ , 13 months; (g) humerus Dd,  $N=264$ , 10 months.

the differential impact of post-depositional taphonomic factors on the preservation and recovery of male and female elements. The more friable, unfused bones of young males were not preserved or recovered in the same quantity as the more hardy bones of females, killed at a later stage of development. This hypothesis



is supported by the better proportional representation of males in early fusing bones, like the humerus, and the steady decrease in the proportion of males in progressively later fusing bones.

#### *Computing male and female survivorship curves*

Despite the high degree of dimorphism in the modern sample, there are still areas of overlap between the size distributions of the male and female population segments, with overlap areas more marked in certain bones than in others. It is therefore quite likely that despite the greater regional homogeneity of the Ganj Dareh sample, there is some overlap between the size range of males and females in this archaeological assemblage as well. One way to isolate this area of potential overlap in the ancient population is to compute the probability of group membership of each measurement on a case-by-case basis, and then eliminate from further consideration those specimens that fail to meet a defined threshold of group membership. This can be accomplished by computing the Mahalanobis distance squared of each measurements from the mean of the ancient male and female groups defined by the imposed cut-off point, and then examining the probability of membership in this group for each different specimen. The dashed lines on either side of the bolder vertical male/female dividing line on the graphs in Figure 8 represents the 90% confidence interval of group membership for each sex. The area isolated in this way generally conforms with the area of overlap between known males and females in the modern sample, and exclusion of this possible overlap zone in a division of the ancient sample into male and female sub-populations should safeguard against misclassification of males and females.

Having divided the ancient population into probable male and female groups, and having defined regions of potential overlap, it is now possible to compute sex-specific age distributions for the Ganj Dareh assemblage. This is done using Redding's (1981a) "fusion score" formula for each element of known fusion age:

$$(f + (i \cdot 0.5) / (f + i + u)) \cdot 100,$$

where  $f$ =fused bones,  $i$ =fusing bones, and  $u$ =unfused bones. The resultant score provides an estimate of the proportion of animals that survived beyond the age at which the element fuses. When the scores of various elements are examined in the order in which they fuse, an impression is gained of the intensity of kill-off of animals over the years represented in the fusion sequence.

Comparing the sex-specific survivorship curves computed this way (Figure 9(a)) reveals a sharp contrast between the kill-off profiles of males and females. Kill-off males appears to begin sometime after the estimated 10-month fusion age of the distal humerus,

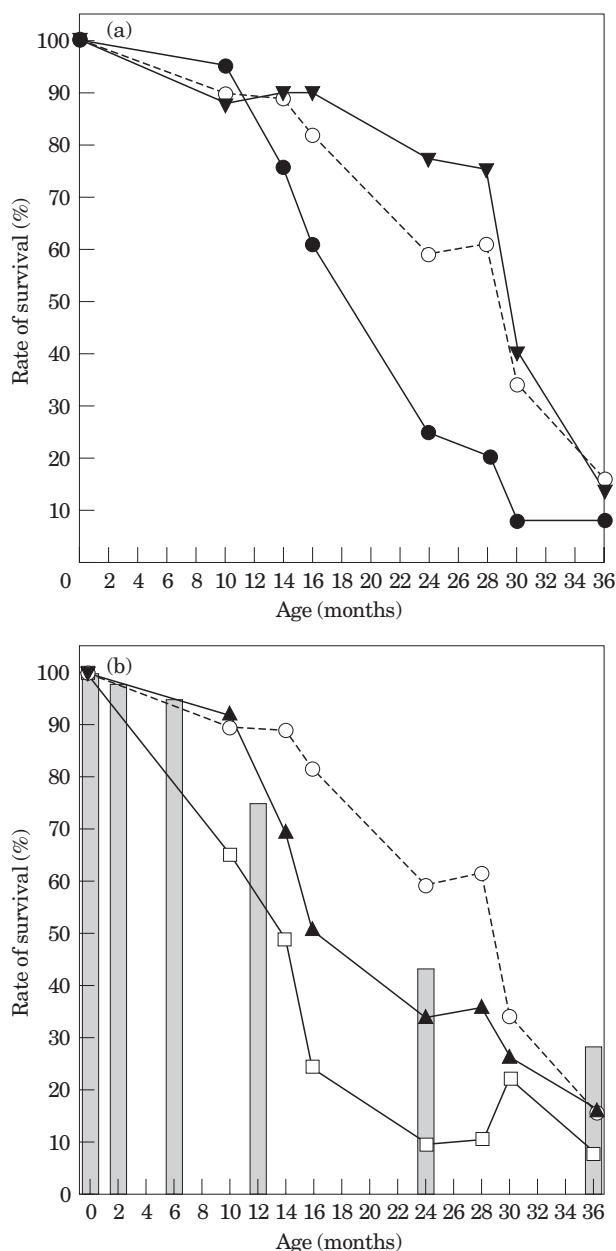


Figure 9. Survivorship curves (a) for male and female Ganj Dareh goats compared to the curve computed using the entire sample of measurable goat bones and (b) the curves computed using the measurable goat bones, all identifiable goat bones, and bones that could only be identified as either sheep or goat. ○, measured goats,  $N=1098$ ; ▼, females 90%,  $N=606$ ; ●, males 90%,  $N=311$ ; ▲, all goats,  $N=2360$ ; □, sheep/goats,  $N=1364$ ; ■, dental age,  $N=250$ .

with survivorship tumbling from 95% at 10 months to 20% by the age of fusion of the distal metacarpal (estimated at 24 months). In contrast, female survivorship remains quite high until sometime between the ages of fusion of the distal metapodials and the calcaneus (between 24 and 30 months), falling to 16% at the age of fusion of the distal radius (c. 36 months).

The dashed line shown in Figure 9(a) represents the survivorship of the combined sample of all measured

goat bones displayed in Figure 8, the males, females, and specimens that fall in the overlap zone between these two groups. Clearly the larger female sample is primarily responsible for determining the shape of this curve, while the young kill-off pattern of the male sample has only a minimal impact on this combined curve. This is due to the under-representation of males in the sample of measurable caprine bones that could be identified to species.

In Figure 9(b) the survivorship curve computed using measurable goat bones is contrasted to a curve computed using the total of all measured and unmeasured goat elements (bones that could be identified as goats, but that did not have preserved metric landmarks), as well as to a “caprine” survivorship curve based on bones that could only be identified as either sheep or goat. Also included is a survivorship pattern on dental age estimates for the combined sample of Ganj Dareh sheep and goats taken from Hesse (1978: 258), shown in bar form. Given the 14 to 1 ratio of identifiable goat to sheep bones in this assemblage, this sheep/goat population can be safely considered to be primarily comprised of goats. The three distributions based on measured goats, all goats, and sheep/goat dental age, all show close agreement up to about 1 year of age, at which point the latter two distributions drop much more steeply than the curve based on measurable goat bones alone. The decline is steeper still in the survivorship curve computed for the bones that could only be identified as sheep or goats, where there is a 35% drop in survivorship between birth and 10 months of age.

Given the emphasis on the culling of young males and the relative longevity of females evident in the sex-specific age curves, the young animals whose slaughter is captured in these non-sex-specific age distributions were most probably predominately males. In fact, the survivorship curve for the total goat population and the caprine dental age profile both closely mirror the survivorship curve computed for male goats in Figure 9(a). The more friable bones of these younger animals are simply less likely to have preserved landmarks that would allow either metric analysis or species identification, and are, therefore, less likely to be included in the sample of post-cranial bones used to construct the sex-specific age profiles. Moreover, as we have seen from the analysis of the modern goats, even when recovered in measurable condition, the bones of young males killed before the fusion of the distal humerus are likely to fall into the female side of the size distribution. Thus, the apparent delay in slaughter of young males suggested by the more gentle drop in survivorship from 0 to 10 months in the male curve (and in all but the sheep/goat curve in the non-sex-specific age profiles), is less an artefact of ancient culling practices, than a reflection of the loss of bones and teeth of very young animals from the sample, and the difficulty of identifying or measuring those that survive. In addition, the initial drop and

then apparent resurrection in female survivorship between birth and 16 months of age is probably a reflection of the misclassification of very young male goats in the female population. It would seem likely, then, that kill-off of males at Ganj Dareh was even earlier and more intensive than indicated by the male survivorship curve in Figure 9(a), beginning during the first year of life, with few males surviving past the point of fusion of the metapodials, at around 2 years of age.

It is important to consider here the calibration of the fusion data with the actual age at death of the animals. As indicated earlier, Silver's age estimates, based on a population of modern domestic cross breeds (Silver, 1963: 254), are widely used as a kind of “industry standard” for age estimation. And while his classification agrees in general terms with other available fusion calibrations, such as Noddle's (1974) estimates for fusion in domestic goats, as Silver notes, it is unlikely that the ages of fusion in Silver's study universally apply to all sheep and goats, irrespective of region, climate, or nutritional levels. In fact, the fusion rates of different species, and perhaps even sub-species, of caprines, raised under different conditions, will almost certainly vary from Silver's estimates. This is perhaps especially true for the 10,000-year-old Ganj Dareh goats, which were only just beginning to come under human control. Indeed, Bullock & Rackham's (1982) data for Scottish feral goats suggests that while Silver's ages of fusion are in general agreement with their estimates for earlier fusing bones (the distal humerus, phalanges, and metacarpals), they may be significantly too young in later fusing bones (the calcaneus, distal radius, and proximal humerus). Thus, the apparent intensification in female kill-off at about 30 months indicated in Figure 9(a) (using Silver's calibration) may actually have occurred at a somewhat older age. Even given this important cautionary note, however, the general sequence and timing of fusion of bones observed by Silver is quite secure, and, therefore, the general patterns of early male kill-off and delayed harvesting of females seen in the Ganj Dareh population is an accurate reflection of the ancient herd management practices.

The Ganj Dareh sex-specific age profiles can be compared to those of the goat population from the nearby, and roughly contemporary, site of Asiab, which is generally accepted as a wild hunted population. Figure 10 presents the distribution of five bones from the Asiab goat assemblage using the size range of the Ganj Dareh population as a scale template. The use of the large Ganj Dareh sample to set this scale is justified due to the environmental and temporal proximity of the two sites. Moreover, in all bones examined the size distribution of the Asiab bones fits well within the limits of the Ganj Dareh distribution (Tables 2 & 3), suggesting that the absence of individuals in the Asiab assemblage at either the smallest or largest extent of the Ganj Dareh range is more a function of sample size than of an overall difference in

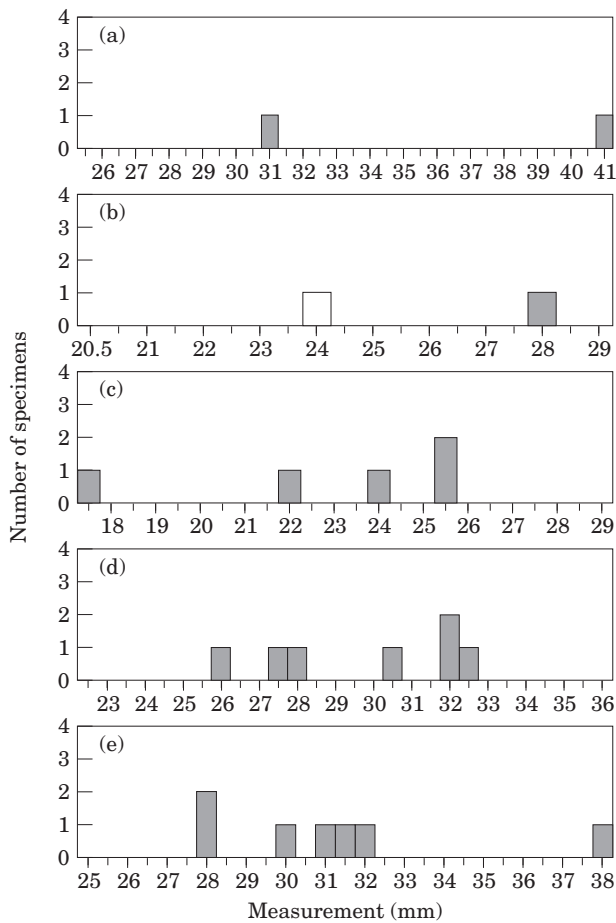


Figure 10. Size distribution of five long bones of Asiab goats. (a) Radius Bd,  $N=1$ , 36 months; (b) calcaneus Bp,  $N=2$ , 30 months; (c) tibia Dd,  $N=5$ , 24 months; (d) 2nd phalanx GL,  $N=7$ , 13 months; (e) humerus Bd,  $N=6$ , 10 months.

the size of goats utilized at these two sites. Yet, despite the small size of this sample, and in strong contrast to Ganj Dareh, there is a clear tendency for the bones of the Asiab goats to fall into the right-hand-side of the scale. Moreover, the majority of these bones, especially among those in the larger presumed male side of the distribution, are fused.

Using the same points of division to separate the Ganj Dareh sample into male and female population segments (without eliminating samples in the potential overlap zone, owing to the small size of the Asiab assemblage), sex-specific age distributions can be generated for the Asiab assemblage (Figure 11(a)). The high survivorship of the male goats from Asiab is striking. Almost all of the males in the sample are older than the age of fusion of the oldest fusing bone. In contrast, the age profile for presumed females suggests the utilization of somewhat younger animals than seen among the males, though it is important to keep in mind here that the unfused bones on the female side might represent either young females or very young

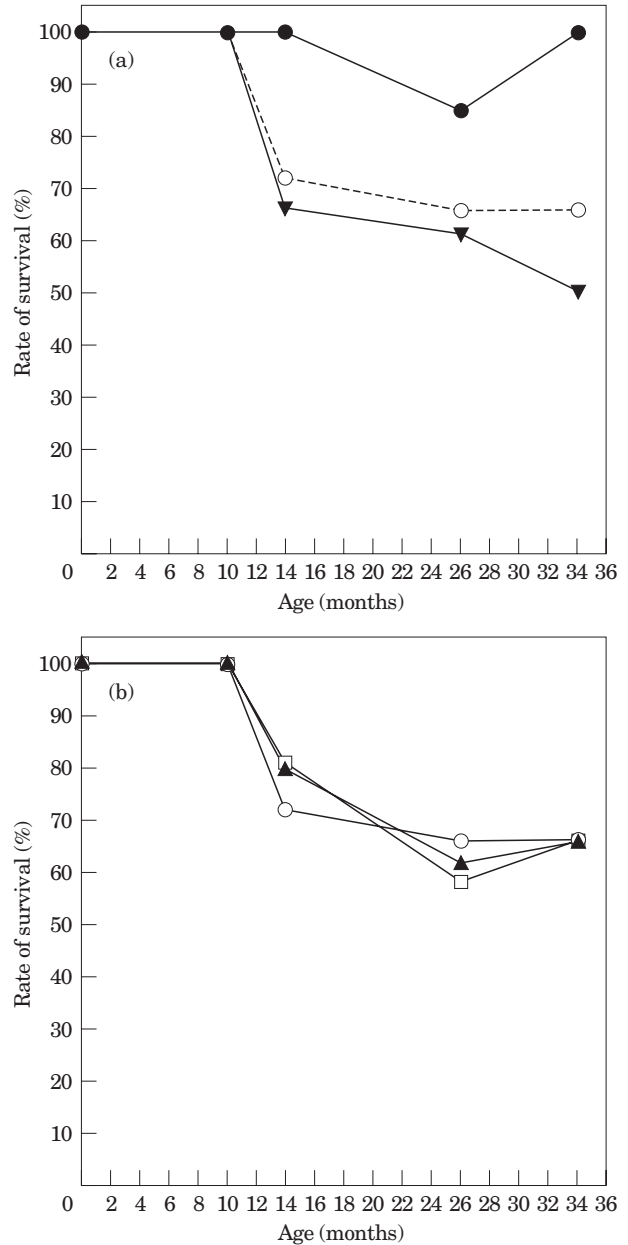


Figure 11. Survivorship curves (a) for male and female Asiab goats compared to the curve computed using the entire sample of measurable goat bones and (b) the curves computed using the measurable goat bones, all identifiable goat bones and bones that could only be identified as either sheep or goat.  $\circ$ , measured goats,  $N=27$ ;  $\nabla$ , females,  $N=19$ ;  $\bullet$ , males,  $N=24$ ;  $\blacktriangle$ , all goats,  $N=62$ ;  $\square$ , sheep/goats,  $N=112$ .

males. When the curves generated for the sample of measurable goat bones are contrasted to those computed for both the entire goat sample and the sheep/goat sample from the site (Figure 11(b)), all three curves indicate a strong emphasis on the utilization of older animals. This pattern is consistent with a hunting strategy that targets older prime-age male animals, but also includes females and younger animals. In contrast, the Ganj Dareh distribution resembles the demography

of a herd managed to produce a reliable supply of meat while promoting the perpetuation of the herd—a strategy which predominates among pastoralists in the region today (Payne, 1973; Redding, 1981b). Thus, despite the lack of any detectable shift in the size of the Ganj Dareh goats from wild goats in the region, this system of controlled culling irrefutably marks them as a managed, and, therefore, domesticated population.

### Size Reduction and Demographic Profiling as Markers of Initial Domestication

This study cast serious doubts on the utility of size reduction as an effective marker of initial domestication in goats. Not only is there little variation in the size between modern wild and domesticated goats, domesticated animals in managed herds of the Early Holocene are also indistinguishable on the basis of size from demonstrably wild animals from the same region. This includes the wild goats from roughly contemporary contexts, as well as those from preceding Late Pleistocene sites in the eastern fertile crescent.

This conclusion is at odds with earlier studies that maintained the Ganj Dareh goats showed a significant degree of diminution when compared to Palaeolithic benchmark populations (Uerpmann, 1979; Helmer, 1989; Bar-Yosef & Meadow, 1995). However, based on this analysis it is likely that what previous studies interpreted as population-wide size reduction in this early domestic goat population was, in fact, a shift in the sex ratio of the adult breeding population in a managed herd. The danger of misreading a shift toward female domination of adult herds as representing an across the board size reduction is, in part, the result of the common practice of measuring only fully fused bones as prescribed by von den Driesch (1976: 4). As shown here, in the Ganj Dareh assemblage the bones of female animals overwhelmingly dominate the sample of fused elements, while the bones of the young males, when preserved in measurable condition, are more likely to be unfused, especially in the case of bones that fuse after about 1 year of age. Moreover, owing to their more friable condition, many of the bones of young males are likely to be too fragmented to permit either measurement or even secure species identification. In contrast, in an assemblage of hunted animals, like that from Asiab and the earlier Palaeolithic sites examined, the bones included in a metric study restricted to fused bones would be dominated by large adult males. Comparison of the sizes of the fused bones from these sites would seem to point to size reduction, when in fact, size variability in these populations is largely attributable to the selection of the age and sex of animals utilized in the past, as well as to taphonomic factors that select against the preservation of the bones of young animals, and methodological practices that limit metrical analysis to fused bones of adults (see Ducos, 1991 and Meadow, 1999).

Although Meadow recognizes the possible impact of the presence of large numbers of older females on the size profiles of managed populations, he also maintains that a shift in the minimum size of elements, plus an increase in variability in the sizes of goat represented in faunal assemblages of late 10th, early 9th millennia, are both indicative of a population-wide reduction in the size of both males and females in these early managed herds (Bar-Yosef & Meadow, 1995; see also Uerpmann, 1978, 1979). However, there is no demonstrable downward shift in the minimum size of the Ganj Dareh assemblage when directly compared to highland wild assemblages, nor is increased variability in size of Ganj Dareh goats indicated by the coefficients of variation in these assemblages.

Another likely contributing factor to the false impression of size reduction in the Ganj Dareh assemblage is the common methodological practice of blending the normalized measurements of many different elements into a single size profile for an assemblage or group of assemblages representing a general temporal period (see Uerpmann, 1979; Meadow, 1989 and, especially, 1999, for a discussion of the history of this technique and a consideration of some of its limitations). This blending of the normalized values of many different skeletal elements exacerbates the bias toward the fused bones of smaller females in assemblages like Ganj Dareh, calling into question the utility of this technique in its intended purpose of tracking population-wide size variation over time. Not knowing the source of the measurements that contributed to a normalized profile, it is impossible to assess whether evident differences between profiles are attributable to population-wide change in ancient populations, to differences in the hunting/herding strategies that may emphasize different ages and sexes of animals, or to other taphonomic and randomizing factors that shaped the range of elements used to compute the coalesced profile. Indeed it would seem that such techniques needlessly blur the fine-tuned sensitivity of individual elements to age-dependent shifts in the proportion of male and female animals in a population, patterns central to monitoring the initial shift from hunting to herding.

This is not to say that domestication has no impact on the size of caprines. Zohary *et al.* (1998) have recently presented a compelling argument for how human management of caprines might result in the diminution of size of individuals in a population, especially male individuals. And while domestic status could not be detected in the size of the small sample of modern domestic goats studied here, especially in female goats, there was some suggestion that male domesticates appear to fall at the lower end of the range of variation of modern wild goats. These, admittedly limited, data lend support to the proposition that domestication results in a lessening in the degree of sexual dimorphism in domestic herds when compared to animals in the wild under selective



pressures that favour greater size in males (Zohary *et al.*, 1998). However, as Zohary *et al.* point out, the length of time it takes for such a change is uncertain and, as indicated by the present study of modern goats, may not be easily recognized.

The smaller size of the Ali Kosh goats when compared to the Ganj Dareh goats might be taken as an indication of size reduction in managed herds (Figure 5) over the 500 to 1000 years that we now know separated the occupation of these two sites (Zeder & Hesse, 2000; Zeder, 1999). It is impossible, however, to tell if the smaller size of this lowland goat population is attributable to selective factors that favour smaller animals in managed herds, to the adaptation of colonizing domestic goat populations to harsher environmental conditions, or to the initial smaller size of a more southerly population of ancestral wild goats. The range of possible factors that might have been involved in influencing the smaller size of the Ali Kosh goats helps underscore the fundamental difficulty inherent in any attempt to employ general size reduction as a marker of goat domestication. There are simply too many other, more potent factors that influence size in goats for size to be confidently used as a marker of their initial domestication. Sexual dimorphism, regional variation, climate, and time have all been shown to have a marked and measurable impact on size in known populations of wild goats. A downward shift in the size of male domesticates would be easily lost among the other, more powerful forces that influence size in these animals.

In contrast, changes in herd demography represent a much better marker of the initial stages of the domestication process. Many of the patterns observed in the Ganj Dareh assemblage in this study were noted by Hesse in his original analysis of this important collection (Hesse, 1978, 1982, 1984). Drawing, in part, from an earlier study by Higham (1967) on European stock rearing, Hesse recognized the marked bimodality in the measurements of various elements, the tendency for unfused elements to be larger than fused elements, and the decreasing proportion of larger specimens in later fusing bones. He concluded that these patterns were indicative of a distinctive demographic profile that he took as a marker of the initial stages of domestication. What was missing from his landmark study, however, was a clear and concrete connection between sexual dimorphism in goats, differential treatment of male and female goats by Ganj Dareh herders, and the observed size and fusion patterns of the Ganj Dareh goat bone assemblage. The modern FMNH goat collection analysed here provides this critical missing link, in that it shows that the bones of male and female goats are highly dimorphic, and that the unfused elements of males older than 1 year are distinctly, and absolutely, larger than the fully fused bones of adult females. Analysis of this modern baseline collection also illuminates the regularity in the male to female size relationship across a broad range of different skeletal

elements and over time. This demonstrated regularity permits, for the first time, the confident separation of ancient caprine bone assemblages into male and female sub-populations, which in turn allows the computation of separate male and female survivorship curves. This study also considers Ganj Dareh within the broader context of other earlier and later archaeological assemblages, and, in so doing, strengthens and extends Hesse's prescient observations into a robust method for firmly establishing the early origins of goat domestication.

Meadow (1989: 83) has argued that age and sex profiles are of limited value as markers of domestication because it is "impossible to use age and sex ratios to *rule out* [original emphasis] selective hunting as an explanation of particular faunal configurations". He also questions whether there is a typical demographic pattern that can be used to detect human management of domesticated herds since ancient herders may have followed different culling strategies to obtain various animal products (i.e. meat, milk, or wool), and he worries that in some cases social reasons might override economic factors in shaping herd demography, or that random acts of God could influence age and sex profiles in managed herds.

It is possible that some hunted assemblages represent strictly seasonal or otherwise highly selective samples of ages and sexes. However, such ephemeral, epiphenomenal hunting events are unlikely to yield a large enough assemblage to allow even the most rudimentary demographic profile to be drawn. Even if they are, it is hard to imagine any selective hunting strategy that would result in the distinctive profile of young male slaughter and prolonged female survivorship of a managed herd. For example, a specialized hunting strategy that targets herds of lactating females and nursing young (the most likely selective hunting strategy to be confused with herd management), would exhibit a heavy emphasis on both very young males and young females, and on adult females in prime reproductive years (Hesse, 1977: 304). This nursery herd age and sex profile would be distinct from the managed herd profile found at Ganj Dareh that combines the focused culling of males up to about 2 years of age with a delayed kill-off of older females. And while these distinctions would be missed with earlier demographic profiling techniques that did not distinguish between males and females, or often even between sheep and goats, given a large enough, carefully collected sample subjected to a comprehensive metrical analysis of both fused and unfused bones, these two demographic patterns should be distinguishable in the sex-specific age profiles made possible with the method developed here.

As to problems caused by the diversity of different possible management strategies in domestic herds, two of three contrasting strategies (maximization for meat and for milk) will produce profiles that emphasize utilization of young males and adult females, with

some differences in the precise ages at which young males and older females are slaughtered (Payne, 1973). Moreover, since generalized management strategies aimed at promoting herd security are capable of yielding the full range of animal products in sufficient quantity to meet the needs of most domestic households (Redding, 1981b), it is unlikely that the kind of extreme specialization that would seriously shift age and sex profiles away from this basic pattern would be seen until the development of highly specialized state-level economies—and perhaps not even then. Finally, while it is sometimes true that non-economic social considerations might affect management decisions regarding which animals to slaughter, or that catastrophic factors like drought or disease might wipe-out whole herds of animals, the fact remains that over the long term, the vast majority of culling decisions will be guided by basic principles that promote the long-term security and productivity of the herd—goals that are bet met by a strategy focused on the kill-off of young males and the preservation of an adult breeding population dominated by females (Redding, 1981b). What is called for is not a rejection of the use of age and sex profiles as a tool for understanding human/animal interaction patterns in the past, but rather the refinement of profiling methods to allow for higher resolution sex-specific age profiles (as is done here), and for the more accurate calibration of fusion patterns with actual ages (a much needed study).

With the methods initially pioneered by Hesse and refined here, we are now in an excellent position to chart the developmental pathways along which the intensive selective hunting strategies that likely preceded initial domestication were transformed into the management strategies that lie at the heart of the domestication process. We may also be able to detect the more subtle nuances in management strategies that indicate shifting economic emphases in the exploitation of managed herds. Optimally, successful application of this approach requires large collections like that from Ganj Dareh, where screening of deposits was routinely followed and where all recovered were saved and curated. Regrettably, there are few extant assemblages that meet these requirements, and it is hoped that this case study demonstration of the substantial future potential of this approach will help to guide recovery and analytical practices in the future. If, however, there are appropriate large assemblages from close temporal and regional contexts to provide an appropriate scale of size variability for different elements, even small assemblages like that from Asiab can be profitably examined with this approach. It is also likely that this method for computing sex-specific age profiles is applicable to any highly dimorphic hoofed stock (sheep, pigs, cattle, and possibly other animals like horses, camels, and llama). Thus, the promise of this new method goes beyond this study of initial goat domestication in the Zagros mountains, potentially offering significant new insight into the domestication in a wide

range of animal species in many different contexts around the world.

## Acknowledgements

This research has been funded by grants from the Smithsonian's Research Initiative and Scholarly Studies Programs. Grateful acknowledgement is given to the staff of the Field Museum of Natural History Departments of Anthropology, Geology, and Vertebrate Zoology for their help in facilitating the study of the modern and archaeological caprine skeletal collections; to A. Aisen, S. Arter, N. Cleghorn, M. Hiers, H. Lapham, S. McClure, C. McLinn, A. Shapiro, and S. Stackhouse for their assistance in this analysis; and to M. J. Blackman, B. D. Smith, and three anonymous reviewers for comments on this manuscript.

## References

- Bar Yosef, O. & Meadow, R. (1995). The origins of agriculture in the Near East. In (D. Price & A.-B. Gebauer, Eds) *Last Hunters, First Farmers: New Perspectives on the Transition to Agriculture*. Sante Fe: School of American Research Advanced Seminar Series, pp. 39–94.
- Bergmann, C. (1847). Über die verhältnisse der wärmeökonomie der thiere zu ihrer grösse. *Göttinger Studien* 3, 595–708.
- Bökönyi, S. (1976). Development of early stock rearing in the Near East. *Nature* 264, 19–23.
- Bökönyi, S. (1977). *Animal Remains from the Kermanshah Valley, Iran*. Oxford: BAR Supplementary Series 34.
- Bullock, D. & Rackham, J. (1982). Epiphyseal fusion and tooth eruption of feral goats from Moffatdale, Dumfries, and Galloway, Scotland. In (B. Wilson, C. Grigson & S. Payne, Eds) *Ageing and Sexing Animal Bones from Archaeological Sites*. BAR British Series 109, pp. 73–80.
- Davis, S. J. M. (1981). The effects of temperature changes and domestication on the body size of late Pleistocene to Holocene mammals of Israel. *Paleobiology* 7, 101–114.
- Davis, S. J. M. (1987). *The Archaeology of Animals*. London: Batsford.
- Davis, S. J. M. (1996). Measurements of a group of adult female Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists. *Journal of Archaeological Science* 23, 593–612.
- von den Driesch, A. (1976). *A Guide to the Measurement of Animal Bones from Archaeological Sites*. Cambridge, MA: Peabody Museum Bulletin 1.
- Ducos, P. (1991). *Bos, Ovis, et Capra dans les sites néolithiques de Proche Orient*. *Paléorient* 17, 161–168.
- Ducos, P. & Helmer, D. (1981). Le point actuel sur l'appartition de la domestication dans le Levant. In (J. Cauvin & P. Sanlaville, Eds) *Préhistoire du Levant*. Paris: Éditions du CNRS, pp. 523–528.
- Ducos, P. & Kolska Horwitz, L. R. (1997). The influence of climate on artiodactyl size during the Late Pleistocene–Early Holocene of the Southern Levant. *Paléorient* 23, 229–247.
- Helmer, D. (1989). *La Domestication des Animaux par les Hommes Préhistoriques*. Paris: Masson.
- Hesse, B. (1978). *Evidence for Husbandry from the Early Neolithic Sites of Ganj Dareh in Western Iran*. Ph.D. Dissertation. Columbia University, Ann Arbor: University Microfilms.
- Hesse, B. (1982). Slaughter patterns and domestication: the beginning of pastoralism in western Iran. *Man* 17, 403–417.

- Hesse, B. (1984). These are our goats: the origins of herding in west central Iran. In (J. Clutton-Brock & C. Grigson, Eds) *Animals and Archaeology: 3. Early Herders and their Flocks*. Oxford: BAR International Series **202**, pp. 243–264.
- Higham, C. F. W. (1967). Stock rearing as a cultural factor in pre-historic Europe. *Proceedings of the Prehistoric Society* **33**, 84–103.
- Hole, F. A. (1987). Chronologies in the Iranian Neolithic. In (O. Aurenche, J. Evin & F. Hours, Eds) *Chronologies in the Near East*. Oxford: BAR International Series, pp. 353–379.
- Hole, F. A., Flannery, K. V. & Neely, J. A. (1969). *Prehistory and Human Ecology on the Deh Luran Plain*. Ann Arbor: Museum of Anthropology, University of Michigan, Memoirs **1**.
- Lay, D. M. (1967). *A Study of the Mammals of Iran Resulting from the Street Expedition of 1962–63*. Chicago: Field Museum of Natural History, Fieldiana: Zoology **54**.
- Legge, A. (1996). The beginning of caprine domestication in south-west Asia. In (D. R. Harris, Ed.) *The Origins and Spread of Agriculture and Pastoralism in Eurasia*. Washington: Smithsonian Institution Press, pp. 238–263.
- Marean, C. W. & Kim, S. Y. (1998). The Mousterian faunal remains from Kobeh Cave: behavioral implications for Neanderthals and early modern humans. *Current Anthropology* **39**, 79–114.
- Meadow, R. (1989). Osteological evidence for the process of animal domestication. In (J. Clutton-Brock, Ed.) *The Walking Larder: Patterns of Domestication, Pastoralism, and Predation*. London: Unwin Hyman, pp. 80–90.
- Meadow, R. (1999). The use of size index scaling techniques for research on archaeozoological collections from the Middle East. In (C. Becker, H. Manhart, J. Peters & J. Schibler, Eds) *Historia Animalium ex Ossibus, Festschrift für Angela von den Driesch. Beiträge zur Paläoanatomie, Archäologie, Ägyptologie, Ethnologie und Geschichte der Tiermedizin*. Rahden/Westf. Verlag Mairleidorf GmbH, pp. 285–300.
- Noddle, B. (1974). Ages of epiphyseal closure in feral and domestic goats and ages of dental eruption. *Journal of Archaeological Science* **1**, 195–204.
- Payne, S. (1973). Kill-off patterns in sheep and goats: the mandibles from Asvan Kale. *Anatolian Studies* **23**, 281–303.
- Redding, R. W. (1981a). The faunal remains. In (H. T. Wright, Ed.) *An Early Town on the Deh Luran Plain*. Ann Arbor: Museum of Anthropology, University of Michigan, Memoirs **13**, pp. 233–261.
- Redding, R. W. (1981b). *Decision Making in Subsistence Herding of Sheep and Goats in the Middle East*. Ph.D. Dissertation. Anthropology Department, University of Michigan. Ann Arbor: University Microfilms.
- Reed, C. A. (1960). A review of the osteological evidence on animal domestication in the prehistoric Near East. In (R. J. Braidwood & B. Howe, Eds) *Prehistoric Investigations in Iraqi Kurdistan*. Chicago: The Oriental Institute of the University of Chicago Studies in Ancient Oriental Civilization **31**, pp. 119–145.
- Reed, C. A. (1983). Archaeozoological studies in the Near East: a short history (1960–1980). In (R. J. Braidwood, L. Braidwood, B. Howe, C. A. Reed & P. J. Watson, Eds) *Prehistoric Archaeology Among the Zagros Flanks*. Chicago: Oriental Institute Publications **105**, pp. 511–536.
- Silver, I. A. (1963). The ageing of domestic animals. In (D. Brothwell & E. Higgs, Eds) *Science in Archaeology*. New York: Basic Books, pp. 250–268.
- Stampfi, H. R. (1983). The fauna of Jarmo, with notes on animal bones from Matarrah, the Amuq, and Karim Shahr. In (R. J. Braidwood, L. Braidwood, B. Howe, C. A. Reed & P. J. Watson, Eds) *Prehistoric Archaeology Among the Zagros Flanks*. Chicago: Oriental Institute Publications **105**, pp. 431–484.
- Street, W. S. & Street, J. K., with Sawyer, R. (1986). *Iranian Adventure: The First Street Expedition*. Chicago: Field Museum of Natural History.
- Turnbull, P. F. (1975). The mammalian fauna of Warwasi Rock Shelter, West Central Iran. *Fieldiana: Geology* **33**, 141–115.
- Turnbull, P. F. & Reed, C. A. (1974). The fauna from the Terminal Pleistocene of Palegawra Cave, a Zarzian occupation site in Northeastern Iraq. *Fieldiana: Anthropology* **63**, 81–146.
- Uerpmann, H.-P. (1978). Metrical analysis of faunal remains from the Middle East. In (R. I. Meadow & M. A. Zeder, Eds) *Approaches to Faunal Analysis in the Middle East*. Cambridge: Peabody Museum Bulletin **2**, pp. 41–45.
- Uerpmann, H.-P. (1979). *Probleme der Neolithisierung des Mittelmeerraumes*. Wiesbaden: Biehefte zum Tübinger Atlas des Vorderen Orients, Reihe A **27**.
- Wilson, D. E. & Reeder, D. M. (1993). *Mammal Species of the World: A Taxonomic and Geographic Reference*. Washington: Smithsonian Institution Press.
- Zeder, M. A. (1999). Animal domestication in the Zagros: a review of past and current research. *Paléorient* **25**, 11–25.
- Zeder, M. A. & Hesse, B. (2000). The initial domestication of goats (*Capra hircus*) in the Zagros Mountains 10,000 years ago. *Science* **287**, 2254–2257.
- Zohary, D., Tchernov, E. & Kolska Horwitz, L. R. (1998). The role of unconscious selection in the domestication of sheep and goats. *Journal of Zoology, London* **245**, 129–135.