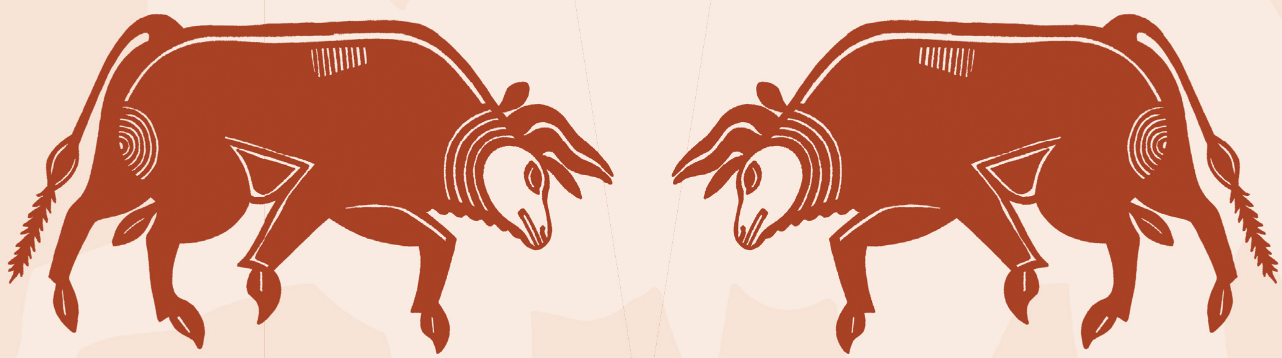
Archaeobiology 3

ARCHAEOZOOLOGY OF SOUTHWEST ASIA AND ADJACENT AREAS XIII



Proceedings of the Thirteenth International Symposium, University of Cyprus, Nicosia, Cyprus, June 7–10, 2017

edited by

Julie Daujat, Angelos Hadjikoumis, Rémi Berthon, Jwana Chahoud, Vasiliki Kassianidou, and Jean-Denis Vigne

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Group photo of the 13th ASWA[AA] meeting June 8th 2017
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Part 2: Subsistence Economies of Early and Late Complex Societies in Southwest Asia and Adjacent Areas

Part 3: Beyond Subsistence: Animals in the Symbolic World of Southwest Asia and Adjacent Areas

FOREWORD

The 13th ASWA conference was hosted by the University of Cyprus, one of the youngest of Europe's universities. In 2019, it was only thirty years since its foundation. Nevertheless, this is a thriving academic institution, which currently consists of eight faculties, twenty-two departments, and eleven research units.

In 1991, and just two years after the university's foundation, the Archaeological Research Unit (ARU) was founded by decree from the Government of the Republic of Cyprus, following the issuance of the dependent legislation by the House of Representatives. The decision to establish the ARU was based on the recommendation of the Interim Steering Committee of the University of Cyprus, which stated the following:

1. Cyprus is offered for primary research in the field of archaeology thanks to its distinctive cultural signature and history, as well as due to the fact that Cypriot archaeology and archaeological research on the island already has a distinguished tradition and international reputation;

2. The subsequent international recognition of the importance of archaeological research in Cyprus should comprise one of the first incentives for choosing the University of Cyprus as a center for postgraduate studies, and will pave the way for the exchange of students and academics between the University of Cyprus and academic institutions overseas.

The faculty members of the ARU, who are also part of the Department of History and Archaeology academic staff, have contributed immensely over the past 28 years to the achievement of the aforementioned objectives for the study and promotion of Cypriot cultural heritage through their research, their teaching, and the practical training they have been providing to students at undergraduate and postgraduate levels. The active study of other regions of the Mediterranean world have not been overlooked either, as members of the ARU academic staff have been carrying out excavations and research projects in Greece, Turkey, and France.

The members of the ARU are actively carrying out research in Pre- and Protohistoric Archaeology, Classical and Byzantine Archaeology but also Archaeometry and Environmental Archaeology, Maritime Archaeology, and Western Art. In the course of the past 28 years, the ARU has laid very stable foundations in all aforementioned specialisations of the archaeological discipline, none of which existed at academic level in Cyprus before the unit's establishment. Through their teaching at undergraduate and postgraduate levels, all members of the ARU academic staff have been contributing to the formation of a new generation of Cypriot archaeologists, equipped with all the necessary knowledge and practical experience needed to excel in this scientific field.

Over the years, the ARU has been very active in organizing international conferences and workshops. The ARU has organized over 50 international conferences, while members of the academic staff have published the proceedings of over 20 scientific meetings held at the ARU.

Thus, when Jean-Denis Vigne came to my office several years ago with the suggestion to co-organize the 13th Archaeozoology of Southwest Asia and Adjacent Areas conference I gladly accepted. The meeting in Nicosia brought together colleagues from all over the world and offered a venue where new results from the field or the laboratory could be presented and discussed. The publication of the conference proceedings enables colleagues who were unable to attend the conference to read about the latest developments in the archaeozoology of this culturally important region.

I would like to close by thanking all the members of the 13th ASWA organizing committee for all the work they have put into bringing so many scholars to Cyprus, many of them for the first time. I would also like to thank the co-editors of this volume for all the work they have put into the publication of the proceedings.

Professor Vasiliki Kassianidou
Director of the Archaeological Research Unit,
University of Cyprus
Nicosia, August 2019

EDITORS' PREFACE

Due to their location at the meeting point of the three Old World's continents—Africa, Asia, and Europe—Southwest Asia and its adjacent areas played a pivotal role in the history of humanity. They received successive waves of our species—*Homo sapiens*—out of Africa. Different processes in several areas of this large region brought about the transition to the Neolithic, and later on the urban revolution, the emergence of empires bringing with them important subsequent religious, cultural, social, and political consequences. Southwest Asia also played a major role in the interactions between East (Asia) and West (Europe) during the last two millennia. The unique importance of Southwest Asia in the history of humanity is strengthened by the, also related to its location, fact that this area is a hotspot of biodiversity, especially in mammals, which were—as everywhere in the world—tightly associated to the history of civilizations in a diversity of roles: game, providers of meat and milk, traded raw material, symbol of prestige and wealth, pets, etc.

Everywhere in the world, the biological and cultural interactions between humans and animals often remain under-evaluated in their heuristic value for understanding complex social and biological interactions and trajectories. This is why, almost half a century ago, archaeologists who were carrying out research and reflecting on such themes founded a very active nonprofit world organization named the International Council for Archaeozoology (ICAZ). This is also why the ICAZ working group "Archaeozoology of Southwest Asia and Adjacent Areas" (ASWA[AA]) was one of the first ones created within ICAZ, constituting one of the largest and most active of ICAZ's working groups.

The ASWA[AA] was formed during the 1990 ICAZ International Conference in Washington, D.C. Its purpose is to promote communication between researchers working on archaeological faunal remains from sites in western Asia and adjacent areas (e.g., Northeast Africa, Eastern Europe, Central Asia, and South Asia). It carries out its mandate mainly through the sponsoring of biennial international conferences. Since 1998, these meetings have alternated in being hosted in Europe or in Southwest Asia: Paris (1998), Amman (2000), London (2002), Ankara (2004), Lyon (2006), Al Ain (2008), Brussels (2011), Haifa (2013), Groningen (2015).

Ongoing armed conflicts and political tensions in several countries of Southwest Asia made it difficult to locate a safe and convenient place that would enable the organizing the 13th ASWA[AA] meeting in within that region. Although Cyprus is currently a member of the European Union, in (pre-)history Cyprus was embedded in the eastern Mediterranean "world." Because of its location, Cyprus was indeed at the confluence of African, Levantine, Anatolian, and Greek cultural streams and, as is common for islands, recombined them in different but always original ways all along its history. Archaeozoology recently provided one of the most convincing illustrations of the tight connection between Cyprus and Southwest Asia, demonstrating that the earliest domesticated mammals, especially cats, pigs, cattle, sheep, and goats, were introduced to the island very shortly after their first incipient domestication on the near continent, that is, during the ninth millennium BC. For all these reasons, Cyprus represented an ideal place to host the 13th ASWA[AA] conference.

Despite the illegal military occupation of part of its territory by a foreign country, the option of hosting the meeting in Cyprus was enthusiastically embraced by all members of the working group, especially because it is open to all nationalities and maintains good diplomatic relationships with a large majority of countries in Southwest Asia. These facts contributed towards the 13th ASWA[AA] meeting in Cyprus (June 7–9, 2017) becoming one of the best-attended ASWA[AA] meetings. It brought together 80 scientists coming from 25 different countries: from Southwest Asia (6 countries), Europe (14 countries), North America (2 countries), and Japan.

They presented their results in 36 oral and 32 poster presentations. They debated the long-term interactions between humans and biodiversity, about the beginning of animal domestication and husbandry, the strategies of animal exploitation from the Paleolithic to modern times, and the symbolic and funeral use of animals through time. They also greatly enjoyed the numerous social events organized, including a fantastic Cypriot mezze dinner, enhanced by a local folk-music band, and a nice excursion to the archaeological sites of Amathous, Kourion, and Khirokitia, and to the museums of Nicosia and Larnaca, which provided ample opportunities for scientific exchanges in a friendly atmosphere.

The hosting of the conference at the new campus of the University of Cyprus was another major reason to the meeting's success. This campus was a convenient and pleasant venue for such a conference, and the strong support of the University of Cyprus, as well as its valuable experience for the organization of such meetings were deeply appreciated by both the scientific organizers and the delegates. Several other partners contributed to the organization: the French archaeological mission "Neolithisation—Klimonas," which is itself strongly supported by the French School at Athens, the Cyprus Department of Antiquities, the French Institute of Cyprus, the French National Center for Scientific Research (Centre National de la Recherche Scientifique [CNRS]), and the French National Museum of Natural History (Muséum national d'Histoire naturelle [MNHN]).

The present volume brings together the texts of 18 of the 68 presentations of the meeting in Nicosia. The editorial board collected the papers and organized their review and editing. We are very grateful to Sarah Kansa (and Open Context), Justin Lev Tov, and Lockwood Press for their constant support in bringing this volume to fruition.

Julie Daujat
Angelos Hadjikoumis
Rémi Berthon, Jwana Chahoud
Vasiliki Kassianidou
Jean-Denis Vigne

1.1 | Assessing Changes in Animal Mobility and Activity Patterns During Early Stages of Domestication and Husbandry of *Capra*

Tell Halula as a Case Study (Euphrates Valley, Syria)

Roger Alcàntara Fors,* Josep Fortuny,† Miquel Molist Montaña,* Carlos Tornero,‡ and Maria Saña Seguí*

Abstract

Domestication implies a certain degree of human control over all aspects of animals' life, including their ability to move freely. Consequently, domestic animals should experiment a significant reduction of their mobility regimes, such as range, duration, and intensity. Bone tissue is a plastic and alive material with the ability to remodel in response to mechanical loading. In Tell Halula (7800–5200 cal BC) exploitation of *Capra aegagrus* and *Capra hircus* played a significant role from its earliest occupations. This study attempts to detect potential variations in cortical bone development using Computed Tomography scanning and cross-section analysis of *Capra* humeri in response to changes in their mobility regimes. Results support domestic specimens with loading patterns matching those of wild specimens together with loading patterns among the domestic group changing through the periods analyzed. Moments of inertia show antero-posterior and mediolateral loading differences between domestic and wild populations that may be indicative of mobility differences. Activity levels, evidenced by the relative amount of cortical bone and the polar moment of inertia, also seem to constitute a distinguishing marker of goat management strategies in the course of the archaeological sequence. The circularity index and the three different cross-sections documented also reinforce this hypothesis.

Keywords

Tell Halula, goat, humerus, early husbandry, management strategies, biomechanics, bone adaptation, mechanical properties, physical stress

Introduction

Domestication is a widely discussed concept that implies several interactions between social, physiological, and ecological domains. Even though animal domestication processes are currently ongoing, the first husbandry practices are documented during the early Holocene and constitute one of the most relevant turning points in human history. In Southwest Asia, the direct control of the productive and reproductive cycles of some animal species resulted in important changes in the economy and social organization of human societies, paired with the development of new work processes and an increasingly sedentary lifestyle. From a biological point of view, it also had an important impact. The adaptation of the animals to the anthropic environment caused physiological, behavioral, and anatomical changes (Helmer 1992). The feeding, reproduction, and mobility patterns of herds were affected in dif-

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ferent ways, under different timings, depending on the species but also on the degree of artificial manipulation to which the species were subjected. Unfortunately, these changes are poorly detected in the archaeological record and zooarchaeology, and the study of the faunal remains is the best direct way to investigate these processes. Nevertheless, different publications have shown that different ways can be used to obtain valuable data on early domestication, revealing that some of the traditional zooarchaeological limitations can be solved with different and complementary analytical approaches. Most of these approaches are based on biogeochemistry, of which stable isotopes and genomic analyses are the most common ones (e.g., Balasse et al. 2015; Bar-Gal et al. 2003; Blaise and Balasse 2011; Makarewicz and Turos 2012; Tornero 2011).

Here, we present and discuss an analytical approach that could be useful to recognize animals subjected to control conditions, causing changes in activity patterns, and physiological stress under different situations from the ones occurring in wild populations. This approach is based on the analysis of structural changes in bone tissue. Although pioneering works based on this approach were published during the 1970s (Daly et al. 1973; Drew et al. 1971; Museum Applied Science Center for Archaeology [MASCA] 1970, 1973), few studies have so far considered inner bone tissue architecture as a potential domestication indicator.

In these early studies (e.g., Drew et al. 1971), the authors compared different structural components of bone tissue in domestic and wild populations through the analysis of spongy and compact bone and articular surfaces. Their results supported that differences in trabecular thickness, the trabeculae, and subchondral plate joint and birefringence in the circumferential layers of transversal sections effectively distinguished between wild and domestic animals. Zeder (1978) considered the methodological approach of these early works valid but noted the importance of assessing whether the results could be biased by other factors, such as the levels of stress that animals were subjected to, mobility patterns, age, or health state of the specimens. Later, Gilbert (1989) also pointed out the importance of determining if the analyzed remains presented taphonomic alterations that could affect their inner structure.

The most important point of these approaches is that they test the correlation between density and bone structure, and the degree of activity of the animals, as it may be affected by the domestication process. The plasticity of bone tissue and its capacity to adapt to the mechanical environment has long been a guiding principle in biological studies (Ruff et al. 2006; Wolff 2012 [1892]). It is known that bone reacts when biomechanical movement generates strains caused by ground impact and skeletal muscle forces (Shaw and Stock 2009).

Based on this principle, some recent studies performed on modern animal populations provide interesting data that can be used as a reference to evaluate animal activity patterns in archaeological fauna remains (Jepsen et al. 2015; O'Regan and Kitchener 2005; Ruff et al. 1993; Stock and Macintosh 2016). It is common in biological and veterinary studies to correlate the growth and differential development of bones with the capability to adapt to mechanical stress. One of these parameters that can be tested in an archaeological study is the cortical width of long bones (Nazem et al. 2015). Hiney and colleagues (2004) evaluated the correlation between density and morphology of the cortical bone in the metapodial diaphysis in three groups of bull calves with three differentiated activity patterns: one with punctual high intensity activity, a free ranging group, and a completely static third group. The results obtained show that mobility is reflected in the percentage of the bone's cortical area and its geometry, with the mineral density of the bone in static populations relatively more reduced. In a similar way, Main and Biewener (2004) analyzed limb loading patterns of young goats in an attempt to relate them to *in vivo* bone strains in the radius of domestic goat, showing that the radius was primarily loaded with bending strains through ontogeny. Later, Niinimäki and Salmi (2016) analyzed populations of reindeer and showed that different points of muscular insertion of the elbow articulation are more developed in wild reindeer populations than in captive populations in zoos. One of the most important and recent publications on this topic was published by Shackelford and colleagues (2013), who focused on testing the changes in bone structure related to mobility reduction—due to domestication—in wild asses.

Analyses of changes in the inner bone structure could represent a useful way to shed light on early husbandry practices and provide an opportunity to identify variations in the mobility and activity patterns of animal populations derived from domestication processes. We therefore propose the hypothesis that animal domestication may involve a greater control of human communities over animals than previously thought. This control could lead in some cases to their breeding and maintenance in the settlements or nearby, thus decreasing the degree of physical activity. In order to examine this possibility, Computed Tomography (CT) techniques represent a noninvasive methodology for fossil remains as its capacity to record external and internal features of bones has been attested (Stock 2002). It is able to identify variations in inner-bone microstructure derived from potential selective pressures and interpret its patterns and intensity. To date, no investigation has been performed on archaeological goat populations, the main focus of the present study.

This paper presents the preliminary results of the application of this approach and methodology to the study of early goat husbandry at the Neolithic settlement of Tell Halula (Middle Euphrates Valley, Syria). The site of Tell Halula, with more than 2,000 years of continuous occupation, allows following in detail the main changes that occurred in early domestic goat-management strategies between 7800 and 5700 cal BC. The main objective is to evaluate if there are variations in the activity levels of the analyzed specimens based on the analysis of the bone structure and, if so, to correlate these variations with the management strategies for this species and the size changes in the animals, data already available from recent studies (Saña Seguí 1999, 2000; Saña Seguí and Tornero 2008, 2013; Tornero 2011).

Materials

Tell Halula is an archaeological site located in the Middle Euphrates Valley in Syria. The archaeological work carried out at Tell Halula during the last twenty-five years has revealed a long sequence of occupation in its more than 11 m stratigraphic sequence. An area of about 4,200 m^2 has been excavated. The sequence of occupation covers a period between 7800 to 5700 cal BC, which is subdivided into thirty-seven Occupation Phases (OP) corresponding to middle Pre-Pottery Neolithic B (MPPNB), Late Pre-Pottery Neolithic B (LPPNB), Pre-Halaf, and Halaf periods (Molist Montaña 2013).

During the oldest occupation phases, dating back to around 7800–7600 cal BC, most of the domestic structures—mainly cooking and storage structures—are distributed in large open areas, approximately between OP 1 to OP 9. At the end of the MPPNB and during LPPNB the excavation of a wide area made it possible to document a living area with an alignment of seven synchronically occupied houses that share some formal features, such as building techniques or spatial distribution. All the houses are rectangular and are identically organized in three or four rooms, with a large open area in front where most of the production activities were carried out. Starting in the Pottery Neolithic, dated around 6900–6800 cal. BC—OP20 to OP32—different levels with low investment in architectural constructions were documented dispersed over large open areas. Circular buildings start to appear, although some houses keep the rectangular and pluricellular organization. During the last occupation phases—OP36 and OP37, dated between around 6000 and 5500 cal BC—rectangular and circular floor plans in combination define the architecture of the site with a preferential use of stone foundations and beaten floors.

To date, a sample of about 35,000 faunal remains has been analyzed (Saña Seguí 1999, 2000; Saña Seguí and Tornero 2008, 2013; Tornero 2011). During the oldest occupations around 7800–7600 cal BC (MPPNB), wild species played a major role in the supply of food while goats were the main domestic livestock. The beginning of sheep husbandry is attested for the first time in OP 8 (7590–7520 BC), and a strategy mainly focused on the consumption of domestic sheep and goats has been documented during the intermediate occupation phases, OP13 to OP19. Cattle are documented from the beginning of the archaeological sequence with low representation values and as a source of meat (Helmer et al. 2005). Pigs are well represented throughout the whole sequence with fluctuating representation percentages, and their domestic form has been identified starting with the first occupation (Alcàntara Fors 2014).

The *Capra* assemblage consists of a total of 1,386 remains (4% of the Number of Identified Specimens = NISP). Due to the characteristics of the archaeological bone remains, the selected fraction was from the medial diaphysis to the distal epiphysis where the remains that could be measured were selected. Sampling was also carried out on the available remains at the Archaeozoology Laboratory of the Autonomous University of Barcelona. In this way, a total of 35 goat humeri were selected for CT scanning. According to the archaeological and historical dynamics represented at the site and the different turning points documented in animal management strategies (Saña Seguí 1999, 2000), samples were grouped in three periods following a chronological order. Thus, 9 samples correspond to Period 1 (OP1 to OP10), 8 samples to Period 2 (OP11 to OP21), and lastly 15 samples correspond to Period 3 (OP22 to OP37). Based on biometrical criteria, 32 remains were classified as *Capra hircus* and three as *Capra aegagrus*. All the analyzed samples are from adult specimens. The wild goat specimens belong to Period 1 (Samples No. 2 and 3) and Period 2 (Sample No. 6) and are represented in an individualized group as a reference for this population.

Methodology

The biometric features of the selected humeri from Tell Halula were recorded following the criteria defined by von den Driesch (1976) and Helmer and Rocheteau (1994). The measurements recorded correspond to the maximum width of the epiphysis (Bd), maximum width of the distal trochlea (Bt), and maximum (H) and minimum height (h) of the trochlea. Measurements of goat humeri from the sites of Abu Gosh (Ducos 1978), Munhatta (Ducos 1968), and Cafer Höyük (Helmer 1985, 1988, 1991) were also included as reference datasets.

The remains were CT scanned using a medical CT scanner Sensations 16 (Siemens) at the Hospital Universitari Mútua de Terrassa (Terrassa, Catalonia) at 120 kV, 59 mA, with an output of 512 × 512 pixels per slice and obtaining a physical resolution of 0.75 mm. The raw data obtained were processed using the software Avizo 7.0 (FEI Company). This software allowed the generation of 3D models for each bone. Then, a slice from the distal diaphysis at the outermost proximal limit of the olecranon fossa was obtained for each bone. This point represents a homologous locus for all the humeri. It is on the bone diaphysis and easy to locate, which permits reliable replication of cross-sectioning procedures. ImageJ software (Schneider et al. 2012) was used to take such measurements at the cortex width in the mediolateral plane, anteroposterior and mediolateral diameters of the subperiosteal section, and of the medullary cavity as well as the total, cortical, and medullary area of the section (Figure 1.1.1).

These measures were used to calculate the physical parameters defined with the C/D ratio (C = cortical thickness; D = diameter of bone), Ct.Ar/Tt.Ar ratio (Ct.Ar = cortical area; Tt.Ar = total area), the second moment of area or moment of inertia (I), and the polar moment of area or polar moment of inertia (J). Values obtained with the calculation of these parameters are representative of the modifications that bone tissue may undergo as a result of its adaptation or response to different loads received during the animal's life, being a reflection of their intensity, recurrence, duration, and direction.

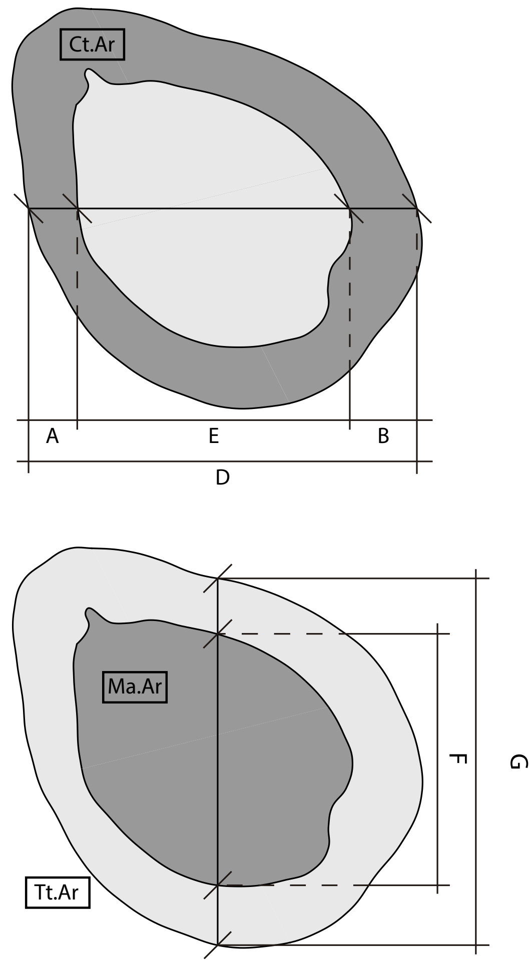

Figure 1.1.1. Measurements on humerus cross section. A + B = Cortical thickness (Ct.Th); D = Mediolateral breadth of the section (ML); E = Mediolateral breadth of the marrow (ml); G = Anteroposterior breadth of the section (AP); F = Anteroposterior breadth of the marrow (ap); Ct.Ar = Cortical area; Ma.Ar = Marrow area; Tt.Ar = Subperiosteal area.

The C/D ratio expresses the amount of cortical bone (sum of medial and lateral thickness) related to the diameter of the bone (mediolateral diameter). The C/D ratio is widely used in veterinary science as a diagnostic tool for the identification of bone growth anomalies and is not affected by age, sex, weight or height (Nazem et al. 2015). The Ct.Ar/Tt.Ar ratio equally expresses the relative amount of cortical bone in the section. Cortical area is related to the compression and traction loadings the bone had to bear (Nordin and Frankel 2001). The moment of inertia (I) reflects the adaptation of the bone to bending and torsional loadings and was calculated in relation to the animal's anatomical axes using the formula for the moment of inertia of a hollow ellipse (Mediolateral moment of inertia: $I_{ML} = 0.0491[AP^3*ML - ap^3*ml]$ and Anteroposterior moment of inertia: $I_{AP} = 0.0491[ML^3*AP - ml^3*ap]$; American Society of Agricultural Engineers [ASAE] 2003; Ruff and Hayes 1983). These two values express the distribution of the cortical mass in response to the analyzed loadings. Consequently, it is expected that the bones of an animal with greater mobility, performing intense runs and changes of direction, should present a more evenly distributed cortical mass, given that their bones must adapt to a great variety of loadings. On the contrary, the bones of an animal with more limited movements, constrained to motions in a straight line, will adapt to compensate for this single recurrent effort (Carlson and Judex 2007). Following the same reasoning, low activity of the animal should be reflected in lower values for this parameter. The relation of this parameter in its two perpendicular axes generates therefore an index of circularity that expresses the previous scenarios. The polar moment of inertia, in other words the result of the sum of any pair of perpendicular moments of inertia, represents the adaptation of the bone to torsional loadings (Daegling 2002; Ruff 2000). The last considerations take into account the morphology of the cross sections given the effects of multidirectional stress to bone growth.

In order to reduce the influence of animal size, the values obtained with the moment of inertia and the polar moment of inertia calculations were standardized using the geometric mean of the four linear measurements Bd, Bt, H, and h. Since the values returned by the formula used to calculate these parameters are expressed in mm^4, the value of the geometric mean was raised to the fourth power. Usual procedures to standardize this data involve using bone length and body mass to compensate for any weight or size difference that may affect the sample (Hiney et al. 2004; Ruff 2000; Ruff and Hayes 1983; Ruff et al. 1993; Ruff et al. 2006; Shackelford et al. 2013). Given the extreme difficulty in accessing these values due to preservation issues in archaeological contexts, Bd, Bt, H, and h are taken here as markers of size and body mass factors, taking into account that breadth and width measurements are substantially a function of weight (Currey 2013).

Measurements' distribution and obtained values in standard error and box plot diagrams enable the assessment of continuity and discontinuity between wild and domestic populations as well as between periods. In order to compare the data according to chronology, the Kruskal-Wallis test was used, with a statistical significance probability threshold of $\alpha = 0.05$ (Hammer et al. 2001).

Results

The different measurements and parameters calculated refer to characteristics and properties of the bone epiphyses and bone section. Firstly, goat size evolution throughout the archaeological sequence was characterized. Then, the values and tendencies obtained with the measurements directly taken from the cross section—bone area, cortical area, and marrow area—are checked. These data are complemented by parameters from the cross sections calculated with the linear and area measurements as previously described. These parameters are related to the bone strength and its capacity to resist different levels and kinds of physical stress.

A reduction in size of goat specimens, in the course of the chronological sequence at Tell Halula, has been previously documented (Saña Seguí 1999, 2000; Saña Seguí and Tornero 2008, 2013; Tornero 2011). The results obtained with Bd and h measurements of distal epiphysis of the analyzed humeri are grouped according to the three periods established as a temporal reference and are presented here by means of standard error diagrams. As can be seen in Figure 1.1.2, the samples selected for this study follow the general trend with a clear difference in these measurements between wild and domestic populations. Kruskal-Wallis p values (Table 1.1.1) corroborate this trend, with the only similarities being between wild goat reference samples taken from the eastern Levant and Tell Halula P1 samples.

Next, values for the area of the cortical mass (Ct. Ar) were correlated with values of the total area (Tt. Ar) in order to evaluate whether the dynamics of

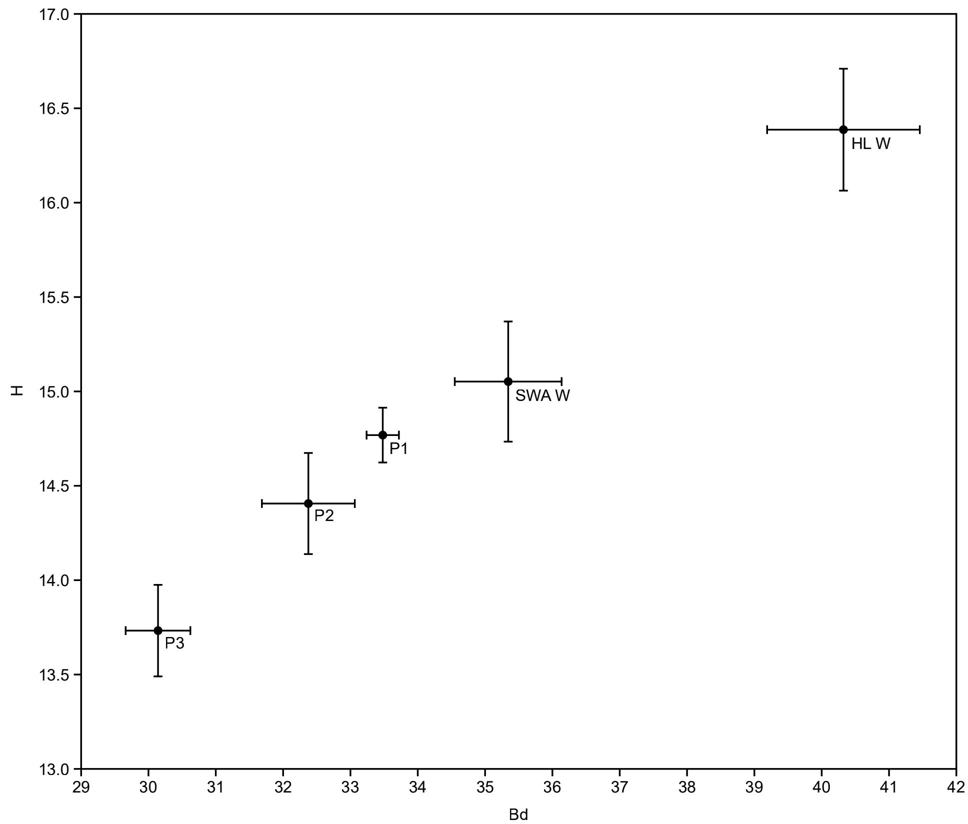

Figure 1.1.2. Standard error diagram of distal breadth (Bd) and minimum height of the trochlea (h). Tell Halula wild goats (HL W, N = 3); Tell Halula domestic goats (P1, N = 9; P2, N = 8; P3, N = 15); Southwest Asia wild goats (SWA W, includes samples from Abu Gosh [N = 20, Ducos 1978], Munhatta [N = 1, Ducos 1968], and Cafer Höyük [N = 1, Helmer 1985, 1988, 1991]). P1 (Period 1), P2 (Period 2), and P3 (Period 3).

Ct.Ar in Tell Halula sequence are similar or not to those obtained for the size. Values of *Capra aegagrus* specimens were also individualized (Figure 1.1.3). The results show a positive correlation between the two areas (r = 0.93476; see Table 1.1.2 for further details), clearly separating the wild population from the rest. Values (P1 Ct.Ar-SD=17.01; P1 Tt.Ar-SD=24.27; see Table 1.1.3) obtained for P1 are grouped and have a lower variability than for the next two periods, especially with the most recent occupation phase (P3). Those specimens that do not follow this trend were marked in the distribution. The progressive decrease documented in these values would be equivalent to the one recorded for size, although between Periods 2 and 3, a sharp reduction in the size of the cortical area is detected whereas Tt.Ar maintains a steady decrease. The correlation of C/D ratio with Bd measurement was used to evaluate the relationship between size reduction of the represented specimens and changes in the cortical bone (Figure 1.1.4). The scatter plot shows the lack of linear correlation between these two values (r = 0.44696, see Table 1.1.2 for further details). P1 specimens have a relatively higher cortical mass than specimens from the other two periods, whereas P3 specimens show greater variability. In the latter case, two groups with different tendencies can be isolated (Group 1 with Samples 8, 9, 13, 14, 29, 38, and 46; Group 2 with Samples 10, 19, 20, 21, 22, 23, 27, and 28). Wild specimens, whose size is greater than the rest of individuals, present intermediate values of relative quantity of the cortical mass, less than what would be expected for domestic goats with same Bd. Likewise, we observe an isolated case that stands out due to an especially low C/D ratio value given its size (Sample 34).

Observed dynamics in the moments of inertia and circularity index show a slightly different path. The distribution obtained from the measurements I_{AP} and I_{ML} (Figure 1.1.5) defines a group of individuals whose values for bending resistance are higher than

Table 1.1.1. Kruskal-Wallis test results of Bd values between Southwest Asia wild goats (SWA W, N=23; Abou Gosh, N=20; Munhatta, N=1; Cafer Höyük, N=1), Tell Halula wild goats (HL W, N = 3) and domestic goats Period 1 (P1, N = 9), Period 2 (P2, N = 8) and Period 3 (P3, N = 15) with a statistical significance probability threshold of α = 0.05 (* represents significant difference).

	WSWA	HL W	P1	P2	P3
SWA W		0,0595	0,6165	0,003892*	3.60E-02*
HL W	0,0595		0,01623*	0,0189*	0,009116*
P1	0,6165	0,01623*		0,01077*	0,0003861*
P2	0,003892*	0,0189*	0,01077*		0,05682
P3	3.60E-02*	0,009116*	0,0003861*	0,05682	

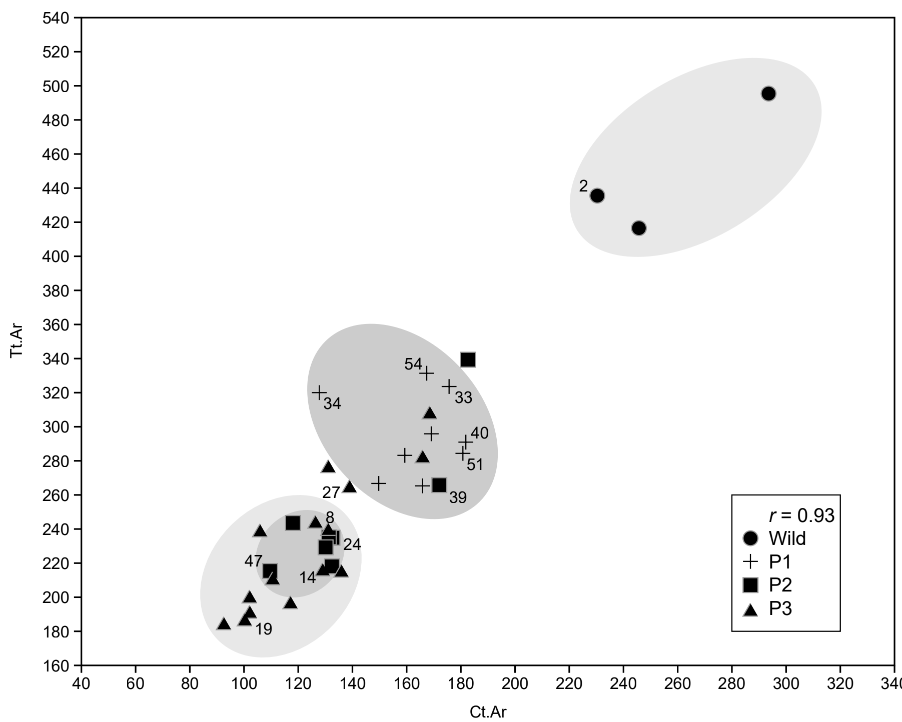

Figure 1.1.3. Bivariate graph of the Cortical Area (Ct.Ar) and the Total Area (Tt.Ar) of the 35 analyzed cross sections within their corresponding group of analysis. Ellipses mark the main concentrations of values for each group.

for the rest of individuals. This group is formed by the three samples of *Capra aegagrus*, two specimens from P1 (Samples 33 and 54) and a specimen from P3 (Sample 20). The greatest variability in this group is observed in the values of I_{AP}, while the values of I_{ML} remain stable. The remaining specimens in the sequence are divided into two main groups. The first one is mainly composed of samples from P3, together with two from P2. The second group, with lower I_{AP} values, is made up of specimens from P2 and P3 equally. Samples corresponding to P1, with the exception of the aforementioned specimens, show intermediate values between these two groups partially overlapping with them. The circularity index, whose paradigmatic case of reference should present a relation of 1:1 (Stock 2006; Stock and Pfeiffer 2004), displays a clear tendency toward lower circularity in the course of the archaeological sequence (Table 1.1.4).

In the same way, the average of the values for the circularity index in wild specimens is the closest

Table 1.1.2. Reduced Major Axis (RMA) Regression results between Cortical area and Total area of the cross section (Ct. Ar–Tt.Ar) and between distal breadth and C/D ratio (Bd–C/D Ratio).

RMA regression		Ct.Ar–Tt.Ar	Bd–C/D ratio
	Slope *a*	1.6352	1.193
	Std. error *a*	0.10113	0.18578
	t	16.169	6.4217
	p (slope)	3.0276E−17	2.8037E−07
	Intercept *b*	26.485	-9.991
	Std. error *b*	245.48	36.55
95% bootstrapped confidence intervals (N = 199)			
	Slope *a*	(1.4542, 1.7674)	(0.5315, 1.5481)
	Intercept *b*	(6.8177, 51.942)	(-21.16, 10.12)
Correlation			
	r	0.93476	0.44696
	r2	0.87377	0.19977
	t	15.114	2.8703
	p (uncorr.)	2.1688E−16	0.0071063
	Permutation *p*	0.0001	0.0073

to those for Period 1. The variability of this index increases over time, reaching values higher than a 2:1 ratio.

The area polar moment represents the resistance to torsional loadings. In this case, results show a population of six individuals (the three wild individuals, Samples 33 and 54 from P2, and Sample 20 from P3) especially resistant to torsional loadings despite having clearly different sizes. P2, with larger specimens than those in P3, records a lower average value of torsional strength equivalent to the lowest resistance values in P3. Although the specimens from P3 are generally of smaller size than the rest of the analyzed sample, their range of resistance to torsional forces reaches the full scope of possible results, with two apparent separate groups according to their greater or lesser resistance to torsion. Larger specimens from P1 (Samples 34, 40, 45, and 55) have high torsional strength values equivalent to the highest resistance group in P3. These tendencies are well reflected in the box plot diagram (Figure 1.1.6), where the existence of a turning point in this parameter can be clearly seen between Periods 2 and 3.

Finally, the morphological analysis of the obtained shaft diaphysis's cross sections was performed. This analysis differentiated morphologies that can be grouped into three main types (Figure 1.1.7). The first type (T1) has a round outline with a protuberance due to the lateral condyle. In the second type (T2), the protuberance of the condyle is maintained, but the rest of the outline acquires a more angular aspect. In the third type (T3), both condyles maintain similar sizes, which gives the section a rectangular profile. This morphological ascription is relevant if one takes into account its temporal distribution, since T1 is documented mainly during Period 1 and is also associated with wild specimens. In the same line, T3 is most frequent during P3. Nonetheless, T2 seems equally distributed between Periods 2 and 3 (Table 1.1.5).

Discussion

Animal domestication—here goat domestication processes—has traditionally been studied through morphometric analysis in combination with mortality profile patterns (Peters et al. 1999). One of the prom-

Table 1.1.3. Summary statistics of Cortical area (Ct.Ar.) and Total area (Tt.Ar) values for each of the analyzed groups of Tell Halula.

	HL W Ct.Ar	**HL W Tt.Ar**	**P1 Ct.Ar**	**P1 Tt.Ar**	**P2 Ct.Ar**	**P2 Tt.Ar**	**P3 Ct.Ar**	**P3 Tt.Ar**
N	3	3	9	9	8	8	15	15
Min	230.353	416.517	127.756	265.326	109.624	215.383	92.545	184.738
Max	293.551	495.434	181.84	331.378	182.631	339.324	168.483	308.43
Sum	769.605	1347.502	1477.371	2661.483	1108.8	1981.415	1856.962	3460.418
Mean	256.535	449.1673	164.1523	295.7203	138.6	247.6769	123.7975	230.6945
Std. error	19.03093	23.77693	5.670556	8.088889	8.983698	14.21732	5.894883	9.95999
Variance	1086.528	1696.027	289.3968	588.8712	645.6546	1617.057	521.2447	1488.021
Stand. dev	32.96253	41.18284	17.01167	24.26667	25.40973	40.21265	22.83078	38.57488
Median	245.701	435.551	167.412	290.969	131.8515	235.0095	126.304	216.333
25 prcntil	230.353	416.517	154.519	274.9705	121.0637	220.907	102.079	197.055
75 prcntil	293.551	495.434	178.2065	321.8085	162.2007	260.2022	135.904	265.152
Skewness	1.319265	1.325194	-1.29104	0.285472	1.025814	2.067436	0.673668	0.621632
Kurtosis	-2.33333	-2.33333	1.79622	-1.34988	-0.0428	4.628463	-0.11251	-0.66028
Geom. mean	255.1691	447.9393	163.3018	294.843	136.7066	245.1954	121.9189	227.8085
Coeff. var	12.84914	9.168709	10.36334	8.205952	18.33314	16.23593	18.44204	16.72119

inent agents in this matter has been the inclusion of biogeochemical studies (Tornero 2011; Tornero and Saña Seguí 2008; Wiener and Wilkinson 2011). Isotopic analyses carried out on samples recovered at Neolithic archaeological sites in the northern and southern Levant (Lösch et al. 2006; Makarewicz et al. 2016; Tornero, Molist Montaña, and Saña Seguí 2016) suggested a wide variety of synchronic caprine culling practices, reflecting geographic as well as temporal differences in the adoption of goat husbandry. Early evidence of domestic goats in this region is hypothesized for Nevalı Çori (Peters et al. 2005), dating back to around 8500 cal BC and is supported by a slight reduction in size—which does not occur for gazelles and bovids, a large majority of female and immature individuals, and an overrepresentation of caprines in the following levels of the site.

Although a higher number of samples would be desirable, the present application studying humeri cross sections was able to measure several strength-related bone parameters and observe their evolution and variations through a sequence of 2,000 years. Among the results obtained, the first question to be taken into account is the progressive decrease in the observed size during the chronological sequence at Tell Halula. The reduction in size is one of the factors generally accepted as a marker, not necessarily unambiguous, of domestication processes (Helmer 1992; Peters et al. 2005; Vigne 2011; Zeder 1999; Zeder and Hesse 2000). Causes for this reduction in size have to be considered, among other factors, within the human selective pressures applied to the species. The detection of biannual reproduction patterns in goats during the MPPNB (Tornero 2011), the prior killing of specimens in their growth stage (Saña Seguí 1999), and a markedly decreased size in relation to its wild agriotype (Saña Seguí 1999) suggest the presence of domestic goat, *Capra hircus*, from the oldest occupations of the settlement. It is interesting to note that sheep was not introduced in this site until Occupation Phase 8 (7590–7520 cal BC) and in parallel an increase in the importance of goat herding can be seen. It is not until the end of the MPPNB that sheep replaced and overtook the economic importance of goats (Saña Seguí and Tornero 2012; Tornero, Balasse, Molist Montaña, and Saña Seguí 2016). The economic

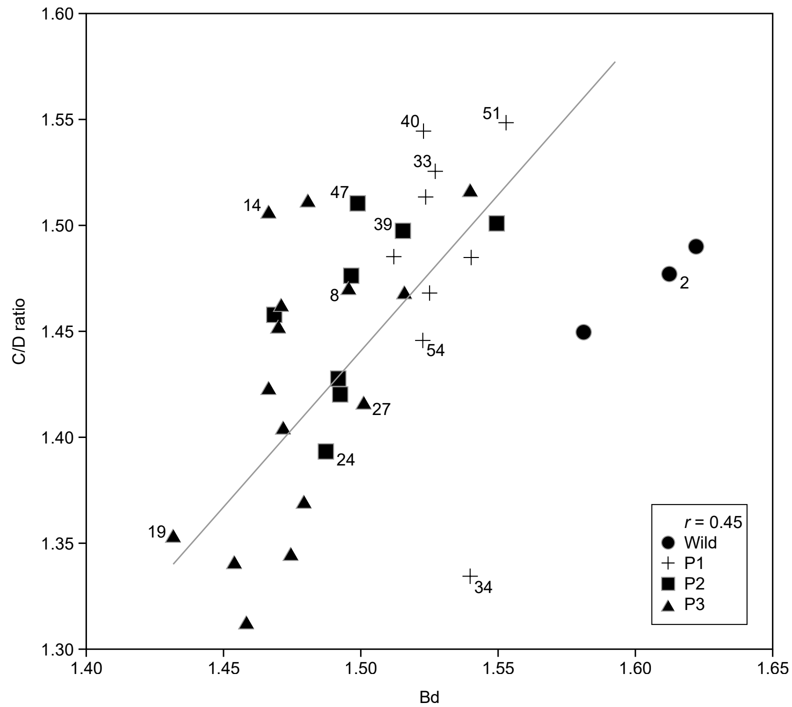

Figure 1.1.4. Bivariate graph of distal breadth of humerus (Bd) and C/D ratio log values of the 35 analyzed samples within their corresponding group of analysis.

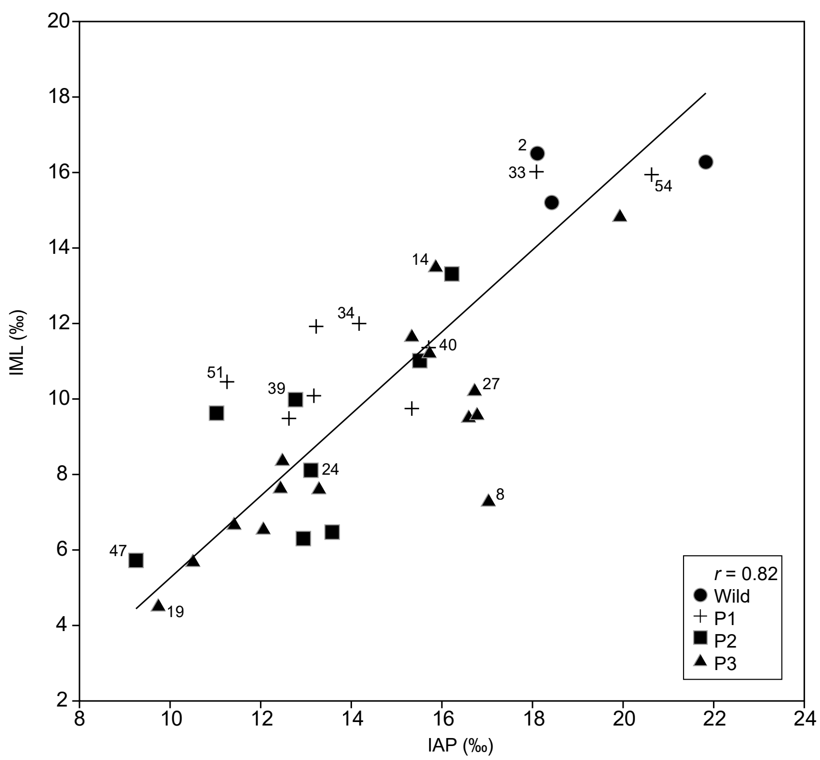

Figure 1.1.5. Bivariate plot of the anteroposterior moment of inertia (I_{AP}, in ‰) and the mediolateral moment of inertia (I_{ML}, in ‰). Values were standardized by the geometric average of Bd, Bt, H, and h rose to the fourth power.

Table 1.1.4. Cross-sectional geometric properties (mean and standard error values) for *Capra aegagrus* (wild) and *Capra* during Period 1, Period 2, and Period 3. Relative amount of cortical bone (C/D ratio; Ct.Ar/Tt.Ar); anteroposterior moment of inertia, anteroposterior bending strength (I_{AP}, in ‰), mediolateral moment of inertia, mediolateral bending strength (I_{ML}, in ‰), polar moment of inertia, torsional strength (J, in ‰) and circularity index (I_{AP}/ I_{ML}).

		Wild	**Period 1**	**Period 2**	**Period 3**
C/D ratio (%)	Mean	29.686	30.726	28.997	26.823
	SE	0.808	1.417	1.000	1.059
	N	3	9	8	15
Ct.Ar/Tt.Ar (%)	Mean	57.043	55.868	55.961	53.730
	SE	2.079	2.456	1.827	1.271
	N	3	9	8	15
I_{AP} (‰)	Mean	19.453	15.370	12.985	14.156
	SE	1.190	0.978	0.649	0.730
	N	3	9	8	15
I_{ML} (‰)	Mean	15.995	12.070	9.180	8.950
	SE	0.401	0.918	0.930	0.698
	N	3	9	8	15
J (‰)	Mean	35.448	27.440	22.166	23.107
	SE	1.358	1.824	1.300	1.369
	N	3	9	8	15
I_{AP} / I_{ML}	Mean	1.217	1.265	1.554	1.667
	SE	0.070	0.053	0.129	0.079
	N	3	9	8	15

importance of goat herding could favor, as pointed out by some of the obtained results, changes in living conditions of these animals, which would affect their mobility and physical activity patterns.

Results show how the relative amount of cortical mass (C/D ratio and Ct.Ar/Tt.Ar) generally tends to decrease progressively over time, although the rate of decrease in cortical mass is not directly related to a size reduction. Both ratios show different values for individuals of similar size. In the case of *Capra aegagrus*, for example, the three analyzed specimens have a relative amount of cortical mass (Ct.Ar/Tt.Ar = 59.25 [Sample 3], 58.99 [Sample 6], 52.89 [Sample 2], and C/D ratio = 30.90 [Sample 3], 28.16 [Sample 6], 30 [Sample 2]) lower than a good number of smaller specimens, such as Sample 40 (62.49, 35.03), Sample 39 (64.74, 31.43), and Sample 14 (59.61, 32.10).

As Ct.Ar is an indicator of the tension and compression loads that the bone has supported (Nordin and Frankel 2001), it is possible to interpret these results as a reflection of the volume of activity that the bone had to cope with and, therefore, of the animal, in the sense of the animal's weight that the bone had to carry. On the other hand, it is necessary to take into account that Ct.Ar varies according to Tt.Ar, that is to say to the bone size, meaning that wide bones have expectedly higher absolute Ct.Ar but lower relative cortical area (Ct.Ar/Tt.Ar or C/D) than narrow bones (Jepsen et al. 2007; Jepsen et al. 2015). This explains why, when C/D ratio is related to size, domestic specimens appear more robust than wild ones. The most significant cases are documented, however, during P3, when two inverse dynamics are differentiated. None of these dynamics is

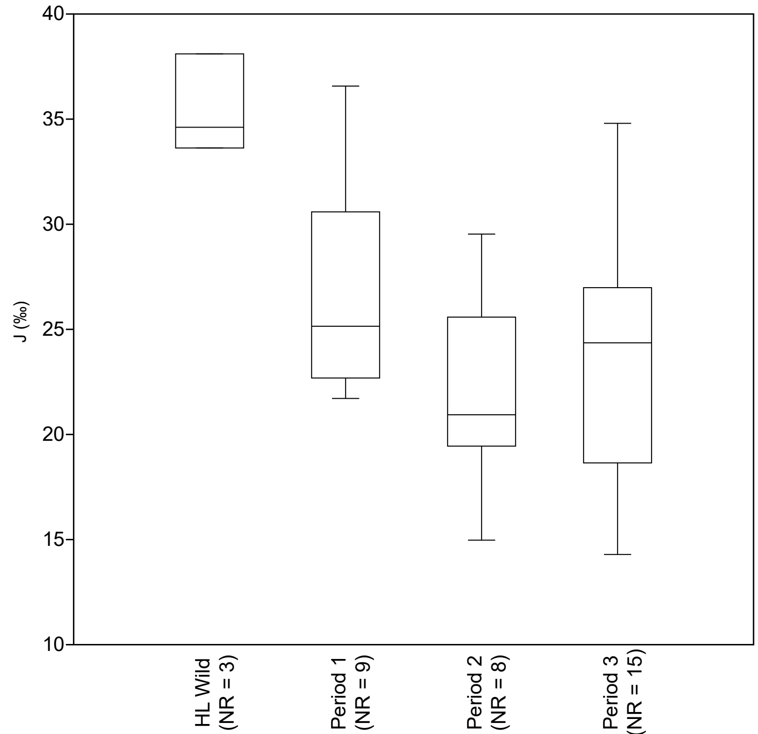

Figure 1.1.6. Boxplot representation of the Polar moment of inertia (J, in ‰) values in each period showing differences in torsional resistance values.

limited to specific phases of occupation. In contrast, from OP 1 to OP 10 the registered dynamics are significantly homogeneous. During the pre-Halaf occupations, a change in goat-herding management strategies would be developing, which would imply an apparent lower volume of activity for part of the flock. There is no direct correlation of this fact with the body size of specimens, which prevents, in all cases, these differences being attributed to sexual dimorphism. In this sense, although sexual dimorphism should not be an accountable variable, a differential management of males and females might result in an interesting point to interpret with our data.

Results obtained for the calculation of the moments of inertia raise several interesting questions regarding changes in goat activity patterns during the occupation of Tell Halula. It can be considered that the greater the loads received—more intense, more recurrent, and more durable—the higher the values of the moment of inertia. Moreover, we should expect higher values in I_{AP} than in I_{ML}, as it relates to the main displacement direction of goats and is thus more constantly exposed to bending loads, which refers to bone growth reacting to loading intensity, movement iteration, or time of exposition (Main and Biewener 2004). This approach individualizes a group of specimens clearly differentiated from the rest because of their high *I* values, which we can relate to a higher mobility regime. This group includes the three specimens of *Capra aegagrus* and samples number 20, 33, and 54, the first two associated with P1 and the latter with P3. These samples correspond to individuals of undoubtedly smaller size than *Capra aegagrus* but which, despite this, show similar bending strength values. In this sense, it is important to highlight that, in addition to their high values, both moments of inertia present similar values and, therefore, a high index of circularity. These values could be indicative of a varied mobility, with frontal and lateral displacements alike that cause loads on the bone from multiple directions (Main and Biewener 2004; Shackelford et al. 2013). For the rest of samples from P1, the values of the moments of inertia decrease in comparison with the maximum activity reference group, although they maintain circularity index values close to 1. This suggests that these individuals may be incurring in loading patterns similar to those of the *Capra aegagrus* group, even if coupled with a lower intensity or recurrence.

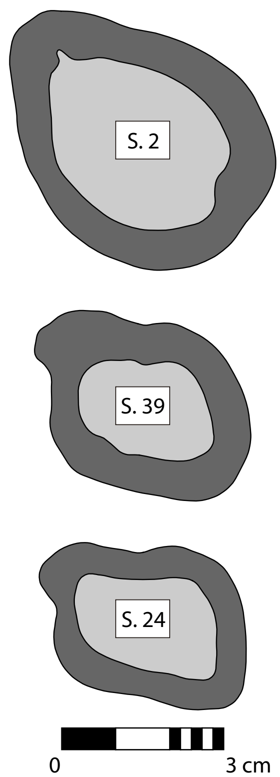

Figure 1.1.7. Examples of the three outline shape types documented for the cross sections. From top to bottom, T1 (Sample 2), T2 (Sample 39), T3 (Sample 24).

Table 1.1.5. Section outline morphotype (T1, T2, and T3) abundance for each of the defined groups: Wild, Period 1 (P1), Period 2 (P2), and Period 3 (P3). Underlined values represent where the highest number of remains for each shape type can be found.

	T1	T2	T2	N
Wild	<u>3</u>	0	0	3
P1	<u>7</u>	0	2	9
P2	1	3	<u>4</u>	8
P3	2	4	<u>9</u>	15
N	13	12	10	

The dynamics documented for P2 and P3 are more complex, as they show a wider range of variability in *I* values and a fluctuating imbalance between both parameter values.

Both Periods 2 and 3 show two clear and matching differentiated groups polarizing around higher (N = 13, I_{AP} = 15.71, σ^2 = 1.15, I_{ML} = 10.97, σ^2 = 2.83) or lower *I* values (N = 16, I_{AP} = 11.98, σ^2 = 1.72, I_{ML} = 7.72, σ^2 = 3.30) that could be interpreted as indicative of higher or lower activity patterns. However, samples corresponding to P2 seem to belong more to the group with low *I* values, meaning lower activity, while samples from P3 are distributed more homogeneously between both groups. It should also be said that the samples from Period 1 are not associated with the wild specimens, which also show a similar grouping.

Additionally, the variability in the values of I_{ML}, that is, the variability in the levels of bending loadings received laterally, is worth noticing. This variability clearly influences the circularity index values, where individuals with high circularity values—close to 1—are perceived along with specimens whose circularity index exceeds the ratio of 2:1. This situation can be related to the reduction of lateral movements in these individuals, thus indicating different loading regimes that may be related to a different mobility, probably focused on a forward movement. Therefore, different groups seem to be defined based on the volume of activity and the type of displacement—or perhaps degree of freedom. If we look into the polar moment of inertia, the torsional resistance values define similar dynamics, identifying the same groups. On one hand, the maximum torsional loading group is maintained with the three specimens of *Capra aegagrus* and Samples 20, 33, and 54. If we take a look at the size of these three samples, Samples 33 and 54 are similar in size, while Sample 20 is consistently smaller. Coincidentally, when taking Bd and h values from Tell Halula *Capra* humeri against a reference sample of male and female wild goat specimens from Abu Gosh (Ducos 1978), these three samples, especially Samples 33 and 54, fall in the same size range as Abu Gosh female goats. Although we must note that most of Halula's domestic specimens fall within that range, just these three samples show similar patterns to those of the previously identified wild specimens, which, in this sense, match Abu Gosh male wild samples. Additionally, the classification of samples according to the three established representative types of cross-section morphology can also be ordered at a temporal level in consonance with these results. More concretely, a certain correspondence can be established between individuals with circularity indexes close to 1 and Period 1. At the same time, T2 only appears during P2 and P3, and T3 is mostly represented during P3 when the most extreme values of all the analyzed samples are recorded.

The results allow us to consider the coexistence of diverse goat management strategies in the course of the occupation sequence at Tell Halula. The data from P1 suggest a relatively homogeneous level of activity for the goat population with an unrestricted freedom of movement that is reflected in bone development similar to that of wild goats. For P2 and P3 greater variability is evidenced: individuals with, possibly, different levels of activity and different degrees of freedom of movement are present. Given that the analyzed samples actually belong to different occupation phases and, consequently, to different flocks, it is difficult to consider the coexistence of different practices, although it is interesting that the evaluated parameters show different dynamics throughout the analyzed sequence and that these dynamics are not directly correlated with the documented decrease in size. The detection of individuals of relatively smaller size with loading patterns similar to, or even associated with, those of *Capra aegagrus* is also highly significant, as it offers evidence for differential treatment among the specimens comprising the domestic sample. This reveals, at least, one practice that mainly generates anteroposterior strains, reducing lateral displacement, and one that maintains a multidirectional strain, therefore indicating a probable varied mobility. Accordingly, there is a wide range of management strategies that should be taken into consideration. Some possible explanations for these differences among domestic specimens might relate to differential management of individuals according to their exploitation and thus, in some sense, also their sex. While sexual dimorphism should not be an issue directly affecting our data, we must take into account that a major product such as milk can only be obtained from females, and this could certainly be the cause of differential management. In this sense, we should consider all possible approaches to herding and their consequences mobility-wise. A full enclosure and confinement of animals would reflect low torsional values and probably a situation close to brittle bones. Enclosure in wide spaces would give a better chance for movement, yet still reduced, thus reflecting low mobility patterns. Higher mobility strategies would probably reflect seasonal movement of herds or some kind of nomadic pastoralism, which include recurrent displacement and interaction with different kinds of landscapes and ground underfoot. Also, as previously stated, the three small specimens grouping with *Capra aegagrus* specimens might indicate that those specimens were female wild goats. In a similar sense, trapping wild specimens and breeding them with the herd or recapturing domestic escapees might result in distinct mobility options.

Similar hypotheses have also been considered in previous studies regarding different species and methodological approaches (Evin et al. 2014; Price and Evin 2019). A straight line of domestication is no longer imaginable. Capturing young wild specimens and raising them as domestics or capturing adults are both plausible options. Bearing in mind the nature of goats, it is also feasible to propose that domesticated specimens might escape to live in the wild.

Taking into consideration the criteria used up to this point, raising young wild specimens as domestic resources will most probably result in bones showing an adaptation to domestic movement "limitations." In a similar way, domestic escapees' bones might readapt, given enough time, to their new wild life. At the same time, the descendants of these escapees living in the wild, while domestic, will show adaptation to wild mobility. What should define the specimens we are analyzing is not their degree of domestication as much as how long and in which manner they moved during their lives as wild or captive individuals.

Concluding Remarks

Computed Tomography (CT) enables us to reveal changes in the morphology and the development of the distal diaphysis of *Capra* humeri throughout the occupation of Tell Halula. Calculation of the amount of cortical mass, either through C/D ratio or through the cortex area, allows us to observe differential developments of the cortical mass that do not necessarily depend on the size of individuals, so that the activity carried out by the animal in life becomes an extremely important factor in the conformation and growth of the bone.

Physical parameters of humeri section allowed an assessment of the directionality and the intensity of loads received, evidencing the existence of different mobility or activity regimes throughout the sequence that could be related to the implementation of various livestock maintenance strategies.

Additionally, we were able to observe how the geometry of humeri sections also reflects some shape variations that could be linked to these same changes suggested by the physical parameters addressed in this paper. Shape variations between wild and domestic animal populations is a widely addressed topic that has received particular attention in the last decade with remarkable results for the identification of human selective pressures and the inference of domestication statuses (Cucchi 2008; Cucchi et al. 2011; Evin et al. 2013). Geometric morphometrics could be implemented to analyze the shape of cross section and study these bone changes through time, thus contributing to our understanding of human selective pressures resulting from different management strategies implemented.

Future and further development of cross-section analysis requires the integration in the analysis, as far as possible, of other long bones—tibia, femur, radius—that enable a broader vision of bone development in response to received loadings. At the same time, we suggest that it is necessary for a correct interpretation of the results to create a broad reference database (such as with specimens from Zeder 2001) to associate with a certain degree of reliability the different patterns of mobility detected in specific livestock practices. Correctly assessing the probable real practices behind different loading patterns is essential if we aim to understand the shifts in animal management strategies linked to Neolithization. Studying modern reference datasets with monitored-controlled factors affecting mobility regimes would help in the interpretation of our archaeological data.

As a matter of fact, we must underscore the need to continuously and actively search for, explore, and improve alternative techniques and methods of analysis in archaeozoology in order to complement, correct, or increase our knowledge of animal domestication. However much we already know, it is still just the tip of the hoof.

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