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Tempo and Mode of Domestication During the Neolithic Revolution: Evidence from Dental Mesowear and Microwear of Sheep

Tempo and Mode of Domestication During the Neolithic Revolution:
Evidence from Dental Mesowear and Microwear of Sheep

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Anthropology

by

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Abstract

The Neolithic Revolution marked a dramatic change in human subsistence practices. In order to explain this change, we must understand the motive forces behind it. Researchers have proposed many different stimuli, with most theories invoking environmental dynamics, human population density increases beyond environmental carrying capacity, and the natural outgrowth of human and plant/animal interactions. However, unanswered questions remain concerning the mechanics of animal domestication. Traditional studies of changing faunal morphology and skeletal population profiles offer some clues, but such research has had limited success identifying stages intermediate between wild and domesticated forms, which makes it difficult to discern initial attempts at animal control, and to fully understand this process.

This dissertation research brings the tools of dental microwear and mesowear to bear on the issue of animal domestication at the site of Gritille, Turkey. Dental microwear and dental mesowear of zooarcheological materials from the site should allow us to identify diet changes related to husbandry (control of movement and penning animals), and to determine whether the process was gradual or abrupt. This in turn will lead to a better understanding of the causes and mechanics of animal domestication during the Neolithic Revolution.

Gritille was occupied during the Neolithic, encompassing the period of animal domestication (traditional faunal analysis methods point to sheep domestication at the site). Collection methods recovered both flora and fauna from the Neolithic occupation, providing Ovis (sheep) remains whose diet can be tracked over the period. The Neolithic period was broken down into three periods. Each period provided statistically significant dental mesowear and microwear signatures, indicating the evolution of human control (domestication) of animals

at this site. Expansion of these methods to other sites allows comparison to understand how similar Neolithic people handled their animals. Further, comparing the Neolithic animals to wild animals from the Near East allows understanding of how humans modified the wild, natural diet and provides information on the types of environments the Neolithic animals were provided.

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Chapter One: Introduction

Domestic animals have been used by humans for a wide variety of resources: food, work power, fuel, medicine, clothing, protection, entertainment, companionship, status, and religious objects (Hemmer 1990). However, questions remain as to how and why 10,000 years ago (i.e., Pre-Pottery Neolithic) people settled down and began the agricultural revolution, which set the stage for modern civilization (e.g., Allen and Cheer 1996). Was the adoption of agriculture necessarily a better subsistence strategy than hunting and gathering? Settling down brought about new diseases, and people became reliant on their land and animals (Angel 1984; Bowles 2011; Larsen 1995; Lösch et al. 2006). This reliance may have led to many sites failing 3,000 years after large-scale farming began (e.g., Rollefson 1996). Archaeozoological remains from some sites indicated that although sites possessed domesticates, these animals were not part of the inhabitants' subsistence strategy leading to questions regarding animal husbandry practices (Lösch et al. 2006). Traditional studies of changing faunal morphology and skeletal population profiles offer some clues, but such research has had limited success identifying stages intermediate between wild and domesticated forms. This inability to distinguish subtle changes leads to difficulty in discerning initial animal control attempts, and in understanding fully this revolutionary process. The research herein utilizes dietary reconstruction methods (dental mesowear and microwear texture analyses) to provide insight into animal husbandry during the Neolithic. Humans controlled all aspects of animal life including diet during the initial domestication process and after. Therefore, dietary reconstruction provides a different insight into domestication than traditional archaeological methods. Through understanding how animals were handled, ideas on why animals were domesticated may be better nuanced.

Domestication Defined

Domestication is subject to much debate, as not only the how but also the why domestication occurred is not fully understood. Even the definition brings debate, as individual ideas encompass a wide range of perspectives. For example, a culture-based definition recognizes community use of the animal, while an osteological definition relies on distinct changes between wild and domestic forms (Dyson 1953). Further, domestication is not strictly a human capability (see Herre 1970 for opposing view). Ants have domesticated other insects and fungi (Reed 1977b). This section presents domestication definitions in a chronological order to show idea development over time.

Bökönyi's (1969) domestication definition included three parts. First, humans selected animals with behaviors favorable for domestication. Humans then removed the animals from their natural habitats (e.g., environment, herd). The selected animals underwent controlled breeding to create profit for the domesticators (e.g., increased number of tamed animals) (Bökönyi 1969). In 1971, Reed opined that domestication is simply human control over animals, specifically their mating[1]. A few years later, Brisbin (1974) presented domestication as a change in human/ animal relationships (e.g., humans no longer viewed animals just wild meat sources). For Bender (1975), domestication was a process of human control that caused accrued genetic change leading to a new domestic species. Comparably, Ratner and Boice (1975) found domestication as the changing of selection factors on animals. These selection factors included natural selection forces (e.g., the factors that animals must adapt to/ evolve), and new factors allowing survival in human-created environments. For instance, as animals became accustomed

[1] Reed later included the fact that domesticated animals could not return to wild forms into his definition (1984).

to living around humans, changes occurred in the flight or fight response. Ultimately, human husbandry creates new genotypes, as natural sexual selection no longer plays a role in animal reproduction. Humans control the breeding process, choosing which animals reproduce (e.g., Cranstone 1969) (Ratner and Boice 1975, Tchernov and Horwitz 1991). In 1978, Ducos developed a definition circumventing contentious issues of the amount of human control (e.g., proto-domestication) and morphological indicators. Ducos proposed domestication happened when animals became incorporated into a society's socioeconomic system (i.e., humans owned animals like any other object) (Ducos 1978).

Hole (1989) believed domestication to be an adaption of humans to their environs, dependent on resources available to them. Bottema (1989) found domestication started when the animal familiarized itself to humans. For Horwitz (1989) domestication was part of a spectrum. The domestication process developed from hunting into incipient domestication or proto-domestication (e.g., Cope 1991 and the use of desert kites). Initial forays into animal handling led to domestication, and finally animal husbandry (i.e., genetic manipulation to produce specific breeds) (Horwitz 1989). In support of Horwitz (1989), Clutton-Brock (1989) found that morphological changes marking domestication occurred after animals were assimilated into society. These morphological changes separated the wild and domestic forms, indicating new breeds due to genetic changes. This genetic separation occurs in the same way new sub-species form in the wild. Therefore, an animal is domesticated if bred under human control (e.g., food, mating, and habitat) for human profit (Clutton-Brock 1989).

Hemmer (1990) defined domestication as keeping and breeding animals under human control. Of special importance to Hemmer's concept of domestication was that domestic animals were no longer regulated by environmental stimuli, like wild animals. The environmental

separation changed not only the morphology but also the physiology of the domestic animal (e.g., birthing season) (Hemmer 1990). Similarly, Price (1998) viewed domestication as a process in which animals adapt to their environment. The phenotypic changes exhibited will vary because not all environments are the same. Therefore, when studying domestication, a range of genetic adaptations occurs. The diversity ensuing makes distinguishing between domestic and wild difficult until all animals within the population reach the same level of genetic adaptations (Price 1998). Ingold (1996) found, after examining ethnographic examples, that domestication was a degreed structure, based on the amount of human involvement needed to establish favorable environments for animal growth. This led Clutton-Brock (1999) to break domestication into a two-part activity. The biological aspect included the actual genetic changes animals underwent from wild to domestic (e.g., retention of juvenile characteristics, reduction of body size). The other aspect was cultural, based on the changing relationship between humans and their animals. This process was not instantaneous, but developed out of other relationships, such as pet keeping (Clutton-Brock 1999).

Russell (2002) found that domestication was based on how humans viewed the animal, either as belonging to the individual or a natural (wild) resource. Arbuckle (2005) defined domestication as the separation through human effort of domestic from wild animals. For instance, domestic animals' reproduction was controlled by humans. Further, domestic animals must adapt through genetic changes to human-created living environments (Arbuckle 2005). Lien (2007) suggested that domestic status was based on human economics. By examining modern domestication within the salmon industry, Lien found that the only difference between wild and domestic salmon was their location (farm versus ocean) and value placed upon them. Other features commonly cited for domestication, such as changes in behavior and mate choice,

did not occur in salmon. Therefore, not all traditional domestication characteristics are good indicators for domestication, as not all species undergo these changes (Lien 2007). Price and Bar-Yosef (2011) simply defined domestication as "morphological or genetic changes" (2011: S165).

In this research, I will use the term domestication any time human control occurred, which changed the animal's natural behavior (e.g., diet, reproduction). This includes both unconscious and conscious control. Unconscious control happened during the initial husbandry process, when humans were beginning to control animals. Animal genetic changes took place without human intention. Conscious selection ensued after humans understood the domestication process and performed selected breeding to obtain specific features and qualities (Higgs and Jarman 1972). As domestication is a single term trying to describe a larger process, difficulty ensues in trying to satisfy all ideas. Since this dissertation is not a theoretical examination of domestication itself, the terms *domestication* and *husbandry* will be used interchangeably, as both involve an active human role and investment in animals' lives. Domesticated animals contrast from animals classified as wild within this dissertation. Wild animals' lives or deaths do not have importance within a society, such as economic value (e.g. Lien 2007). Instead, animals classified as wild are viewed as a part of the environment or landscape.

Domestication Theories

Despite decades of research, the motive forces behind animal domestication and the processes by which it first occurred are still not known or understood. Theories regarding domestication abound concerning where and why domestication first occurred, what animals

were used, what changes animals underwent, and how domestication affected society (Buitenhuis 1996). Childe (1939), for example, suggested that domestication resulted from an environmental trigger, specifically a dramatic drying. The harsh climate caused humans, animals, and plants to gather around water sources, which created new relationships and ultimately led to domestication. Some more recent researchers, such as Binford (1968) and Cohen (1977a, b), favored sedentism and increasing human population overwhelming the land's carrying capacity. Still others have suggested that domestication was a natural outgrowth of human-animal interactions, with animals first serving as hunting decoys or pets prior to their domestication for exploitation as food and other products (Reed 1959, Uerpmann 1996). Isaac (1962) speculated domestication was born of spiritual necessity, as people needed a ready supply of sacrificial animals. On the other hand, Hayden (1992) conjectured societal hierarchies and competition spurred domestication in order to have surplus resources. These theories have been developed by looking at the archaeological record and patterns within. Lamentably, interpretations based on traditional reconstruction methods can often be used to support varying domestication arguments, providing little advancement in understanding why the Neolithic Revolution occurred.

Traditional Reconstruction Methods

Tradional zooarchaeological methods used to indicate animal husbandry include morphology, metrics, and demographic profiles. For example, domesticated herds tend to have longer-lived females than males due to differential cull rates associated with the balance of food needs and population maintenance (Zeder and Hesse 2000). Morphological trait changes associated with domestication include decreases in overall body size, cranial capacity, facial

length, and teeth. Also, domesticates tend to be less sexually dimorphic and have changes in horn appearance and shape related to maintaining juvenile features (Leach 2007, Zeder 2006a). While the studies of demographic profiles and morphological features have contributed much to our understanding of animal domestication, these approaches often lead to a simple dichotomous classification—domesticated or not—which provides only limited detail on the timing and processes by which it occurred. Unfortunately, morphological distinctions most likely did not occur immediately after husbandry began. Instead, many generations transpired before genetic changes accumulated to evolve domestic species (Reed 1971). Zeder (2011) proposed that 1,000 years after animal management started, morphological distinctions between wild and domesticated animals could be seen. However, this belief was not shared by all (e.g., Horwitz 1989, Arbuckle 2005).

Further, questions remain as to when domestication first began. Was it a novel invention at the start of the Neolithic? Did incipient domestication occur during the Natufian (Moore 1982, see also Jarman and Wilkinson 1972)? Of course, we must also remember that domestication was not a single occurrence, but rather an event that could have occurred at multiple places at multiple times (Flannery 1983). Moreover, these disparities are often echoed in genetic studies, in which the molecular clock dates for genetic changes are often very different from the dates the archaeological record provides (Dobney and Larson 2006). For example, while archaeological evidence points to sheep domestication around the beginning of the Holocene (Neolithic) 10,000 years ago, molecular clock data gives much earlier dates such as 84,000 to 134,000 years ago (Dobney and Larson 2006, Guo et al. 2005). Although DNA analysis seems like a simple solution to discovering the origins of domestication, there are inherent issues with this technique, including recovery of usable DNA within the archaeological

material (Dobney and Larson 2006). Therefore, other reconstruction methods are warranted, which are free from the inherent problems traditional methods possess (see Chapter 4 for discussion of methods and problems), and can be used across species and time.

Dietary Reconstruction

In this research, dietary reconstruction techniques will be used. Dental dietary reconstruction techniques can be used on the teeth of any domesticated or wild animal. Specifically, in this research, dental mesowear and microwear analyses will be used to understand diet during this critical period of initial domestication. Both these methods utilize the amount of enamel wear present on the teeth to reconstruct dietary patterns, as dental wear provides important insight into an animal's life. During life, dental wear guides dietary choices, the amount of food eaten, and in extreme cases of dental senescence, leads to starvation and death (Jurado et al. 2008). Dental mesowear and microwear analyses provide a way to understand diet through different aspects of wear, gross and microscopic. Furthermore, these reconstruction methods have shown to be useful in comparing animals eating similar diets over time and space through years of researach. The method's repeatability indicates the inherint assumption used (animals eating similar diets in similar environments possess similar effects on the dentition) is not problematic, unlike some archaeological based methods (see Chapter 4 for discussion of archaeological based methods) (Rose and Ungar 1998). In fact, some of the earliest microwear studies involved the study of sheep teeth (e.g., Baker et al. 1959). Furthermore, using the dentition in understanding domestication is not novel. Teeth survive more often than bone and undergo size change in correspondence to body and other morphological indicators often used to determine presence of absence of domestication at a site

(Flannery 1983). In this research, archaeological samples from Neolithic animals will be compared to wild animals to understand how human control modified wild dietary types.

Gritille

The study proposed here will examine ovicaprines from the archaeological site of Gritille (Turkey) to test hypotheses regarding domestication and handling of animals during the Neolithic. Several discontinuous occupations were represented at the site: Pre-Pottery Neolithic B, Early Bronze Age, and Medieval (Ellis and Voigt 1982). The Neolithic deposits (8,500-7,700 BP) were separated into four discrete stratigraphic units (Phases A-D, A-most recent) (Monahan 2000). Traditional metric and morphological analyses (e.g., size of teeth) indicated domestication occurred during the Neolithic; by Phase B, animals were morphologically domestic (Monahan 2000). By comparing Gritille animals to other archaeological sites and wild animals, understanding can be gained as to how initial husbandry methods affected diet (see below). Each archaeological unit/ phase at Gritille provides unique information. For instance, Phase C provides information as to what occurred prior to morphological/ genetic changes, Phase B encompasses maintenance of domesticated animals, and Phase A indicates the reaction of agriculturalists to environmental degradation.

Initial Husbandry Methods

Strict human control and separation of domesticates from their wild progenitors had to take place for domestication to occur (Lien 2007). This separation stopped gene flow between the two populations, which allowed genetic changes to build up, creating morphologically distinct domestic species. If this separation had not occurred, animals would remain wild, and

morphological changes seen in domesticates would not have arisen (Lien 2007, Zeder 2006a). Modern herd structures (e.g., mixed herds) and handling, such as allowing herds to roam freely across the landscape, most likely did not occur back then (e.g., Harris 2002, Khazanov 1994). Archaeological evidence does not support mixed herds during the initial domestication attempts. Instead, sites possessed and domesticated either sheep or goat before introducing another domesticate species (e.g., Moore et al. 2000). For instance, at Gritille the favored ovicaprine was sheep (Monahan 2000).

Overtime, whether goats or sheep were chosen to be domesticated, morphological changes like size occurred. However, as Arbuckle (2005) has noted, domestication itself does not produce size change. Instead, morphological and size change occurred through conscious selection over time for smaller animals, or by dietary stress associated with reduced food, penning, or other unfavorable conditions (Zohary et al. 1998 and references therein, see also Brochier et al. 1992). This underscores the need to understand the role of diet in domestication and the important role that dietary reconstruction can play in understanding the process. Humans had to be careful in ensuring animals received the proper nutrition, as not only were the animals' gastrointestinal systems and bacteria within adapted to particular diets, but the incorrect foods could cause improper wear on teeth which could lead to early deaths (an issue seen in zoos today) (Jurado et al. 2008, Van Soest 1994). Human's strict control on movement and diet was evidenced by Grupe and Peters (2011) isotopic analyses of wild and zooarchaeological fauna from Near Eastern sites. The study revealed that even during the early part of the Neolithic, the wild and domestic animals had different isotopic values with domesticated animals reflecting a diet dependent on crops cultivated by Neolithic humans (Grupe and Peters 2011). Dietary reconstruction methods will provide similar understanding for the site of Gritille.

Dietary Comparisons

In this research, Gritille will be studied and compared to other archaeological sites from the area and modern wild animals from elsewhere in the Near East. Specifically, specimens will be examined to understand the process of domestication, as traditional morphological analyses indicate Gritille animals were domesticated (Monahan 2000, 2007). However, morphological changes may have appeared after the actual domestication occurred (see Chapter 4). In addition, the end of the Neolithic occupation will provide information on the impact Neolithic agricultural practices influenced the landscape around the site. This understanding of landscape is important as some sites were abandoned at the end of the Neolithic, possibly due to environmental degradation (e.g., Rollefson and Köhler-Rollefson 1989). The mesowear and microwear on the archaeozoological samples will be compared to wild-shot specimens to understand how husbandry practices affected the animals (i.e., how similar or different are the Gritille animals from a traditional wild diet). The wild baseline provides insight into the environment through comparing which known-environment wild animals align to the Gritille material. In addition, sites from around the Near East will be examined and compared to Gritille to understand how initial husbandry practices compare to later times. Although the archaeological samples have undergone deposition and other taphonomic processes, as King et al. (1999) found dietary microwear was not altered[2] (e.g., browser wear was not damaged to look like grazer wear).

Chapters

Chapter 2 provides general information on dietary reconstruction methods. Chapter 3

[2] If taphonomic processes occurred, such as abrasion, the alteration would be in a recognizable pattern, which can be ignored when the tooth is examined (King et al. 1999).

provides a literature survey on animals utilized in the study and environmental reconstruction methods. Chapter 3 includes the statistical analyses of the extant baseline specimens. In Chapter 4, the Neolithic in the Near East is explored. This chapter includes a brief survey of the Neolithic and theories surrounding domestication and pastoralism. In addition, archaeological domestication reconstruction methods will be examined to understand traditional analyses. The end of the chapter provides statistical analyses of the dietary reconstruction methods used on the sample of caprine teeth from the Neolithic site of Gritille. Chapter 5 examines how the Neolithic Gritille compares to several other archaeological sites from the Near East to see whether patterns exist in husbandry methods. Chapter 6 summarizes and provides overall conclusions based on the results of this dietary reconstruction research.

Chapter Two: A Review of Approaches to Dietary Reconstruction

A great deal of information can be garnered from a tooth, from the species of animal, to its size and age, and its dietary habitats (Silver 1970). The teeth of goats and sheep, who are ruminants (rechew their cud), play an important role in breaking down plant material (Geist 1971, see Schmidt-Kittler's 1984 examination of form vs. function). The adult dental formula found in goats and sheep is 0 0 3 3/ 4 0 3 3[3] (Figure 2.1) (Harrison 1968, May 1977, Weinreb and Sharav 1964). The lower incisors meet up against a tough dental pad while the other lower teeth (premolar and molars) interdigitate with their upper counterparts (May 1977). Goats and sheep are classified as having hypsodont teeth (i.e., high-crowned teeth adapted for grazing) and selenodont molars (i.e., crescent shaped enamel cusps and dentin pattern) (Croft and Weinstein 2008, Davis 1987, Harrison 1968, Geist 1971, Weinreb and Sharav 1964). Further, goat and sheep premolars are molarized, square to rectangular in shape. Like the molars, premolars have lophs (i.e., enamel ridges) running parallel to the tooth row in a mesiodistal direction, allowing an increased surface area on which to process ingested food. During mastication, the ruminant's jaw moves laterally (i.e., the chewing stroke), catching the browse or graze between the lower teeth moving across the upper teeth (Crompton and Hiiemäe 1969). However, although teeth are *adapted* to eating browse or graze, this does not mean a specific animal actually ate these foods. There is a difference between what an animal is *capable* of eating, and what it eats on a daily basis. Tooth wear provides information on what the tooth contacted in life (e.g., diet) (Teaford 2007). The research here focuses on two dietary reconstruction methods, mesowear and

[3] This notation indicates the adaptation of the canine as an incisor. The formula can also be written 0 0 3 3/ 3 1 3 3. The deciduous dentition lacks premolars (May 1970, Weinreb and Sharav 1964).

microwear, which rely on dental wear to reconstruct diets. The following chapters use these reconstruction methods to examine gazelle, goat, and sheep diets. The rest of this chapter examines the ruminant diets and provides background information on mesowear and microwear analyses.

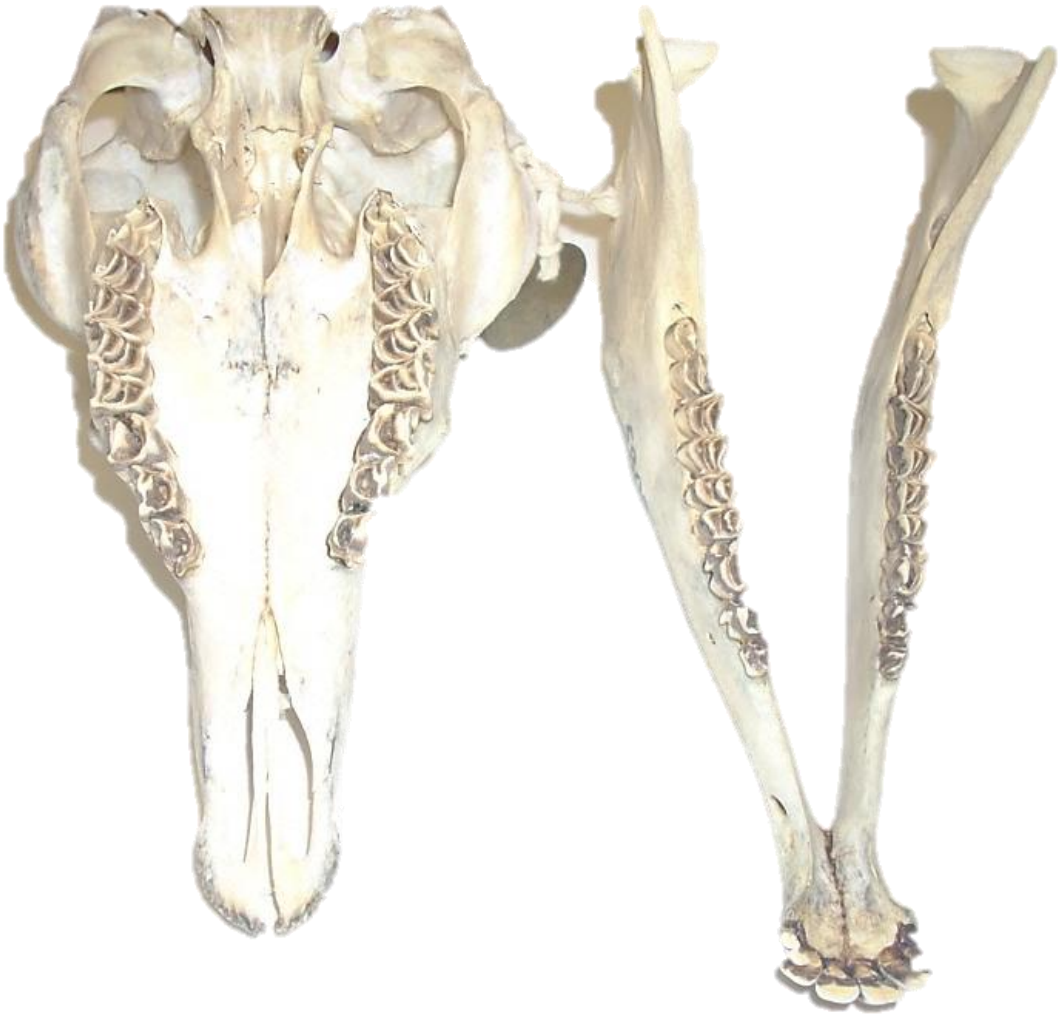

Figure 2.1. Photograph of sheep dentition (*Ovis vignei dolgopolovi* (FMNH 5801)) showing differences between maxillary dentition (left) and mandibular dentition (right). Photograph taken by M. Zolnierz.

Rumination

Caprines (goats and sheep) and gazelles are herbivorous ruminants, which means they consume browse or graze and re-chew their cud (Table 2.1) (Reed 1969, Shackleton 1997). In order to break down the food consumed, ruminants have a four-chambered stomach (rumen, reticulum, omasum, and abomasum) that allows food to ferment[4] prior to entering the digestive system proper (Geist 1971, Reed 1969, Van Soest 1994). Initial ingestion of food is cursory, as the goal is to mix food with saliva to form a bolus, which is swallowed (Van Soest 1994). The majority of food breaks down during rumination, which varies between animals due to food adaptations (Hulet et al. 1975). For example, when goat and sheep are fed the same, goats spend more time chewing (i.e., initial ingestion) than sheep. However, sheep ruminate (i.e., regurgitate and chew) more than goats. Goats are better able to break food down into smaller pieces during the initial ingestion. Their higher salivary production allows goats to eat more fibrous foods, which bacteria in the gut digest (Domingue et al. 1991).

[4] Fermentation is defined as "metabolism by microorganisms in the absence of oxygen . . . [which] converts carbohydrate into organic products such as volatile fatty acids, lactic acid, and ethanol" (Van Soest 1994: 24).

Characteristic	Browse	Graze
Definition	Herbaceous and woody dicots (forbs, shrub leaves and stems)	Monocots (grass)
Cell wall	Thinner, lignin	Thicker, cellulose
Digestibility	Quick	Slow
Dispersion	Dispersed	Uniform
Location	Low to high growth	Low
Plant architecture	Large-scale heterogeneity of nutrition, new growth at tips	Homogenous source of nutrition, new growth at base
Plant defense	Tannins and other toxins (chemical digestion changes)	Silica (mechanical digestion changes)
Animal	Goat, pig	Cattle, gazelle, sheep

TABLE 2.1. Generalized property distinctions (left column) between plants classified as browse (middle column) and graze (right column). The bottom row indicates animal preferred preference when both types are available (modified from Shipley 1999, see also Van Soest 1994).

Ruminants do not directly obtain the nutritional value of what is ingested. Instead, microbes break down the cellulose and other material consumed (Geist 1971, Reed 1969). The microbial breakdown produces several products, such as volatile fatty acids. From these end products, the animal gains energy and other nutrients (Van Soest 1994). Cud is brought back up from the rumen for continued chewing to reduce the size of the ingested particles, and provide more surface area for bacterial attachment (Geist 1971, Reed 1969, Van Soest 1994). Rumination occurs at irregular times throughout the day, and will vary based on type of food ingested (De Vree and Gans 1975, Gordon 1958b, Hulet et al. 1975, Van Soest 1994). When chewing, researchers have found animals do not have a preferred or favored side. Instead, when

the food is consumed, a few bites will be taken on one side and then passed to the other side (De Vree and Gans 1975). Because humans lack the microbial relationship seen in ruminants to break down fibrous plant parts like cellulose, these animals may have been favored for domestication, as they do not compete for the same nutritional resources (Reed 1969).

Mastication

Contact between food and teeth, during initial ingestion and rumination, occur during the power stroke of the chewing cycle[5]. Some animals, inclusing humans, primates, and rhinoserouses, have two phases of the chewing cycle (related to centric occlusion) in which the muscles in the head move the jaw in an upward then downward movement (see Fortelius 1985, figure 13 for illustration). However, gazelle, goats, and sheep have one phase in which the jaw is pulled in one upward movement. The contact between the food and teeth occurs as the lower jaw moves upward in a buccal-lingual direction (Fortelius 1985, Franz-Odendaal and Kaiser 2003, Janis 1990, Kay and Hiiemae 1974). Specifically, during the occlusal phase the posterior aspect of the mandibular dentition contacts the middle of the maxillary counterpart. The anterior half occludes with the anterior part of the upper tooth and the back of the tooth medially to it (Fortelius 1985, see Every et al. 1998 Figure 11 for illustration).

Browsers versus Grazers

Grazers often live in open habitats, while browsers prefer more enclosed locations such as forested areas. Browsers prefer leaves and twigs off shrubs and low trees while grazers eat

[5] The other two parts of the chewing cycle are the closing stroke and the opening stroke (Fortelius 1985).

grasses and forbs (Table 2.1) (Clauss and Dierenfeld 2008, Shackleton 1997). Browsers and grazers can be distinguished not only by adaptations of their gastrointestinal systems, but other anatomical and physiological features as well. Anatomical differences include the shape of the premaxilla bone and snout width, the mandible shape, and tongue. These have adapted to the process used in selecting leaves off plants versus taking in clumps of grass. Physiological differences include saliva and structure and passage time within the gut (e.g., browsers take longer to pass material) (Clauss and Dierenfeld 2008, Clauss et al. 2008, Pérez-Barbería and Gordon 1999, Valli and Palombo 2008, Van Soest 1994). For instance, grazers like sheep are able to exploit larger amounts of cellulose. Goats, although able to eat this material, do not process cellulose as efficiently (Van Soest 1994). A browser is limited in the extent it can consume graze because of its anatomical and physiological adaptations to browse. Therefore, a browser cannot switch to become a full-time grazer (Demment and Longhurst 1987). This specialization can be seen within the rumen, as not only the development of the rumen is visibly different (e.g., the formation of papilla), but the microorganisms living in it are distinct (Van Soest 1994). The live organisms used in rumen digestion include bacteria (the main organism), protozoa, and fungi. A balance of these organisms needs to be maintained for digestion to occur properly. Typically, when a diet change occurs, the bacteria take about one to two weeks to return to a normal, active state. The consequences of not adapting include bloat (discussed previously), and in extreme cases, can cause death (Van Soest 1994). This fact becomes important in situations where animals are moved into new environments, or even zoos. Theoretically, early domesticators may have faced this microbial balance problem as well when trying to keep animals in a husbandry situations that may have included food sources the animals were not used to eating. Further, if incorrect food is provided, changes in dental wear may

occur. Since longevity is based on the ability to eat, fast dental wear is problematic, leading to death if not monitored (Clauss and Dierenfeld 2008, Clauss et al. 2008, see also Clauss et al. 2007).

Ungulates Dietary Preference

Ungulates prefer fresh, green material, which provides higher protein to fiber ratios (Arnold 1964, Bell 1970). After preferential material is consumed, less preferred material is eaten, which varies between animals (Bell 1970). Grazing by multiple animal species in the same area becomes beneficial as preference varies between species (e.g., Animut and Goetsch 2008 and references therein). Each species will eat and modify their diet to meet their nutritional needs and reduce any intestinal discomfort due to eating foods their microorganisms are not adapted to (Animut and Goetsch 2008, Arnold 1964, Bell 1970, see Hulet et al. 1975 and references therein). This ability to maintain mixed species herds like goats and sheep provides an advantage to not only herders today but also it would also have for Neolithic farmers as well (Animut and Goetsch 2008). As a plant or grass matures (e.g., produces flowers, seeds), its nutritional value decreases. Van Soest (1994) noted after harvesting, cereals' stubble provided very little nutritional value. This brings into question the idea that chaff was used as a fodder source for Neolithic animals due to its low nutritional value. Further, if the rumen microorganisms are not able to digest the material consumed, the specialized bacteria cannot perform their job and the animal will suffer (Van Soest 1994, see also Hofmann 1989).

Gazelle Diet[6]

[6] Three species of gazelle will be examined in Chapter 3 as part of the extant sample *Gazella*

Gazelle tooth form is similar to sheep and goat (i.e., hypsodont and selenodont), although gazelle teeth tend to be relatively smaller based on smaller body sizes. The dental formula is 0 0 3 3/ 3 1 3 3 in the adult (Kingswood and Blank 1996). Gazelle are able to adjust to different food resources (Mendelssohn 1974). For mountain gazelle (*Gazella gazella*), the majority of the diet consists of graze (i.e., herbs and grasses). However, during the dry season when graze is not in peak, gazelle will eat browse (approximately 35% of their diet) (Baharav 1974a, 1981, 1983, Kingswood and Blank 1996, Martin 2000). Preference is given to young, green material within the gazelles' reach (Baharav 1981, 1983). During the Street Expedition, from which part of the extant sample stems, goitered gazelle (*Gazella subgutturosa*) were observed eating during the early morning, late afternoon, and evening hours (Lay 1967). Dorcas gazelle (*Gazella dorcas*) live in desert or semi-desert areas, and have specialized feeding behavior, allowing them to survive in these areas during the dry season (Carlisle and Ghorbial 1968, Yom-Tov et al. 1995). This species browses on *Acacia tortilis* or other members in this plant family. The green leaves provide them with the proper amount of nutrition and water. Therefore, dorcas gazelle do not require daily water intake beyond that which they get from their food (Carlisle and Ghorbial 1968, Yom-Tove 1995). This behavior is seen in other gazelles in the dry season as well (Baharav 1983, Martin 2000).

Goat Diet

Goats easily adapt to their environments, through eating both browse and graze. In doing so, goats are often categorized as intermediate feeders, instead of just browser (Animut and

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subgutturosa subgutturosa, Gazella gazella bennetti, and *Gazella dorcas dorcas*. Their general dietary information is provided here, and Chapter 3 will provide more information on these species.

Goestch 2008, Wasse 2001). For instance, Shaler (1895) noted the ability of goats to survive in New York City by eating advertisement paste and stray weeds. Their ability to survive a wide range of circumstances is thought to be related to their ability to recycle nitrogen, allowing the animals to conserve protein (Animut and Goestch 2008).

Sheep Diet

Sheep are usually classified as grazers. Some researchers place sheep into the intermediate category like goats, as sheep will change their feeding behavior if graze is limited (Arnold 1964, Hulet et al. 1975). Distance from other resources such as water, and the geography of the pasture also influence eating habits (Arnold 1964). However, even though they are often classified as intermediate feeders, sheep are noted to prefer graze (Van Soest 1994). Further, sheep possess specific preferences to the parts of graze eaten (Animut and Goetsch 2008; Arnold 1960, 1964). For instance, they preferentially eat the leaf portion instead of the stem (Arnold 1960, 1964). When biting, sheep tend to remove only the upper parts of the plant (Arnold 1960, 1964). This behavior is regulated by the structure of the mouth, as the tongue does not extend out. Instead, the lips, lower incisors, and upper dental pad are responsible for breaking off pieces of food (Hulet et al. 1975).

Sheep do not graze continuously. Instead, like other ruminants, they alternate between eating, ruminating, and resting. The most active graze times are around sunrise and late afternoon to early evening, although timing varies based on the quality of food available (Hulet et al. 1975).

Dietary Reconstruction Methods

Unfortunately, an animal's dietary category or normal food preferences do not mean the animal ate that material throughout its life. This caveat is especially important when considering domesticated animals, as their natural dietary instincts are overridden by humans' control. Therefore, adaptations like tooth shape and morphology, and skull morphology (that normally indicate dietary type) cannot be relied upon exclusively to provide information on the actual diet eaten. Further, plant remnants recovered at sites do not necessarily reflect animal diets. For instance, fodder was not likely cooked or brought near fires, and thus not preserved in the archaeological record proper. Since fodder can come from many sources beyond what is eaten by humans, this lack of record becomes problematic (Mainland 1998b). As such, other methods are turned to in order to reconstruct what was actually ingested by animals, which are based on the animal remains or what can be recovered from them. For instance, Middleton and Rovner (1994) reconstructed caprine diet through phytoliths recovered in the animal's calculus (see below for discussion on phytoliths).

Coprolites

Examining domesticated animal feces is a direct method to determine what the animal consumed, and how husbandry influenced diet. By examining coprolites microscopically, pollen, seeds, and plant fragments provide information on diet and seasonality (Akeret and Rentzel 2001, Akeret et al. 1999, Rasmussen 1993). Seasonality is based on what seasonal plants were found in the coprolites (Akeret and Jacomet 1997, Akeret and Rentzel 2001, Akeret et al. 2001, Rasmussen 1993). Based on what season coprolites came from, husbandry methods can be interpreted. For instance, at Horgen Scheller (Switzerland) only winter plants were found in the coprolites. This indicated that during the winter, the farmers kept animals close to the

settlement, possibly penning them at night. During the summer, animals were taken further from the settlement, and therefore no coprolites were recovered (Akeret and Jacomet 1997). At the Neolithic site of Arbon Bleiche 3 (Switzerland), Akeret and Rentzel (2001) determined the season of the deposit. From this, the researchers discovered that during the winter, animals received tree-based fodder, as other favorable resources were not available (Akeret and Rentzel 2001). Seasonality can also be reconstructed if the coprolites are recovered in layers (Charles and Bogaard 2005, see also Karg 1998).

Issues: Survival of recognizable plant material through the gastrointestinal system depends on processing before feeding (Charles and Bogaard 2005). Unfortunately, the amount of processing in the Neolithic is not known. Further, the probability of survival of material through the digestive system varies by food type. For instance, Gardner et al. (1993) found thicker coated legumes were recovered in recognizable form more often than thinner-coated grass seeds. Interpreting diet through recovered pollen can also be problematic. Akeret et al. (1999) noted pollen in feces can come from sources other than diet, such as inhalation, and ingesting food polluted with other pollen (see also Moe 1983). Pollen can contaminate feces on the ground also, through either the air or soil. Depending on animal movement, this pollen will provide an inaccurate picture of not only environment but diet as well (Akeret and Jacomet 1997)

Sheep and goat feces can be recognized in archaeological sediments (e.g., Akeret et al. 1999). However, distinguishing sheep from goat excrement is challenging, as both form similarly shaped pellets (Akeret et al. 1999, Akeret and Rentzel 2001). Goats tend to produce larger shaped pellets than sheep. Van Soest (1994) believed this trait to be linked to the goat's

digestive system adaptation to browse. Determining whether feces was left from domesticated or wild animals can be difficult, such as when examining cave sites used as animal shelters during the Neolithic. By examining the context of the feces, such as cultural remains and compaction associated with the coprolites, how the animals were handled can be elucidated (Rosen et al. 2005). However, problems occur when separating feces from other husbandry remnants, such as bedding or other archaeological debris (Akeret et al. 1999, Akeret and Rentzel 2001, see also Courtey et al. 1991). If coprolites were used as fuel, only material able to survive burning will remain, like seeds (Charles and Bogaard 2005). When animal dung is used for fuel, it is often mixed with plant materials to aid the burning process. If not correctly analyzed, this material may be mistaken for part of the animals' diet (Charles and Bogaard 2005).

Isotopes

By examining the chemical makeup of bone and teeth, researchers can ascertain what plant types were consumed, when the animal was weaned, what environment the animal was living in, and movement (e.g., migration, herding). Further, isotopes can sometimes help determine an animal's domestication status. Husbandry methods, which have an impact on diet and dental wear, can also alter the isotopic signatures of domesticated animals. This distinction is based on comparing known-wild animals to archaeological samples to see how similar or different their isotopic signals are, as domesticated animals will possess different isotopic signals as discussed below (e.g., Hu et al. 2009). Bone and teeth provide slightly different isotope signals, and therefore cannot be directly compared between samples. However, comparison within samples provides insight into the animals' life (e.g., weaning) as isotopes are integrated into bones and teeth at different rates. Teeth record the first few years of life while bone

constantly changes due to bone turnover (Charles and Bogaard 2005). Dental studies are focused on here, since teeth are the focus of this research.

Dentin: Dentin is found inside the tooth, and provides information on diet and environment during its formation. Comparing collagen found in the dentin with bone collagen provides dietary differences over an animal's lifetime if the tooth has a limited growth period (Balasse et al. 2001). For example, nitrogen isotopes in collagen will differ from the bone, reflecting early diet such as weaning. However, if a tooth continues to grow throughout life, the isotopic nitrogen levels between bone and teeth will be similar (Bocherens et al. 1992).

Enamel: Dental enamel, composed of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), undergoes less digenesis than other faunal tissues. As such, enamel analysis is thought to provide more accurate information on ingested materials (Balasse 2002, 2003; Balasse et al. 2001, Grine et al. 1987, Hu 2009). Further, once formed[7], enamel does not undergo remodeling, and therefore presents dietary and climatic information from the time of formation. Since the formation time varies between the parts of the tooth (e.g., crown vs. neck), sampling across the tooth's surface provides information on different times within an animal's life (Balasse 2002, 2003; Balasse et al. 2001, Grine et al. 1987, see also Zazzo et al. 2010). The time resolution is dependent on the precision of the procedure used to sample the enamel. In a study of cow molars, enamel sampling suggested the mineralization process took six to seven months. Since molars do not develop at

[7] Enamel formation occurs in two steps. The first step in amelogenesis is the formation of the enamel matrix. In the second step, mineralization of the matrix occurs, which typically takes longer than the first part. The rate of each stage varies between species. For instance, sheep and goat mineralization takes twice the amount of time than matrix formation did (Balasse 2002, 2003, see also Suga 1982).

the same time, each molar (1, 2, 3) provides a different period in life (Balasse 2002). Balasse et al. (2001) overlapped isotopic curves from sequential molars, and found the curves did not directly correspond even though the teeth formed around the same time. Other physiological factors influence enamel formation and deposition, like sex, animal size, diet, and health, and must be accounted for during isotopic examination (Fricke and O'Neil 1996).

Carbon Isotopes ($\delta^{13}C$): The carbon component recovered from dental tissue provides information on diet, namely consumption of C_3 versus C_4 plants and source food canopy height, based on the carbon isotope ratio ($\delta^{13}C$)[8] (Balasse 2002, Balasse and Ambrose 2005). This comparison is possible as C_3 plants provide more negative $\delta^{13}C$ than C_4 plants (Ambrose and DeNiro 1989, Bocherens et al. 2001). Specifically, the distinction between these plants is due to different carboxylating enzymes (i.e., CO_2 fixing enzyme found during the first step of photosynthesis). C_3 plants use ribulose diphosphate carboxylase, which is most efficient at lower temperatures. C_4 plants use phophenolpyruate carboxylase, which is better suited for higher temperatures (Van Soest 1994). The product of this enzyme in C_3 plants is a 3-carbon molecule and in C_4, the enzyme produces a four-carbon molecule (Ambrose and DeNiro 1989). Other distinctions between the plants can be seen in the organization of vascular bundles, storage, and rate of carbon dioxide exchange (Van Soest 1994). The C_3 plants include trees, shrubs, and temperate grasses living in moderate temperatures. The C_4 plants are found in warm/ tropical climates, and include tropical grasses and herbaceous dicots. These plants survive high temperatures, light, and water stress (Ambrose and DeNiro 1989, Balasse and Ambrose 2005). Because of the isotopic differences, distinctions on dietary preference can be made (e.g.,

[8] The standard that carbon isotopes are compared is the PDB marine limestone (Ambrose and DeNiro 1989).

browsers, grazers, and intermediate feeders) (Ambrose and DeNiro 1986, Balasse and Ambrose 2005).

Carbon isotopes are not necessarily straightforward as described above, as other influences change the carbon isotopic levels in plants, such as location. This change then will be passed on to the animals consuming these plants, influencing their carbon isotope level. For instance, in forests, because the canopy hampers airflow (CO_2), plants have lower $\delta^{13}C$ levels. Low light and higher humidity tends to make plants more negative than a similar plant outside the forest (Ambrose and DeNiro 1989, Heaton 1999). However, this fact can be used to determine where a species preferred to graze (e.g., within a forest or out in the plains). For forest living species, $\delta^{13}C$ inform where feeding occurred (e.g., in the canopy or on the ground) (Ambrose and DeNiro 1986). Other issues to consider are different parts within plants may have 1-2 ‰ difference. Even plants in the same region can have different values based on the microenvironment, genetics, and life history (e.g., what harvest the seed came from) (Heaton 1999). $\delta^{13}C$ can track variations based on seasonal plant changes, human management strategies, or herding (e.g., Makarewicz and Tuross 2006, Pearson et al. 2007). However, which factor specifically influences the carbon isotopic levels cannot be determined without other evidence. Therefore, other isotopes are examined in tandem with carbon isotopes to place them into context (Bocherens et al. 2001).

Oxygen Isotopes ($\delta^{18}O$): Oxygen isotopes inform researchers on water intake through forage and drinking. Because oxygen isotopes vary between seasons due to temperature, humidity, evaporation, and precipitation source, isotopic differences provide information on environmental conditions and seasonality (e.g., Kirsanow et al. 2008). In warmer months, the

ratio is higher than in cooler periods (Balasse et al. 2002, 2003, Fricke and O'Neil 1996, Gat 1980). The water the animal consumes influences the overall $\delta^{18}O$ values, which can be seen when examining inter-tooth isotopic variation (Fricke and O'Neil 1996). All else equal, browsers and mixed-feeders have higher oxygen isotope levels than grazers. This enrichment is based on browsers obtaining their water from food, while grazers tend to obtain water from actual water sources (Sponheimer and Lee-Thorpe 1999). Typically, plants grow during/ from spring rains and winter melting, and reflect this value in their isotopic composition (Fricke and O'Neil 1996).

Other physiological factors in animals can influence the oxygen isotope level, such as panting (Sponheimer and Lee-Thorpe 1999). Factors like movement between different water sources (pastoralism) or use of stagnant water sources (e.g., well) may provide incorrect environmental signals (Balasse 2003, Fricke and O'Neil 1996). Within wells or other protected water sources and large water reserves (e.g., groundwater), the isotope value does not change seasonally like rivers (Fontes 1980, Fricke and O'Neil 1996). This means the values found within these stagnant water sources reflect the original water source. Water that moves away from a source will inherit different isotopic values from its mixing and moving (Fontes 1980). Altitude can cause a decrease in $\delta^{18}O$ while temperature rise increases $\delta^{18}O$ values (Henton et al. 2010). Caution must be used with any isotope, as variation between modern comparisons and archaeological samples needs to be understood (e.g., evaporation rates) (Balasse et al. 2002, Henton et al. 2010). Differences seen could be due to seasonal variation or husbandry techniques that do not correlate between the present and past (Balasse et al. 2002).

The combination of oxygen and carbon isotopes values can provide important information that can help researchers parse dietary and environmental effects. For instance,

Bocherens et al. (2001) found the $\delta^{18}O$ varied between wild and domestic animals in Iran. The domesticated animals showed signs of $\delta^{18}O$ depletion, expected from water at higher elevations. However, the carbon isotope indicated C_4 plants in the diet, which are not found at high elevations in the area. The authors concluded the domesticated animals were moved to different elevations during the year. The animals' water supply was brought from higher elevations to lower elevations through a canal system, providing an explanation for the disparity between the isotope values (Bocherens et al. 2001, see also Henton et al. 2010, Mashkour et al. 2005).

Nitrogen Isotopes ($^{14}N/ ^{15}N$): Nitrogen isotopes[9] are introduced during the nitrogen cycle that occurs between the air, plants, and soil (Létolle 1980, Ambrose and DeNiro 1989). Plants (e.g., legumes) utilizing nitrogen modified from bacteria in the soil will have lower $\delta^{15}N$ at 0‰ than plants that do not utilize bacterial nitrogen. Plants in very dry soils and marine soils have the highest nitrogen values due to these conditions inhibiting bacteria from carrying out nitrogen fixation. Plants in moister, cooler soils will have lower values than the drier soils (Ambrose and DeNiro 1989, DeNiro and Epstein 1981). Animals will have higher levels of ^{15}N than plants they consume, usually 3-4‰ higher nitrogen isotopic values (Ambrose and DeNiro 1989, Létolle 1980). Modern samples are often grown in fertilizers, making comparisons to archaeological samples difficult (DeNiro and Epstein 1981, Létolle 1980).

Recent studies have shown nitrogen isotopes recovered from bone collagen reflect more than dietary nitrogen levels. Nitrogen isotopes are influenced by the environment in which the animal lived. A species living in dry, warm areas will have a higher $\delta^{15}N$ than the same species

[9] The reference for stable isotopic ratios for nitrogen is the "atmospheric (AIR) N_2 for nitrogen" (Ambrose and DeNiro 1989: 408). The largest reservoir of nitrogen is in the air, usually in the form N_2 (Létolle 1980).

eating the same diet in a cool, wet location. Hypotheses regarding this phenomenon include depleted nitrogen in animals living in hot, dry climates. Other research has suggested the bacteria found within the digestive tract preferring lighter isotopes affecting the isotope reconstruction. The overall age of the animal may also play a role in the nitrogen isotope levels (Ambrose 2000, Ambrose and DeNiro 1989). When random parts of a goat's digestive tract were sampled for $\delta^{15}N$, each part provided a unique isotope value providing further questions regarding the use and understanding of this isotope (Ambrose 2000).

Strontium Isotopes ($^{87}Sr/^{86}Sr$): Strontium is incorporated from the bedrock into the food animals consume. The isotopes are part of strontium's radioactive decay. Therefore, resources from older geological formations will have higher levels of ^{87}Sr than younger formations. This feature becomes important when tracing pastoral or wild animal movement between different geographic areas/ formations (e.g., Bogaard et al. 2013, Meiggs 2007, Sealy et al. 1991). Balasse et al. (2002) found plants showed less strontium isotope variation than the underlying geological formations. This may indicate differences in soil incorporation leading to variable strontium levels, or dust incorporated from the air can average strontium levels making the use of strontium more complicated (Balasse et al. 2002).

Technically, strontium does not have a metabolic function in animals. Instead, strontium is incorporated into the body or teeth because it mimics calcium. Calcium and strontium are stored in the body and released when needed. This reservoir effect can play a factor in later interpretations as well (Balasse et al. 2002).

Linear Enamel Hypoplasia (LEH)

Seasonality, birth, weaning, and other stressful life events have been reconstructed by examining linear enamel hypoplasia (LEH) on teeth. Stress events disrupt the process of enamel formation, causing horizontal depressions across the adult tooth. By taking measurements of where LEH are on a tooth, the time of the formation and therefore the stress event can be recreated. Most archaeozoological studies using this method have been performed on suids (i.e., pigs) (e.g., Dobney and Ervynck 2000). LEH can be used across populations due to their predictable patterns, allowing researchers to compare different Neolithic areas and to wild specimens. LEH have been found to increase during the Neolithic, indicating domestication was not an easy process on animals (Dobney et al. 2007). Balasse et al. (2010) and Upex et al. (2012) have started investigating the applicability of LEH analysis with caprines. With time, understanding caprine life events may be possible (Upex et al. 2012).

Dental Wear

Dental wear was originally used to age teeth, as gross wear increases with age. Later, researchers realized diet played a role in dental wear (Rose and Ungar 1998). Originally, internal food properties were thought to cause dental wear. For instance, Barnicoat investigated different aspects of the sheep's dental complex, properties of the food eaten (e.g., chemical components of soil and graze), environment, and management practices to understand what caused the wear. Barnicoat (1957, 1959) concluded the leading cause of wear (both abrasive and erosive[10]) was from the graze properties. However, stocking rate, size of sheep (i.e., overweight

[10] Abrasive wear was defined as mechanical removal of enamel (e.g., soil on the plant or hard material within the plant). Erosion was seen as chemical removal of enamel (e.g., compounds within plants that could dissolve tooth material) (Barnicoat 1957). Dental erosion was thought to be a product of plants, since ruminants produce large amounts of saliva during ingestion and rumination that reduce the impact of the animals' digestive acids (Barnicoat 1957, Barnicoat and

sheep tended to eat more), and precipitation were also recognized in increased wear situations (Barnicoat 1957, 1959). Baker et al. (1959) discovered opal phytoliths, produced by plants, predominantly in a fractured state in sheep feces (see also Danielson and Reinhard 1998). Phytoliths formed when silica, dissolved in groundwater, entered into the plants vascular system. The silica became deposited within intercellular parts of the plant, forming unique structures for each plant (Piperno 2001, Rovner 1983). The fractured phytoliths were broken during rumination and eventually passed out the digestive system via feces (Baker et al. 1961). It was once thought that since the phytoliths ranged from 5.6-6.5 on the Moh's scale (scale based from 1-10) while dental tissue was only 4.5-5, dental wear was caused by phytoliths. Specifically, phytoliths in the ingested materials became trapped between teeth and removed enamel. However, newer research (e.g., Lucas et al. 2013, Sanson et al. 2007) indicated phytoliths may not always be as hard as once thought, and therefore, not play a critical role in forming microwear as previously thought. Early researchers also noted other hard minerals present in the soil could have contributed to dental wear as well, which more recent research indicated was the case (Baker et al. 1959, Fox et al. 1996). For instance, grasses lower to the ground would have dirt and other abrasives adhering to it (Clauss et al. 2008, Lucas et al. 2013). In fact, Mainland (2003) and Rensberger (1978) both related the striations found in grazer dental microwear (discussed later in the chapter) to the amount of grit in the diet.

Mesowear: Dental mesowear analysis relies on the development of wear facets over the lifetime of an animal. This dental wear is due to the animal's diet, specifically the abrasiveness of the food eaten and attrition when the teeth contact during chewing (Fortelius and Solounias

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Hall 1960).

2000, Rivals and Athanassiou 2008). Mesowear analysis examines the buccal aspect of upper molars (paracone and metacone), and records the cusp shape (sharp, round, blunt) and the height between the cusps (high, low) (Fortelius and Solounias 2000). Browse causes more attritional wear (i.e., tooth on tooth or thegosis[11]) due to the jaw movements required to process the food. This attrition results in sharp cusp tips, and high relief between cusps. Graze, on the other hand, contains abrasives that wear down the enamel during the mastication process. The abrasion causes more rounded to flat cusp apices, and low relief between cusps (Blondel et al. 2010, Croft and Weinstein 2008). Mixed feeders are intermediate between grazers and browsers (e.g. Rivals et al. 2011).

The original mesowear examination by Fortelius and Solounias (2000) focused mesowear analysis on upper second molars due to how food is placed and moved within the mouth. Further, the mechanics of jaw movement produce different pressure on the upper and lower teeth, which could upset wear (Kaiser and Fortelius 2003). Franz-Odendaal and Kaiser (2003) and Kaiser and Fortelius (2003) researched whether other teeth (e.g., lower teeth, other upper molars) could be used within mesowear analysis. These studies found attrition was different between the upper and lower dentitions, with lower teeth experiencing more abrasion regardless of diet (e.g., for a dentition consisting of sharp upper molars, the lower dentition may be rounded). This difference in shape would then provide a different characterization and classification of the animal's wear (Franz-Odendaal and Kaiser 2003). Extending the mesowear examination to other upper teeth, such as the first and third molars, was successful (e.g., Franz-

[11] Every et al. (1998) report that thegosis occurs at times when the animal is not eating (i.e., going through the chewing cycle without food) such as at night or when the animal is stressed (e.g., placed in overcrowded pen, sight of predator). This natural occurrence is thought to help keep edges of teeth sharp for effective food processing (see Gordon 1958a for examination of rumination at night).

Odendaal and Kaiser 2003, Kaiser and Solounias 2003). Extending mesowear increases the applicability of mesowear to archaeological contexts where not all teeth are present or difficulty exists in distinguishing the different molars apart out of context.

For the most part, mesowear has been applied to paleospecies in which extant taxa are compared to assess changes over time (e.g., Blondel et al. 2010, Croft and Weinstein 2008, Merceron et al. 2007, Schubert 2007, Valli and Palombo 2008). To do these studies, similar diets between extant and extinct animals are assumed to wear teeth in the same manner. Of course, dietary types (e.g., browse, graze) include a wide-range of food, so more research needs to be done to refine and hone the analysis (Croft and Weinstein 2008). For instance, Mellado et al. (2005) discovered through mesowear analyses, dietary differences in male and female goats between seasons. Further, wear state influenced food choice (Mellado et al. 2005). Clauss et al. (2007) and Kaiser et al. (2009), used mesowear to compare modern zoo giraffes to their wild counterparts to understand the effects of foddering. These authors found captive giraffes, normally browsers in the wild, had marked abrasive wear and lower relief, a grazer's pattern. The zoo's fodder caused increased wear rates because it contained more abrasives than the giraffe's natural diet. This study indicated mesowear analysis was useful in distinguishing wild from captive ruminants (Kaiser et al. 2009).

Microwear: Microwear analysis distinguishes dietary types based on the patterns abrasives leave behind on the surface of enamel during mastication. These patterns are related to the properties of the ingested material and the movements of the jaw during mastication (Janis 1990; Mainland 2003; Merceron et al. 2004a, b, 2005; Scott 2012; Solounias and Hayek 1993; Solounias et al. 1988; Ungar et al. 2007). Grazers' microwear is composed predominantly of

long, narrow scratches (Daegling and Grine 1999, Mainland 2003, Rensberger 1978). Browsers that eat harder foods have wear surfaces dominated by pits. In general, these features will be larger than those left behind in a folivorous diet (Daegling and Grine 1999). This microscopic wear lasts a few days to a few weeks. Each meal slowly replaces the previous meal's affect on the enamel surface. The rates vary depending on the properties of the food ingested (Covert and Kay 1981, Teaford and Oyen 1989a, see Mainland 1998a for opposing view).

Early dental microwear studies involved laboratory experiments and studies of known-diet animals. For instance, Walker et al. (1978) examined two hyrax populations over the wet and dry seasons. *Procavia johnstoni matshiei* predominantly grazed while *Heterohyrax brucei dieseneri* browsed. The microwear distinguished the browsers versus grazers as well as *P. johnstoni* dry season dietary shift to browse (Walker et al. 1978). These results were corroborated by DeNiro and Epstein's (1978) carbon isotope examination of the same specimens. Despite results like Walker et al. (1978), questions were raised on the usefulness and reliability of microwear. For example, Covert and Kay (1981), in trying to replicate an earlier study performed by Ryan (1979), could not distinguish microwear left from experimental diets. However, later studies have recognized microwear reliability in understanding and reconstructing diets (Rose and Ungar 1998 and references therein, Strait 1997).

Microwear researchers are transitioning to a new method of microwear analysis, dental microwear texture analysis (DMTA). Dental microwear texture analysis involves a white-light confocal profiler and scale-sensitive fractal analysis for a 3-D characterization of the microwear pattern left on the enamel surface. DMTA is a faster method than previous Scanning Electron Microscope (SEM) based studies. In addition, observer measurement error is eliminated because the surface characterization is automated (Gordon 1988, Grine et al. 2002, Scott et al. 2006). For

example, in traditional SEM based studies, specimen placement within the machine is crucial, with differences in placement leading to varying electron scatter patterns and therefore different images. These image differences result in dissimilar interpretations of the microwear signature (e.g., pit or scratch size are seen differently when viewed from different angles) (Gordon 1988). This problem is alleviated when using DMTA, as the confocal profiler collects x, y, and z data surface points, which will always have the same plot location. From these data points, the microwear texture is determined (Ungar et al. 2003). Unlike previous microwear studies, which characterized a tooth's surface by the number and size of pits and scratches, DMTA uses five variables[12] to characterize surface texture. These variables derive from metrological techniques of fractal analysis, which arise from examining the wear surface at different scales (Scott et al. 2006, Ungar et al. 2003). Each DMTA variable relates to slightly different aspects of diet. Like previous microwear analyses, DMTA shows differences between species diets, including ruminants (Scott et al. 2005, Ungar et al. 2007). Specifically, anisotropy (*epLsar*) and complexity (*Asfc*) are useful for distinguishing grazers from browsers. Higher anisotropy values, related to directionality of features (e.g., scratches), indicate a grazer diet. Higher complexity is seen in browsers, which corresponds to different surface features (e.g., pits). As discussed previously, this is related to processing the ingested material. Graze, in principle, requires movements that are more lateral across the shearing facets, which can also create prism plucking (see Teaford and Runestad 1992). Browse, on the other hand, is expected to require more vertical movement to crush the ingested material. The action produces features of various sizes based on the ingesta's fracture properties (Scott 2012, Ungar et al. 2007). For example,

[12] The five microwear variables are *Asfc* (surface complexity), Smc (scale of maximum complexity), *epLsar* (anisotropy), *Tfv* (texture fill volume), and *HAsfc* (heterogeneity) (Scott et al. 2006).

Merceron et al. (2010) found seasonal and sex differences in deer diet using DMTA due to shifts in seasonal food preference and nutritional requirements of the animals (see also Merceron et al. 2004b).

Goat Microwear Studies: Published research on goat microwear is limited (e.g., Rivals et al. 2011). Solounias and Moelleken (1992) examined several fossil goat species to understand how diet varied among evolving species, and how these species adapted to their environments. Mainland included goats within a larger microwear examination of sheep to understand differences in grazing diets (e.g., Mainland 1998a).

Sheep Microwear Studies: The earliest published dental microwear analysis involved sheep. Baker et al. (1959) used microwear to understand excessive wear in pastured sheep. Their research recovered fractured grass phytoliths in the sheep feces. Chewing compressed the phytoliths between the teeth causing wear, although the authors acknowledged soil adhered to food probably played a role too (Baker et al. 1959). Several years later, Healy and Ludwig (1965) found pasture type, specifically pastures with high concentrations of exposed soil, affected rates of dental wear. The soil contaminated ingested food, and added varying amounts of abrasives to the ingesta (e.g., clay less abrasive than sand). In addition, pasture stocking rate affects wear. Higher stocking densities led to increased wear rates, as the animals quickly ate through favorable foliage until only resources close to the ground and soil contamination remained (Healy and Ludwig 1965, see also Covert and Kay 1981, Daegling and Grine 1999, Walker et al. 1978). Dust from the air, brought down by rain, potentially also affects microwear (Puech et al. 1986). Foddering can reduce the amount of wear during times of food scarcity by

providing food from sources not contaminated by soil, but the wear will be dependent on the fodder source (Healy et al. 1967). Therefore, microwear reflects not just diet, but also a sheep's environment and handling.

In the late 1990s and early 2000s, Mainland reinvestigated sheep microwear to determine whether microwear could be used to reconstruct archaeozoological samples. For instance, Mainland (1998a) compared deciduous premolars of sheep and goats allowed to graze naturally to sheep and goats foddered with hay. The microwear analysis indicated distinctions between the two diets. The foddered animals had more pits and wider scratches than the grazing animals. The causes behind the microwear differences were not articulated in the paper (Mainland 1998a). Mainland (2003, 2006) also examined microwear differences between sheep in different environments. Pastured sheep had striated surfaces, due to soil ingestion. The sheep raised in wooded areas possessed pitted surfaces with only a few scratches. This wear pattern is consistent with a browsing diet of more tree and shrub parts (Mainland 2003, 2006). Further, Mainland and Halstead (2005) found dietary differences in caprines recovered from ceremonial contexts when compared with caprines recovered from daily refuse pits. The former had small microwear features indicative of soft diets, whereas the latter featured high striation levels suggesting a more abrasive diet. These results suggested to the authors that the ceremonial animals, at least for a small portion of their lives, were fed a different diet from the animals used for human consumption (Mainland and Halstead 2005). Rivals and Deniaux (2003) examined microwear of mid-Pleistocene sheep, and found a typical grazer pattern. Later, Rivals and Deniaux (2005) examined late Pleistocene microwear of two caprine species from known-context sites. The results indicated microwear could help determine seasonality of death in addition to environmental differences between sites (Rivals and Deniaux 2005).

Combined Microwear and Isotopic Analyses: Combining dietary reconstruction methods allows researchers to appreciate the types of plants consumed and how the animals utilized their environments. For instance, Merceron et al. (2004a) used isotopic and microwear analyses to understand how grazers, mixed feeders, and browsers co-inhabited two Late Miocene sites. From the analyses, the authors were able to reconstruct the sites' palaeoenvironments. Henton (2012) combined oxygen isotopes with microwear analysis to understand herding and seasonal management at Ç atalhö yük (Turkey). By combining these two methods, Henton was able to find that caprines neither were herded long distances from the site nor were they raised on field stubble. Instead, herds were pastured in fields close to the site year-round. This practice only changed later at the site, either due to new domesticated animals being introduced or possibly changes to the environment (Henton 2012).

Composite Mesowear and Microwear Analyses: Combining mesowear and microwear allow understanding of lifelong and seasonal dietary patterns. Several recent studies combined dental mesowear and microwear analyses to understand fossil species diets (e.g., Merceron et al. 2007; Rivals and Athanassiou 2008; Rivals et al. 2007, Schubert 2004; Valli and Palombo 2008). In most cases, mesowear and microwear pointed to similar dietary reconstruction. However, Merceron et al. (2007) found fruit eating yielded a mesowear signature consistent with a mixed-feeder diet, while microwear pointed to a fruit-based diet (low number of scratches, high number of small pits). Further, Valli and Palombo (2008) discovered microwear allowed subtle differences to be discerned that mesowear was not able to pick up due to its averaging nature. Similarly, Rivals and Athanassiou (2008) noted gazelles with seasonal or regional differences

provided slightly different microwear signatures. The same gazelles' mesowear was similar, indicative of mixed feeding. More recently, Rivals et al. (2011) performed low-magnification light microscopy microwear analysis and modified mesowear analysis on wild and domesticated animals from the Neolithic site of Kouphovouno (Greece). Both mesowear and microwear were said to distinguish wild from domestic animals, although given the date of the site, most of the animals (up to 95%) were interpreted as domesticated. Wild goat mesowear analysis, which included both upper and lower second molars, indicated an abrasive diet, similar to a grazer diet. This is counter to what has been observed for wild goats today, which rely on browse. The authors indicated the odd findings might have been associated with changes to plant properties due to altitude. Domesticated goats, on the other hand, had intermediate tooth relief indicating mixed feeding. The microwear of wild goats featured a high number of pits, consistent with browsing. Domesticated sheep and goats possessed high numbers of parallel scratches and variable pit percentages. This signature was interpreted as reflecting a grazer diet. Either goats and sheep were kept in overstocked conditions, leading to increased soil ingestion, or there were seasonal differences in dietary resources (Rivals et al. 2011). As Schubert (2004) concluded, combining mesowear and microwear offered a more robust reconstruction of diet. For instance, C_3 graze could complicate efforts to use δC^{13} to calculate graze-browse ratios that comprised the diet. Therefore, mesowear and microwear may provide more insight than stable isotope analyses alone in some cases.

Domestication and its Influences on Dietary Signatures

Questions remain on the use of penning during the Neolithic, especially given modern herding practices. Penning, foddering, and other husbandry practices affected animals' daily life

and diet (e.g., Bogaard and Isaakidou 2010, Hediger 1964). Although penning is not utilized a great amount in the Near East today, many researchers believe penning and other means of animal control were crucial in the initial domestication stages (e.g., Köhler-Rollefson and Rollefson 2002, Peters et al. 2005, see also Brochier et al. 1992 for archaeological indicators). Penning kept animals in a central location after foraging during the day. This practice allowed for the collection of manure that could be used for crops, and protected domesticated animals from predators (Halstead 1981). Using carbon and nitrogen isotopes, Pearson et al. (2007) reconstructed herding strategies from two sites in Turkey. Through traditional archaeozoological reconstruction methods, the earlier site of Aşıklı Höyük was thought to have practiced caprine proto-domestication. The isotopes indicated a very restricted diet, with strict human control over the movement of the animals. At the later site of Ç atalhö yük, isotope values indicate diverse diets, possibly representing pastoral movements. Herders moved further from agricultural areas around the site, and provided animals with a more varied dietary resource base (Pearson et al. 2007).

Questions involving fodder are difficult to address through traditional archaeological indicators discussed above. This issue stems from the fact that animal fodder is often believed to have originated as a remnant of human diets (i.e., non-human accessible parts of plants like the shafts of grains), making a distinct fodder signal difficult to distinguish from what humans were consuming (Jones 1998). However, foddering does not have to come from sources humans were consuming. For instance, researchers have discovered foddering with sources not edible by humans has been practiced since prehistory (e.g., Rasmussen 1989, 1993; Robinson and Rasmussen 1989). In Neolithic occupations in northern Europe, animals were foddered with twigs and other tree parts, which would not be part of a human's diet. Since trees were part of

the Neolithic settlement, the use of this as fodder may be overlooked if dietary reconstruction were not performed (Rasmussen 1989, 1993).

The use of microwear to examine foddering in goats and sheep was established by Mainland (1998a). She found microwear distinctions between foddered animals and those allowed to graze freely in pastures. Specifically, individuals that grazed ingested more grit than those fed processed fodder, which consisted of different types of dried grasses. Mainland hypothesized the process that the hay underwent may have altered its characteristics leading to the difference in microwear signatures (Mainland 1998a, see also Mainland and Halstead 2005). Makarewicz and Tuross (2006) used carbon and nitrogen isotopic analyses to understand how pastoralists used fodder collected in the summer during winter shortages. When compared to wild animals, foddered animals' isotopes indicated a stable diet instead of switching from C_4 plants in the summer to C_3 plants in the winter as did wild animals (Makarewicz and Tuross 2006). In a later isotopic analysis, Makarewicz and Tuross (2012) found that during the PPNB (8,000BC) site of Abu Gosh (Israel), inhabitants were provisioning goats with fodder, before morphological indicators marked these animals as domesticates.

Conclusion

Dental reconstruction techniques can be used on the teeth of any domesticated or wild ruminant, and have shown to be useful in comparing animals eating similar diets over time and space. In this dissertation, dental mesowear and microwear analyses are used to examine ruminant diet. Specifically, examination will include wild taxa from the Near East to create a wild diet baseline and elucidate possible environmental distinctions between species. This information will also allow understanding of how domestication and human husbandry practices

affected captive animals. In addition, Neolithic mesowear and microwear from the site of Gritille will be examined. Since the Neolithic is separated into distinct phases, each phase will have mesowear and microwear analyses done in order to understand how the evolving Neolithic and husbandry practices affected the animals. Finally, Gritille will be compared to other archaeological sites from around the Levant to understand how husbandry practices affected diet. Both these methods utilize the amount of enamel wear present on the teeth to reconstruct dietary patterns, as dental wear provides important insight into an animal's life. During life, dental wear guides dietary choices, the amount of food eaten, and in extreme cases of dental senescence, leads to starvation and death (Jurado et al. 2008). Dental mesowear and microwear analyses provide a way to understand diet through different aspects of wear, gross and microscopic.

Chapter Three: Extant Fauna

Near East Animals

The majority of animals recovered from Near Eastern Neolithic contexts originated from the Order Cetartiodactyla (even toed ungulates) (e.g., deer, gazelle, goat, sheep, pig) and Suborder Ruminatia (cud chewers). Three of the four domesticated animals of this period (e.g., cow, goat, and sheep) are members of the Family Bovidae. In addition, gazelles, relied heavily upon during the Natufian period (see Chapter 4), belong to the Family Bovidae as well (Harrison 1968, Reed 1971, 1984). Furthermore, goats and sheep are members of the Subfamily Caprinae. Based on molecular data, goats and sheep separated 5-7 million years ago (Bunch et al. 1976, Brumford and Townsend 2006, Shackleton 1997). Further subdivisions of each species occurred during the Pleistocene (Bunch et al. 1976, Brumford and Townsend 2006, Shackleton 1997). Reed (1971) postulated that evolutionary changes goats and sheep underwent during previous climatic shifts earlier in the Pleistocene enabled them to adapt, and later, become domesticated. Because of their shared evolutionary history, many traits and behaviors are common between the two species (e.g., sexually dimorphic males marked by horns that served in dominance displays) (Brumford and Townsend 2006, Shackleton 1997). Differences in morphology and genetics enable researchers to separate goats and sheep. However, issues do arise with bones from archaeological contexts (see Chapter 4) (Buckley et al. 2010). Here, general information on each of the species examined in this study (gazelles, goats, and sheep) is provided.

A comparative baseline will be developed from extant animals examined. Because the samples collected have known origins, the baseline will provide information on environment to which the Neolithic Gritille samples can be compared. This comparison is especially important, as researchers still do not understand handling methods during the Neolithic. Further, insight can

be gained as to whether initial agricultural practices were detrimental to the landscape and failure of Neolithic sites.

Animal Range

Understanding how animals move, what environments they prefer to inhabit, and other behaviors allows archaeologists to understand archaeological site use (e.g., what season a settlement was inhabited, the environment) by extrapolating what occurs today to the past. However, difficulties arise when using modern animals as proxies for archaeological site reconstruction since a number of factors influence animals (e.g., humans move animals and animals migrate, environments change, and the archaeological record itself has limitations) (Jarman and Wilkinson 1972, Uerpmann 1987). For example, modern animal distribution may not reflect the distribution or home ranges of the past (Jarman and Wilkinson 1972, Uerpmann 1987). Over 10,000 years of adaptions enable modern caprines (goats and sheep) to thrive in their current locations. Furthermore, the number of home ranges varies between species. Some species may maintain two (e.g., summer and winter pastures) while others inhabit several home ranges (e.g., some male sheep have up to seven). The distance between home ranges differs, leading to varying migration lengths (Geist 1971). The following paragraphs summarize the general location of animals examined in this work and seasonal movement, if practiced.

Gazelle: Gazelles inhabit much of the steppe and desert into mountainous regions of the Near East (Baharav 1983, Harrison 1968, Mendelssohn 1974, Mendelssohn et al. 1995). Each species adapts to survive in its unique environment (e.g., marked seasonal change, very steep, non-rocky terrain) (Martin 2000, Mendelssohn et al. 1995). During the Natufian and Neolithic

periods, several varieties of gazelles were present. Since distinctions between species are difficult to ascertain, the actual species number is not known (Uerpmann 1987). Three species of Near Eastern gazelles will be examined in this research: *Gazella dorcas* (Dorcas gazelle), *Gazella gazella* (mountain gazelle), and *Gazella subgutturosa* (goitered gazelle), which may have been present around Gritille during the Neolithic. Dorcas gazelles spread from Africa to the Near East. These animals are still located in desert regions around the Sinai Peninsula up to the Dead Sea (Israel). The Taurus Mountains blocked these gazelles from entering Turkey (Anatolia) (Carlisle and Ghorbial 1968, Mendelssohn 1974, Uerpmann 1987, Yom-Tov et al. 1995). Mountain gazelles are still present in Israel, Lebanon, Syria, Jordan, and the Arabian Peninsula in the mountain and hill areas (Baharav 1974b, Mendelssohn et al. 1995, Uerpmann 1987). Goitered gazelles are found from Arabia to Mongolia in semi-desert steppes, ranging from sea level to 1,500m (Kingswood and Blank 1996, Lay 1967, Uerpmann 1987). Migration varies within these three species. Dorcas and mountain gazelles remain in narrow home ranges. Goitered gazelles, on the other hand, have large home ranges, and cover great distances during migration. This great movement may reflect the larger size of the species, which requires more sustenance than seasonal forage can supply (Martin 2000). Since ranges overlap and bone morphology is similar, distinguishing species recovered from archaeological sites is difficult (Clutton-Brock 1999).

Goat: Wild goats (*Capra aegagrus*) tolerate a variety of environments and elevations. Modern populations prefer craggy environments possessing trees and shrubs (Lay 1967, Uerpmann 1987, Wasse 2001). Today, goat populations range from the Austrian Alps through the Near Eastern mountain ranges into the Indus Valley (Harrison 1968, Horwitz and

Ducos1998, Isaac 1970, Mason 1984). In Israel and Jordan today, the only wild caprine is the Nubian Ibex (*Capra [ibex] nubinana*). In Israel, the ibex inhabit the more arid parts of the country (east and south), while in Jordan, the ibex occupy the Rift Valley and Rum Mountains (Alkon 1997, Hays and Bandak 1997, Uerpmann 1987). Palaeozoological records indicate ibex have lived in Israel for the past 200,000 years. On the other hand, wild goats were present in Israel up to the Neolithic (Uerpmann 1987). Both wild goats and ibex were present in Lebanon and Syria until the 1900s (Serhal 1997a, 1997b). In Iran, ibex and wild goats still exist (Ziaie 1997).

Sheep: Wild sheep are present in the Zagros Mountains and Turkey, although whether these distributions reflect the past is unknown (Horwitz and Ducos 1998, Ziaie 1997). *Ovis orientalis* (red sheep) inhabit open areas (e.g., steppes, semi-deserts, valleys with dwarf brush vegetation) in southwest Asia, from Turkey to the Zagros Mountains (Epstein 1971, Uerpmann 1987). *Ovis vignei* (urial) populate more eastern mountain areas. Urials are naturally separated from the red sheep by the Caspian Sea and deserts of Iran (Clutton-Brock 1999, Uerpmann 1987). Sheep tend to have a limited home range in which they graze. Typically, females remain within the same home range their entire lives. Males move to different areas, especially prior to breeding season (Hulet et al. 1975). Although sheep possess social hierarchies and territories, they do not defend territories as strongly as other animals (Clutton-Brock 1999).

Behavior and Features

Although gazelles, goats, and sheep all evolved to live in the Near East, each adapted to different ecological niches, as discussed above. For instance, goats became specialized to live in

rocky, mountainous terrain. Sheep, on the other hand, preferred hilly environments (Geist 1971). This adaptation led to the development of different survival behaviors. Within this section, general behavior and features of gazelles, goats, and sheep to allow survival in the Near East are provided.

Gazelle: Gazelles rely on vision to survive within their environment (e.g., locate predators) (Mendelssohn 1974). Typically, gazelles are slender animals with long legs, which allow efficient movement through their environs (e.g., steppes and deserts) (Harrison 1968). However, there are physical differences between species, and some traits are preserved in the archaeozoological record (Table 3.1). For instance, mountain gazelles exhibit long legs and curved horns. Dorcas gazelles possess shorter legs and straighter horns (Harrison 1968, Kingswood and Blank 1996, Mendelssohn et al. 1995, Yom-Tov et al 1995). Species color and pelage length vary depending on environment, with colors ranging from darker browns and blacks on the back and lighter gray colors on the ventral surface. Intra-species distinctions occur due to sexual dimorphism. Males possess larger, thicker horns while females may not have symmetrical horns. In some species, females lack horns entirely (Harrison 1968, Kingswood and Blank 1996, Mendelssohn et al. 1995).

		Gazella dorcas	*Gazella gazella*	*Gazella subgutturosa*
General description		Small with slender build, long ears, short legs	Larger, slender, longer legs	Large, thicker body, males develop throat swelling during rut
Color		Light fawn to sandy brown, stripes on face	Darker with marks on flank and face	Fawn to white, white especially on face, tend not to have face or flank stripes
Horns	Female	Long	Short, stubby	Variable
	Male	Long, slender, nearly straight	Short, thick, semi-curved	Well-developed curved shaped, also have throat swelling

Table 3.1. Basic character descriptions, coat color, and horn shape differences in males and females of the three gazelle species examined in this research (Groves and Harrison 1967).

Gazelles often live in groups. However, group size and composition vary between species, and depends on resource availability (i.e., the more resources available, the higher the gazelle density). Interspecific competition (e.g., with domesticated sheep and goats) and predators (including humans) affect modern gazelle herds. In addition, group composition varies depending on rut. For example, mixed herds occur in some species outside of mating. During rut, sex-segregated herds develop (Martin 2000). Established gazelle males have marked territories, which female groups move through freely. Sub-adult and non-established adult males form bachelor herds. Usually males join bachelor herds when their horns start growing (Baharav 1974b). Only males with territory mate, so competition occurs between bachelor adults and territory-holding males (Baharav 1983, Martin 2000, Simmons and Ilany 1975). Females form groups with other females and their young. However, after fawning, females become solitary (Baharav 1983, Simmons and Ilany 1975). Because females require significant resources during pregnancy and lactation, bachelor males relinquish favorable browsing areas. Reproductive

males may help with this movement (Baharav 1974b, 1983).

Rut occurs during the latter part of the year. For goitered gazelles, rut runs between September and January. Births transpire the following March or April, when needed dietary resources are abundant (Baharav 1983, Kingswood and Blank 1996, Martin 2000). Mountain gazelles' mating occurs around October and November. However, species in coastal areas have two birthing sessions (January and July), as moderate climate supports resource presence year-round (Martin 2000, Mendelssohn et al. 1995). Females reach sexual maturity between 1 and 2 years of age. Usually one birth takes place per season, although twinning occurs in some species, such as goitered gazelles (Baharav 1974b, 1983; Kingswood and Blank 1996). Nursing lasts from 3 months to half a year after birth (Kingswood and Blank 1996).

Goat: Wild goats adapted to mountain terrain, and became efficient climbers (Becker 1998, Clutton-Brock 1999, Epstein 1971). This climbing modification does not transfer well to flat ground (e.g., gait becomes slower) (Becker 1998). However, goats adapt better to environmental changes, enduring alterations in temperature, food, and other factors better than sheep. Because of this plasticity, modern pastoral societies keep more goats than sheep when environmental stability is questionable (Khazanov 1994). Wild goats' behavior, including group organization, differs seasonally depending on estrus (Hemmer 1990). For instance, males tend to form bachelor herds of four to six animals (Lay 1967). Furthermore, many subspecies of goats can interbreed when located together, although wild goats and ibex cannot (Uerpmann 1987).

Wild goats are slender, standing 95 cm tall at the shoulders. Males possess distinct, long beards and long, scimitar-shaped horns (Harrison 1968, Epstein 1971, Porter 1996). Goats are sexually dimorphic in body mass, with females smaller than males. Female horns, if present, are

smaller and spaced further apart on the skull (Harrison 1967, 1968; Epstein 1971). The dorsal coat color changes with season. During the summer, the coat takes on redder color. In winter, the coat becomes browner with gray accents. In both seasons, the ventral coat is white. Black markings on the face, neck, and limbs vary from animal to animal (Epstein 1971, Lay 1967, Porter 1996). Male markings tend to be more distinct (Harrison 1967).

Sheep: Clutton-Brock (1999) stated sheep are less wary of predators than are gazelles; their senses are instead honed towards finding food. Sheep are good runners, although not as quick as gazelles, and can climb (Becker 1998). The morphology of their metapodials allows them to run quickly in hilly, but not rocky, terrain (Epstein 1971). Wild sheep move more rapidly than domestic sheep through fields, but spend more time resting. During rest, wild sheep remain together. Domestic sheep are more independent and disperse far from their group (Hemmer 1990). Sheep separate into female and male groupings. Female groups tend to remain static while male groups change during different breeding seasons. In the wild, sheep breeding periods vary depending on location. Factors influencing breeding include temperature, food, mate availability, and photo stimulation/ regulation of hormones (Balasse and Tresset 2007, Hulet et al. 1975). For instance, females in tropical climates are receptive year round. In temperate climates, breeding is seasonal (Balasse and Tresset 2007, Hafez 1952, Rosa and Bryant 2003). All males are able to breed year round due to continuous spermatogenesis (Rosa and Bryant 2003). Most wild sheep species can interbreed with other subspecies, creating viable offspring. The ability to create hybrids creates uncertainty in distinguishing species groups (Uerpmann 1987, Valdez et al 1978).

Other distinctions occur between males and females due to sexual dimorphism. Males

are larger than females. Males possess horns, created through annular rings, that arc into a circle. Longer horns mark not only longer life, but also better nutrition. Horns are used for fighting and mating displays. Female horns are either absent or undeveloped (Geist 1998, Harrison 1968). Intra-species differences are also seen in coat colors (Epstein 1971, Harrison 1968). Variation ranges from black, to shades of brown, to white (Harrison 1968). For instance, red sheep have fawn colored backs, white undersides, and throat ruffs made up of white and black hair (Epstein 1971).

Separating Goats from Sheep

Physical features, as discussed above, can distinguish live goats from sheep (and gazelles). However, these features do not always translate to the archaeological record where only part of the skeleton remains (Table 3.2). Separating sheep from goats remains is important to understand what occurred archaeologically, as these species require different husbandry techniques (e.g., differences in environmental tolerance, secondary product production) (Buitenhuis 1995, Halstead et al. 2002). For instance, at Tepe Ganj Dareh (Iran), the demographic profile indicated sheep were hunted. The goat profile suggested these animals were under human control (Hesse 1984). At Mehrgarh (Pakistan), different husbandry strategies were reconstructed for caprines as well. Goats were domesticated early in the settlement's history, with decreased size stabilized early in the settlement's development. For sheep, domestication occurred very slowly, as evidenced by a longer period for size change. Strong husbandry control occurred over goats but not sheep. Sheep were possibly allowed to interbreed with wild animals (Meadow 1984, see also Redding 1984). At both sites, if the caprines were evaluated as just one group, an incorrect understanding of what occurred would be obtained. The following

paragraphs discuss methods used to distinguish caprine materials.

***Ovis* sp.**	***Capra* sp.**
Tail shorter than ear	Tail longer than ear
Pedal glands	Pedal glands absent at least in hind feet
Sub-caudal glands absent	Sub-caudal glands present in males
No beard	Beard in males
Male horns spiral or bend in an arc	Horns scimitar shaped, twisted like a screw, or bent back over the neck in a single spiral
Coronal suture at an angle, lambdoidal suture straight	Coronal suture straight, lambdoidal at an angle
Preorbital gland present and lachrymal developed	No preorbital gland or lachrymal pit
Infraorbital foramen small and well defined	Infraorbital foramen large but not well defined
Premaxillae not wedged between nasals and maxillae	Premaxillae upper ends wedged between the nasals and maxillae

Table 3.2. Comparison between distinct features of sheep (on left) and goat (on right), including both soft-tissue and skeletal features (Modified from Payne 1968).

Bone

Skeletal morphological features have been identified to separate goats from sheep. The more elements preserved and examined, the more certain the designation (e.g., Boessneck 1970, Clutton-Brock et al. 1990, Hildebrand 1955, and Prummel and Frisch 1986). Distinguishing features include differences in horn shape, attributes of the skull, such as the presence of the preorbital gland in sheep but not goats, the shape of the mastoid process, and cervical vertebrae morphology (Boessneck 1970, Clutton-Brock et al. 1990, Geist 1971). The humerus, femur, pelvis, and lower leg bones possess distinguishing features (Boessneck 1970). However, not all features identified as unique are successful in separating animals from archaeological contexts. For example, Buitenhuis (1995) examined sheep and goat scapulae, and through Principal Component Analysis, found features of the scapula neck and articulation areas could separate modern goat and sheep species. When archaeological materials were examined, the pattern was not found. This inability to separate older material extended to a site thought only to have domesticated animals (Buitenhuis 1995). Similarly, Clutton-Brock et al. (1990) found not all of the features ascribed to separate goats from sheep worked on all species. Feral Soay sheep from the island of Hirta (Scotland), for example, possessed morphology aligned with goats rather than sheep, such as the scapulae. Although feral, sheep could not interbreed with goats, indicating an issue with the criteria (Clutton-Brock et al. 1990). Payne (1969) discovered a method of separating goats from sheep using the ratio of the distal metacarpal condyle measurements. Payne found this method separated the species into two discrete groups, as sheep had smaller medio-lateral condyle width measurements (Payne 1969).

Drew et al. (1971) proposed using petrographic and x-ray defractometer with emission spectrographic analysis to examine thin sections of animal bone to see structural differences

between domesticated and wild animals. The authors found differences, but cautioned the use of this method due to the limited nature of the comparative study. Watson (1975) furthered this caution by discovering collagen degeneration the culprit for visual differences. Zeder (1978) tested sheep from varying ecosystems and found no statistically significant differences between the materials. Therefore, thin sections were not reliable in distinguishing species or wild or domestic status.

DNA Analysis

Ancient DNA (aDNA) analyses on Neolithic bones have proven able to distinguish sheep and goats, due to base pair differences (Bar-Gal et al. 2003, Buckley et al. 2010). Loreille et al. (1997) were also successful separating sheep from goats using mitochondrial DNA (mtDNA). However, as Bar-Gal et al. (2003) demonstrated, although genetic analysis is more nuanced than morphological distinctions in separating sheep from goat bones, many drawbacks have to be overcome, such as DNA degradation. The authors tested two bones of unknown ancestry from the Neolithic site of Hatoula (Israel), and were only able to recover DNA from one. Initial morphological analysis by S.J. Davis indicated these bones were from sheep. This identification was then used to indicate domestication during Hatoula's PPNA period. DNA analysis on the bone confirmed the bone was from a goat. The second bone had problems in the region the primers were sequenced for, indicating the need for multiple primer sequences during the analysis (Bar-Gal et al. 2003).

Buckley et al. (2010) offered Zooarchaeology by Mass Spectrometry (ZooMS) as an alternative to aDNA given cost, time, and degradation when trying to separate sheep from goat bones. Their analysis relied on bone collagen peptide sequences, specifically the collagen's

amino acid sequences, which are distinct between sheep and goats. In the pilot study on 26 samples from Domuztepe (Turkey), even bones whose morphology was questionable produced a mass spectrometry reading to assign bones as either sheep or goat (Buckley et al. 2010, see also Price et al. 2014).

Isotopes

Balasse and Ambrose (2005) were able to separate sheep (grazers) from goats (browsers) based on their carbon isotope values ($\delta^{13}C$) in a C_4 ecosystem. As discussed in Chapter 2, the carbon isotope comparisons are possible as C_3 plants provide more negative $\delta^{13}C$ values than C_4 plants (Ambrose and DeNiro 1989, Bocherens et al. 2001). Because sheep consumed higher levels of grass, the $\delta^{13}C$ were higher than goats. Caution was given for using this method in C_3 environments, as both sheep and goats would be consuming plants with similar isotopic values (Balasse and Ambrose 2005, see also Schubert 2004). This caveat is important as C_3 plants played an important role during the Neolithic, and husbandry practices, such as foddering, would create similar isotopic signatures among the domestic animals (see Chapter 4).

Teeth

Payne (1985) described species differences in both deciduous and permanent mandibular dentition that enabled separation of sheep from goats. For example, for the permanent first molar, differences occurred on the mesial border of the tooth with goats narrowing towards the occlusal surface. In sheep, the same surface narrowed and became wider near the occlusal surface. However, as interstitial and occlusal attrition occur, this difference is quickly worn away (Payne 1985). Other researchers have modified and built on these criteria, such as Helmer

(2000) for premolars, Balasse and Ambrose (2005) for premolars and molars, and Halstead et al. (2002) for mandibles and the molars therein (Table 3.3) (see also Zeder and Pilaar 2010). Grine et al. (1986) provided a separation method based on distinctions between goat and sheep enamel microstructure, specifically prisms. By sectioning and grinding mandibular first molars, a facet formed that was etched and examined using a SEM. In the middle or intermediate layer of enamel, dimensions taken of the microstructure tended to be statistically significant in separating caprines. Goat structures were larger than sheep and allowed for species separation (Grine et al. 1986). This method requires damage to the tooth, which was not an option for specimens included in this research.

Researcher	Tooth	Feature in goat	Feature in sheep
Balasse and Ambrose (2005)	M_2 and M_3	Mesial face is narrow and becomes smaller towards the occlusal surface	Mesial face is broad and becomes wider towards the occlusal surface
	M_2 and M_3	Mesial face has pronounced curve towards buccal	
Halstead et al. (2002)	M_1, M_2, and M_3	The mesial buccal edge of the tooth is concave	The mesial buccal edge of the tooth is convex
	M_1, M_2, and M_3	The distal buccal cusp points in a posterior direction (in M_3 this feature is found in the central cusp)	The distal buccal cusp points anteriorly like the medial cusp
	M_1, M_2, and M_3	The buccal cusps tend to be pointed anteriorly giving a triangular appearance	The buccal cusps tend to be more rounded
	M_1	May possess an extra enamel pillar on the buccal surface	
Payne (1985)	M_1	Interlobar pillars sometimes present	Not present
	M_1	Mesial fold narrows at the top of the crown and is shorter (similar to Balasse and Ambrose 2005)	Mesial fold narrows then widens

Table 3.3. Summary of research focusing on mandibular dental morphology used to separate goat from sheep molars. The individual who noted the feature is on the left. The tooth or teeth are indicated next followed by a description of the feature in the goat and sheep (right column).

Environmental Reconstruction Methods

Currently, the majority of the Near East experiences a Mediterranean climate. The summers are hot and dry. Precipitation falls during the winter, when the temperatures are cooler (Baruch 1986, Bellwood 2005, Geyh 1994). Significant variation does occur by altitude. For instance, on mountains, temperatures drop and precipitation increases the higher the elevation (Baruch 1986, Bellwood 2005). Weather systems move from the Mediterranean in the west eastwardly, providing the most moisture to western and northern areas (e.g., Anti-Lebanon Mountains receive 2,000 mm mean annual). This precipitation pattern causes desertification in the eastern and southern regions (e.g., <200 mm annually) (Baruch 1986, Bar-Yosef 2011, Geyh 1994). The topography is instrumental to dramatic weather shifts occurring if weather patterns change slightly coming off the Mediterranean (Bar-Matthews et al. 1999).

How this climate compares to the past, such as during the period of domestication, is not known (see Mayewski et al. 2004 for climatic change map). For instance, Bar-Yosef (1998b) stated the climate in the past was the same as today. Behre (1990) also found the climate the same but with the exception of the early Neolithic. Many methods have been utilized to understand the environmental conditions of the past (discussed below). Fluctuations most likely occurred during the Holocene transition, from dry and cool at the end of the Natufian (15,000-12,000 B.P.) to warm and moist during the Neolithic (12,000- 8,000 B.P.) (Bintliff 1982, see Bender 1975 for map).

Many researchers have hypothesized that the Neolithic Revolution (i.e., domestication) was set in motion by climatic change, specifically the Younger Dryas at the end of the Natufian (around 13,000 B.P.). Cold, dry conditions forced people to find new subsistence methods, as their previous hunting-gathering strategies were no longer meeting their dietary needs (e.g., Bar-Yosef 2000, 2011; Bar-Yosef and Belfer-Cohen 1992; Belfer-Cohen and Goring-Morris 2011;

Byrne 1987; Childe 1957; McCorriston and Hole 1991; Wasse 2001) (see Chapter 4). The Neolithic experienced a warming trend with increased rainfall (Moore and Hillman 1992). However, not all areas may have been affected by climate change. For example, some areas may have maintained a mesic environment (i.e., temperate) during the Younger Dryas, allowing for animals and people to thrive (Horwitz and Ducos 1998). In addition, domestic activities had an impact on the environment, leading to great changes on the landscape (see Chapter 4 PPNC description). For instance, domestic animals displaced endemic ones and ate vegetation[13]. Humans turned to burning to provide space for their own crops and animals. Papachristou et al. (1997) discovered that when woody brush was burnt, the resulting growth was of better quality and more favorable to ruminants than the previous vegetation. These anthropogenic changes may have started prior to the Neolithic Revolution and continued until the end of the Neolithic. Not only would these changes influence the landscape itself, but also the indicators that allow for environmental reconstruction (discussed below). For example, by burning trees, the pollen analysis would indicate a steppe environment, which may have reflected the botanical character of an area, but not its precipitation (Clason and Clutton-Brock 1982). The following pages provide a survey of environmental reconstruction techniques that have been used in the Near East to understand the environment during the Neolithic.

Carbon Isotope Discrimination (Δ)

Plant carbon isotopes ($\delta^{13}C$) come from two sources: air (CO_2) used for photosynthesis (δ_a) and ground water. The carbon isotope discrimination (Δ) calculates out the amount of carbon from the air used for photosynthesis, leaving the amount of carbon contributed from

[13] Maisels (1998) suggests that with changes in climate, annuals would not be affected like other types of plant species (see also McCorriston and Hole 1991).

ground water. This value provides the researcher with the amount of water available for plant growth. Values from archaeological samples are compared to plant samples with known water sources to understand the past growing environment (Araus et al. 1998). For example, at the PPNB site Tell Halula (Syria), carbonized flax seeds were investigated (Araus et al. 1999). Significant differences occurred between the Middle and Late PPNB, indicating a marked decrease in precipitation or water availability. The seeds' Δ values were higher than modern plants grown through dry farming but lower than irrigated plants. This result indicates that during the PPNB, Tell Halula received more precipitation, and less evaporation occurred due to higher humidity. Precipitation gradually decreased, and farmers started planting in alluvial soils (Euphrates River) (Araus et al. 1998). Similarly, nitrogen isotopes ($\delta^{15}N$) can also be used in conjunction with carbon isotope ratios for determining aspects of past environments. Like carbon, nitrogen also is influenced by temperature and precipitation values (Ambrose and DeNiro 1989).

Fauna

Fauna recovered provides information on environments surrounding an archaeological site, as animals thrive in specific habitats (see Bender 1975: 151 for illustration). For example, during the PPN at Abu Hureyra (Syria), steppe animals such as gazelles were common. Therefore, a steppe environment must have been located within hunters' travel distance from the site. In addition, aurochs (*Bos primigenius* or wild cattle) and brown bear (*Ursus arctos*) remains were found, indicating forests were located not far from the site. Later in the PN, although aurochs were still found, other forest species were missing, indicating a shift from forest to gallery forest or forest-steppe. This shift in environmental signal may indicate a change

in climate towards drier conditions (Bökönyi 1982). Tchernov (1998) noted the presence of bird and rodent species during the Natufian/ PPNA periods indicated the Levant was not as dry as predicted by some using other environmental reconstruction methods.

In addition to what ecosystems an archaeological site was surrounded, fauna can also help reconstruct what season a site was occupied (Davis 1987). This reconstruction is based on migratory animals' age and structures created by seasonal deposition of tissue, like antlers. If birth season was known for a species, sutures, teeth, and long-bone ends provide seasonal information by reconstructing the number of months since birth (Davis 1987, Bökönyi 1972). Further, measuring bones infers climate, since animal size varies based on environment. However, human intervention could change size in animals (e.g., domestication), so care must be used when using this method (Peters et al. 2005).

As previously discussed, isotopes can be used to understand environment. Examining isotopes in animal bones and teeth provides information on what was consumed and, therefore, the habitat. For instance, carbon isotope values provide information on the types of plants (C_3 or C_4) eaten, as plants undergo photosynthesis differently (see Chapter 2). Different isotope values indicate in what type of environment the animals were living (e.g., C_4 plants denote warmer and drier conditions) (Ambrose and DeNiro 1986, Goodfriend 1990). Nitrogen isotope values provide information on precipitation, as animals undergoing stress display different nitrogen levels compared to well-watered animals (Ambrose and DeNiro 1986). Bone oxygen isotopes indicate whether water is derived from food or consumed directly, which gives insight into precipitation (Balasse et al. 2002, 2003). In addition, by tracing the isotope values of the same animal species over time, understanding of climate can be obtained (e.g., Goodfriend 1990). A large sample size consisting of many species needs to be examined to depict the environment

accurately (Ambrose and DeNiro 1986). Further, caution needs to be given to diagenesis (i.e., breakdown of minerals in bone), which alters the isotopic values and therefore the environmental interpretation (Goodfriend 1990).

Issues: Faunal reconstruction can only be reliably applied to recently excavated sites, as earlier Near Eastern excavations only recovered complete bones and trophy items. Most faunal remains were discarded. It was not until the last third of the 20th century that excavation techniques were improved, so archaeozoologists could accurately reconstruct faunal compositions (Buitenhuis 1996). In addition, environmental change between the Neolithic and present may have altered animal distribution to the extent that modern populations are not a reliable indicator of past populations (i.e., modern populations have adapted to novel environments) (Harris 1996). Furthermore, we do not understand past hunting behavior, which influences interpretations based on faunal remains (e.g., Becker 1998, Bökönyi 1972, Buitenhuis 1995, Hassan 1975). Taboos regarding specific land or animal may have influenced hunters (Becker 1998, Bökönyi 1972). Humans may have chosen to exploit one environment or animal over another, producing a skewed faunal representation and therefore environmental reconstruction (Bökönyi 1982, Reed 1983). For instance, Hassan (1975) provided an ethnographic example from a Bushman tribe in Africa. The environment supported over 200 animals. Of these animals, only 54 were considered edible. Moreover, of these edible species, only 17 were regularly hunted for consumption (Hassan 1975). Because we cannot understand behavior, Becker (1998) felt faunal analysis was not a reliable method for environmental reconstruction. However, Buitenhuis (1990) found prior to the Neolithic that faunal analysis did provide information to reconstruct environments around sites. Once the Neolithic Revolution

occurred, animals reflected a site's economy and the people's needs as opposed to the environment through hunting (Buitenhuis 1990). Still, an environmental signal was provided through the wild animals recovered or shifts in domestic animals (Bökönyi 1978, Bogaard 2005). For instance, the shift from goats to sheep during the PPNC might indicate changing environments, with a new subsistence strategy being adapted to survive the changing conditions (Bogaard 2005).

Although goats prefer steep cliffs while sheep prefer hilly areas, both are adaptable to different environments, making reconstruction more difficult (Bender 1975). Furthermore, lack of archaeofauna does not necessarily imply a site was not occupied, such as in seasonal occupation reconstructions, unless a large time sample is present (Bökönyi 1972, Davis 1987). In addition, items like horns were valued for multiple uses, such as tools. These prized items were traded between sites thus interfering with site interpretation (Payne 1972). On the other hand, people would not keep bones deemed no longer necessary. Unwanted bone disposal varied. Often archaeological bones are recovered from secondary use deposits (e.g., use of trash pits to build walls). Further, scavengers and other environmental factors affect bones at a site, which is discussed more in Chapter 4 (Binford and Bertram 1977, Meadow 1978, see also O'Conner 2000). All of these issues impede the straightforward use of fauna to understand what occurred at an archaeological site.

Flora

Remnants of plants (e.g., seeds, pollen) recovered from archaeological sites provide information on environment, as plants grow in specific settings (Behre and Jacomet 1991). Phytoliths recovered from the soil directly relate to which plants grew there. Phytoliths do not

degrade[14], and remain within the soil long after the plant has died. Phytoliths develop during the life of the plant as deposits of silica compounds between the plant's cells. (Piperno 2001, Rovner 1983). Because of this formation process, each has a unique shape that allows researchers to identify plant families or higher orders. If plants underwent water stress, their cells and therefore phytoliths may be impacted (e.g., reduced size), which provides information on precipitation. Because both pollen and phytoliths are recovered from soil samples, they can be used together for more nuanced environmental reconstruction (see below for pollen analyses) (Piperno 2001).

Issues: Several concerns arise when using flora to reconstruct the environment, especially during periods when human and animal interactions increased. First, floral reconstruction relies on finding botanicals carbonized or preserved in waterlogged environs (Behre and Jacomet 1991). The preservation process is very selective, especially in human settings. Some plants, like cereals or weeds, have a higher chance of coming near fires while others, such as fodder or fruits, may not (Behre 1990). For instance, Helbaek (1970) and Renfrew (1969) hypothesized most carbonized seeds recovered from archaeological settings came from humans' attempt to dry grain for human consumption. Grain also entered the archaeological record through burning animal dung for fuel[15] (Miller 2001). Unfortunately, when seeds carbonize, morphological changes occur. Analyzing carbonized remains requires careful examination to recognize specific features seeds originally possessed (Helbaek 1970, Renfrew 1969). In addition, seed preservation in water environments is not uniform, leading to

[14] Damage can occur like breakage. Soil pH, either very high or very low, influences phytoliths as well (Rovner 1983).
[15] Increased dung use indicated decreased amounts of wood for fuel (Miller 1996).

challenges using this as a representative reconstruction technique (Behre and Jacomet 1991). With some plants, including cereals, domestic seeds can be distinguished from non-domesticated ones. However, this peculiarity is not universal, as fruit and legumes seeds are not easily distinguishable (Behre 1990). Similarly, in some cases, phytoliths are distinct between wild and domestic forms, such as maize (Piperno 2001). However, phytolith formation is dependent on the amount of silica in the soil. Higher silica levels produce plants with higher phytoliths, influencing what remains in the archaeological record. Furthermore, not all plants produce the same level of phytoliths. Finally, there are still a large number of plants to be investigated to create a substantial database for phytolith comparison to allow meaningful environmental reconstructions (Piperno 2001).

Another issue when reconstructing the environment from flora is the assumption of uniformitarianism. Researchers assume plants appear in similar situations/environments in the past as today. Unfortunately, humans have played a large role in plants' locations, raising concern for this type of reasoning and reconstruction method (Behre and Jacomet 1991).

Ice-Core

Examination of ice cores provides information on past climates, climatic event dates, and temperatures. Ice cores are created in areas with yearly snowfalls that produce ice layers. In these layers, gasses and aerosols are trapped. Dating is understood by comparing the trapped matter with the layers to known world events, such as volcanic eruptions. Ice cores are rather reliable for informing us on atmospheric composition and therefore climatic conditions. Comparisons between ice sheets can be done by comparing and corroborating sequences (Alley 2000). The Greenland Ice Core has been intensively studied, and provides the most extensive

climatic information, including temperature. Other ice-core data exist from the Byrd, Taylor Dome, and Vostok ice cores in Antarctica; Canadian Artic; and the Huascaran and Sajama in the Andes mountains in South America (Alley 2000).

Ice cores have been examined in order to understand temperature changes that may have spurred the Neolithic Revolution (see explaniation of theory in Chapter 4). Specifically, temperature is reconstructed based on the isotopic composition of the water in the ice. The isotopic difference is created by either oxygen or hydrogen having extra neutrons, creating what is termed heavy water. The amount of heavy and light water will vary depending on atmospheric temperature/ conditions. Cold conditions will have lighter water than will warmer periods. Warmer temperatures will have heavier oxygen/ hydrogen due to extra neutrons (Alley 2000, Gat 1980). For example, at the end of the Younger Dryas (around 11,000 BP), marked increase in temperature was noted in the Greenland ice core data (Alley 2000). The temperature changes may have impacted the environment, including changing the distribution of wild animals available to the people in the Neolithic, which possibly led to animal domestication.

Issues: Several of the ice cores (e.g., Andes) lack the timing correlation of the Greenland ice core. Of note, even with parallels between ice cores, climatic reconstructions do not match. For instance, Antarctic ice cores do not indicate as dramatic climatic changes as the Greenland cores. The Byrd ice core (west Antarctica) provides evidence for climatic changes during the Younger Dryas. However, the Taylor Dome core (east Antarctica) does not recreate the Younger Dryas. Instead of a cooling event, Taylor Dome indicated a warming trend (Alley 2000), which indicates the need to understand how local conditions influence ice core data as well.

In examining precipitation and heavy water, interpretation problems arise due to isotopes

diffusing into other areas within the ice sheet. Moser and Stichler (1980) reported the movement (or diffusion) of isotopes between 7 and 8cm, towards a more homeostatic level. Since ice cores are meters long, this may not be a significant factor in long-term understanding. Furthermore, other factors influence precipitation beyond temperature. This situation then creates issues when trying to associate isotopic levels in ice cores to temperatures, making direct relationships not possible (Moser and Stichler 1980). Finally, deuterium, the heavy isotope of hydrogen in heavy rain, can naturally vary widely depending on location. For instance, in the eastern Mediterranean, deuterium levels are high stemming from the evaporation of water from the Mediterranean Sea into very dry continental air that surrounds the sea (Gat 1980). This natural variation creates another impediment in using ice core data to understand what occurred during the Neolithic in the Near East.

Pollen

Pollen grains, like plant phytoliths, are used to understand past environments by reconstructing what plant species were present at a site (Bottema and Barkoudah 1979). Environmental reconstructions using pollen begin with soil sediment cores (Baruch and Bottema 1991, Bender 1975, Dimbleby 1970). In the Near East, core samples were recovered from lakes or former lakes (van Zeist and Bottema 1982, see Baruch 1994 for map). Southern Levantine information comes from cores taken from a former lake in the Hula Valley (northern Israel) and the Aammiq wetlands (Lebanon) (Baruch and Bottema 1991, Bender 1975, Makarewicz 2012). In the northern Levant, the Ghab Valley (northwest Syria) provides information on plants and climatic data. Pollen entered the lake sediments from plants surrounding the lake and from farther afield via aeolian currents. Pollen's unique microscopic structure allows its separation

into different floral types. By comparing the amount of each pollen type from an archaeological sample to those from known ecosystems, researchers determine what environment produced the profile (Baruch and Bottema 1991, Bender 1975). For instance, high tree pollen levels indicate forest cover. Over time, a decrease in this ratio could signal clearing of forests by humans, increased animal grazing, or fires (Dimbleby 1970). Rossignol-Strick (1995) used pollen analysis to determine the Younger Dryas in the Near East was marked by dry (<150mm annual rainfall), and cold conditions (winter temperatures below freezing). Specifically, this was created through finding pollen of *Chenopodiaceae*, which grew in arid, saline soils (Robinson et al. 2006).

Pollen can be collected from the archaeological record through soil samples and animal coprolites. However, since animals are selective and mobile, this indicator is not specific to a location (King 1977). Carbon dating of the soil from which the pollen was recovered allows comparison of pollen sequences with each other (Baruch 1994). Further correlation comes from marine cores taken from large bodies of water like the Mediterranean Sea (Bar-Yosef 2011). This ability to compare sea to land is important, as Rossignol-Strick (1995) believed marine-based evidence was more accurate due to dating issues of land derived pollen samples.

When Near Eastern pollen cores are examined, differences are seen when comparing Ghab (southern Levant) to Hula (northern Levant) cores. Pollen records accumulated during the Pleistocene/ Holocene transition indicate different environments (Baruch 1994). At the end of the Natufian, the Ghab pollen sequence indicates the region became arid. The Hula sequence, on the other hand, signals humidity. Both indicate colder temperatures during the Younger Dryas. However, the Ghab became wetter while the Hula dried (Baruch and Bottema 1991, El-Moslimany 1994, van Zeist and Bottema 1982). When the Holocene started, conditions in both

areas became similar, with the pollen cores signaling increased moisture (e.g., increased values of oak and grass pollen) (Baruch and Bottema 1991, El-Moslimany 1994). This finding may denote northern and southern Levant experienced different climate trajectories, a trend that may be mirrored in culture (see Chapter 4) (Baruch 1994, Baruch and Bottema 1991). Alternatively, the difference between the two cores might mean dating of one or both cores was incorrect. The Ghab pollen core was based on one ^{14}C date. The Hula sediment core had more dates and was correlated with another Hula core also carbon dated (Baruch 1994). However, Bender (1975) presented data in which the Ghab core correlated with a core from Greece. Recently, van Zeist et al. (2009) presented a modified dating of the Hula pollen core, rejecting past radiocarbon dates. Therefore, although pollen informs on environment, imprecise dating makes it difficult to corroborate pollen samples between Near Eastern cultural periods, and to understand what occurred during the Neolithic Revolution.

Issues: Because of the great distance between index pollen cores and archaeological sites, difficulties arise in comparing local sites to the larger, established sediment cores (Baruch 1986, 1994). Bottema and Barkoudah (1979) investigated how pollen travels in different environmental regions around Lebanon and Syria. Their results indicate that some floral species, such as herbs and shrubs, are underrepresented in the pollen spectra unless the sample derives from the area immediately around the plant (Bottema and Barkoudah 1979). This underrepresentation was due to unequal production of pollen among plants (Behre 1990, Bender 1975). This phenomenon is also influenced by overgrazing, in which plants are not given the opportunity to flower/ produce pollen. Plant overgrazing is not only a modern problem but occurred in the past as well, which could affect archaeological pollen samples. Furthermore,

arboreal species are often overrepresented, signaling tree presence when none may have existed in the local area (Bottema and Barkoudah 1979). This is due to air-borne pollen being able to travel great distances before settling (Behre 1990, Bender 1975). In addition, pollen preservation is affected by soil. For instance, soil microbes destroy pollen. Acidic soils, bog peat, arid conditions, and low temperatures prevent microbe growth and facilitate preservation of pollen (Dimbleby 1970). Correction factors may be needed to overcome overrepresentation of one species over another (Bender 1975, El-Moslimany 1994).

When examining preserved pollen from Neolithic contexts, distinction between domesticated and wild plant pollen is difficult (Behre 1990, Leroi-Gourhan 1969). Furthermore, human modifications to lands through farming and pasturing animals create new environmental conditions (e.g., removing forests allowing more cereals to grow implying steppe conditions) that might mirror changes due to natural climatic change. Although some species, like weeds, indicate human modification, these species are not universal. Therefore, generalization for large areas based on a standard pollen core may not be correct (Behre 1990). In addition, as discussed above, it is difficult to correlate cores where dating is problematic. To do so requires a flawless collection of pollen cores, which often is difficult to do (e.g., lakes are not prevalent next to each archaeological site). This inaccessibility creates difficulty in understanding local archaeological environments (Baruch and Bottema 1991).

Speleothems

Speleothems are secondary mineral deposits (e.g., flowstones, stalactites, stalagmites) typically formed in limestone or dolostone caves. These structures typically form when dissolved carbon (CO_2 and HCO_3) from the topsoil seeps into caves through groundwater and

solidifies (Geyh 1994, see Lachniet 2009 for illustration of process). Deposition and speleothem formation increase during wet times as more groundwater enters the cave carrying carbon (Geyh 1994). Older speleothems are examined to determine past rainfall amounts by making comparisons to modern speleothems with known patterns of deposition (Enzel et al. 2008). Environmental conditions also can be ascertained from speleothems by analyzing $\delta^{18}O^{16}$ and $\delta^{13}C$ values. For the carbon isotope, half of all speleothem's carbon comes from surrounding bedrock while the other portion comes from the vegetation overlying the cave (Frumkin et al. 2000). Specifically, C_3 vegetation introduces lower $\delta^{13}C$ (more negative) than C_4 plants (Bar-Matthews and Ayalon 2003). In other words, carbon isotopic values near 0‰ reflect drier conditions and predominance of C_4 flora. Values around -12‰ indicate an abundance of C_3 plants (Frumkin et al. 2000). The temperature when the speleothems formed, precipitation, and ground water affect the oxygen isotope, as seen previously in the Ice-Core section (Bar-Matthews and Avalon 2003, Bar-Matthews et al. 1999, Lachniet 2009). Because of the complex nature of speleothem formation, correction factors have been established to evaluate isotopes correctly for localized conditions. The correction factors take into account the known conditions around the cave that may influence isotope levels and removes their signals to provide a more accurate evaluation of cave events (Geyh 1994).

Within the Near East, several speleothems have been identified and used to reconstruct past environments. Major speleothems in Israel are found at the Soreq Cave and Ma'aleh Efriam Cave (Bar-Yosef 2011, see also Makarewicz 2012). During the Younger Dryas, a peak in the $\delta^{18}O$ values occurred for the speleothems at Soreq Cave. This isotope level could be related to a

[16] With the oxygen isotope, whether the isotope values represent the actual local precipitation environment or from where the precipitation originated is debatable. In other words, the question remains if the isotopes are reflecting the local Near East rainfall or Mediterranean Sea conditions, which formed the weather leading to the rainfall in the Near East (Enzel et al. 2008).

Heinrich event when large quantities of polar ice melted, introducing large amounts of fresh water into the oceans (Bar-Matthews et al. 1999). This event decreased the water surface temperature and salinity in the northern Atlantic Ocean (Bar-Matthews et al. 1999, Bar-Yosef 1998b, Robinson et al. 2006). Geyh (1994) noted a decrease in precipitation during the transition from the Pleistocene to Holocene, due to changes in the inter-tropical convergence zone that influenced major climate patterns (e.g., monsoon winds). However, the correction factor used on the speleothems to derive this conclusion was based on European and not Near Eastern caves. Therefore, the results may not be accurate (Geyh 1994). Another spike in $\delta^{18}O$ and a drop in $\delta^{13}C$ occurred around the end of the PPNC (Berger and Guilaine 2009). This change in climate towards drier conditions may provide evidence as to why Neolithic sites failed at the end of the PPNC (see Chapter 4).

In addition to carbon and oxygen, other speleothem isotopes can be examined, such as uranium and strontium. These isotopes provide information on how rainfall interacts with the soil and rock of the cave prior to deposition into speleothems. Uranium, similar in pattern as oxygen isotopes, reflects soil moisture above the cave. Strontium values provide information on the rainfalls' water source, although dust and other impurities can mix in and alter strontium values (Bar-Matthews et al. 1999). Speleothems can be dated using thermal ionization mass spectrometry (TIMS) on the ^{230}Th-^{234}U isotopes (Bar-Matthews and Ayalon 2003).

Issues: Enzel et al. (2008) drew the interpretation of the Soreq sequence into question. These researchers believed at the end of the Pleistocene what had previously been interpreted as dry environments, may have been wetter. Any climate shifts were only minor events (Enzel et al. 2008). Furthermore, although similar weather patterns are exhibited by Near Eastern

speleothems, they do not align chronologically with each other or with other environmental indicators, such as ice cores (Bar-Yosef 2011, see Bar-Matthews et al. 2009 for opposing view). As other indicators already discussed, calculations used to determine isotopic values assume rainfall (e.g., light or heavy isotopes) and cave water seepage have always followed the same pattern (Bar-Matthews and Ayalon 2003). For instance, heavy water rainfall alters the normal equilibrium of CO_2 in the soil, which affects the carbon isotope values. Carbon isotopes are also influenced by fluctuations in air CO_2 levels (an issue in modern times), and the amount of weathering cave rocks undergo overtime. The uncertainty of the carbon and other isotope values creating speleothems affects the correction factor needed to determine the isotope level.

Another factor in correctly interpreting/ understanding Near Eastern climate is the Mediterranean Sea. The Mediterranean Sea is the source of Near Eastern precipitation so knowing, for instance, whether water vapor amount remained consistent throughout studied sequences is important (Bar-Matthews et al. 1999). Bar-Matthews et al. (1999) suggested that although climatic changes, such as temperature, may have occurred at the beginning of the Holocene, changes in the Mediterranean Sea might also have had an impact on the Levant. This influence requires much more extensive research beyond the Near East to understand rainfall (speleothems).

Other Methods

The Cooperative Holocene Mapping Project (COHMAP)[17] used a multitude of environmental reconstruction techniques (e.g., pollen, lake levels, marine plankton) to examine

[17] "COHMAP involved a multi-institutional consortium of scientists studying late Quaternary environmental changes as recorded in geologic data and simulated by numerical models" COHMAP 1988: 1043.

climate change starting from 18,000 years ago. Around 15,000 years ago (Natufian), the researchers found the earth's tilt changed, resulting in increased seasonality for the Northern Hemisphere. For the Near East, around 18,000 years ago, the pollen indicates cooler and drier conditions. Opposingly, lake levels[18] were higher indicating increased moisture (rainfall) (COHMAP 1988). El- Moslimany (1994) questioned the accuracy of reconstructing precipitation through lake levels, as seasonal rains do not influence the environment in a similar manner. Summer rains did not have as marked an impact as winter rain since the former are more sporadic and variable. Furthermore, Robinson et al. (2006) noted finding enough locations to create a complete sequence for lakes difficult to obtain. This problem is exaggerated by many Levantine lakes being part of the tectonic rift, which influences what parts are visible for reconstruction today (Robinson et al. 2006). Therefore, although lakes serve as a repository for precipitation, within the Near East, they cannot provide an accurate account of what has occurred.

Dietary Reconstruction

Environmental reconstruction methods encompass a wide range of analyses. However, no technique provides for reliable, cross-location information on environment (e.g., faunal and floral analyses require assumptions of distributions, while isotopic analyses require correction factors). Conversely, dietary reconstruction methods have been shown useful in comparing animal diets over time and space. The assumption that animals eating similar diets in similar environments confer similar effects on the dentition has been supported through decades of research (Rose and Ungar 1998). Therefore, in this research, extant taxa from known

[18] Lake levels signal precipitation and run-off, sea level changes, evaporation and humidity, and tectonics (Robinson et al. 2006).

environments will be examined to understand their diets, which then will form a baseline to compare archaeological samples. This comparison should provide insight into what environment archaeological animals were exposed and whether this environment changed overtime.

Hypotheses

Based on the literature, the mesowear and microwear signatures of the extant animals, especially gazelles, living in different environments, are expected to be different enough to separate the animals examined (gazelles, goats, and sheep) through statistical analyses given access to different food-types in different habitats.

H_0 no dietary difference between species: no change in central tendencies for mesowear and microwear variables between the different species taxa or individual species.

H_{A1} dietary differences: differences in mesowear and microwear are seen reflecting dietary preference. Gazelles and goats should provide a browser-based signal while sheep should indicate a grazer-based diet.

In addition, expected dietary differences should occur between animals collected in different environmental zones (e.g., desert vs. forest).

H_{A2} dietary habitat differences: in comparing the location of collection for species, differences between collection sites should occur. Dryer-based animals will have wear signatures reflecting a diet consuming more grit and browse.

H_{A3} dietary seasonal differences: in comparing the season of collection for the species, differences between seasons occurs. For instance, grazing animals collected in the spring should evince a dietary signal towards graze. Animals collected when preferred plants are no longer available will shift towards browse.

Materials

Specimens from the Field Museum of Natural History (FMNH) (Chicago) are included as comparison samples in this study (Table 3.4). These specimens were wild animals shot[19] in their natural habitats during expeditions to the Near East. Often questions arise due to the unknowns surrounding museum collections, such as diet (Teaford 2007). However, specimens used in this dissertation had known provenances (location and collection dates). This information provides some insight into the animals' environment prior to death. For instance, specimens came from the Street Expedition, which ran for seven months (June 1962 to February 1963). The goal of the expedition was to collect geographically diverse mammal skeletons from all over Iran using various hunting and trapping techniques (Table 3.5) (Lay 1967). Other collectors' samples include Baum, Burris, Dinkha, Eastwood, Firouz, Field and Martin, Hoogstraal, Lay-Nadler, Lazer, and Reed. These specimens were collected during the 1900s, with the latest sample used recovered in 1974.

[19] There are many modern domesticated goat and sheep subspecies present in the Near East today (e.g., Porter 1996), but were not included within this study due to funding and availability of specimens.

Species	Scientific Name	Common Name	Female	Male	Unknown	Total
Gazelle	*Gazella dorcas dorcas*	Dorcas gazelle	5	6	1	**12**
Gazelle	*G. gazella bennetti*	Chinkara	5	2	0	**7**
Gazelle	*G. subgutturosa subgutturosa*	Goitered gazelle	7	5	4	**16**
Gazelle Total			**17**	**13**	**5**	**35**

Table 3.4. List of wild specimens used in this study collected from Field Museum of Natural History animal collections. Species nomenclature follows Shackleton (1997). The last line indicates the total number of individual teeth (upper and lower) examined in the study. Continued on next page.

Species	Scientific Name	Common Name	Female	Male	Unknown	Total
Goat	*Capra aegagrus aegagrus*	wild goat	16	14	0	**30**
Goat	*C. hircus*	goat	2	1	0	**3**
Goat Total			**18**	**15**	**0**	**33**
Sheep	*Ovis* sp.	wild sheep	4	5	0	**9**
Sheep	*O. aries*	sheep	2	3	0	**5**
Sheep	*O. orientalis gmelini*	Armenian mouflon	7	9	0	**16**
Sheep	*O. orientalis isphaganica*	Esfahan sheep	2	1	0	**3**
Sheep	*O. orientalis laristanica*	Laristan sheep	2	3	0	**5**
Sheep	*O. orientalis urmiana*	Urmian red mouflon	3	1	0	**4**
Sheep	*O. vignei dolgopolovi*	Urial	8	7	1	**16**
Sheep Total			**28**	**29**	**1**	**58**
Total Wild Teeth			**126**	**114**	**12**	**252**

Table 3.4 (Cont.). List of wild specimens used in this study collected from Field Museum of Natural History animal collections. Species nomenclature follows Shackleton (1997). The last line indicates the total number of individual teeth (upper and lower) examined in the study.

Province	Location in Iran	Town	Environment
Bushehr	South western Iran along the Persian Gulf	Ahram	Located near the base of the Zagros mountains and shores of Persian Gulf, gazelles present
Mazandaran	North central Iran along the Caspian sea	Gorgan	Located between Caspian Sea forests and drier Turkmen plains
Sistan and Baluchistan	South eastern Iran along the Gulf of Oman	Iranshahr	Oasis town surround by dry areas and a river and mountains, gazelles and urial present
Fars	Southern Iran next to Persian Gulf	Jahrom	Very dry area with less than 20cm precipitation annually, very limited plant life
Kermanshah	North western Iran near the Zagros mountains	Kerman	A high interior basin, featuring sand dunes and low precipitation
West Azerbaijan	North west Iran on border with Turkey	Khvoy	Salt flats near mountains, grassy vegetation present
West Azerbaijan	North west Iran on border with Turkey	Maku	Surrounded by mountains with xeric plants, some springs provide oasis for plants
Khorasan	North eastern Iran on border with Afghanistan	Shahabad Kaur	Located in mountains, with basin supporting gazelles, rugged mountains supporting goats
Semnan	North central Iran	Shahrud	Located on the periphery of the Great Salt Desert, small streams support minimal vegetation and gazelles
Mazandaran	North central Iran along the Caspian sea	Varangrud	Surrounded by mountains, making the area dry, modern agricultural growth supported by irrigation

Table 3.5. A subsample of locations the Street Expedition visited to collect specimens housed at the FMNH. The province in Iran is listed on the left followed by its general location in Iran. The city located closest to the camp is listed in the middle followed by the general environment the expedition experienced during the week or so stay at that location during the 1960s in the right column (Lay 1967).

Individual tooth contextual information was recorded along with needed dental analyses information (described below). Measurements and photographs of the individual teeth were also taken to provide reference details during the latter analyses occurring at the University of Arkansas. Because of the nature of the collection, both upper and lower teeth were available to study. However, due to preservation issues at the FMNH, tooth cracking was prevalent in the collections. Therefore, a consistent dentition side was not used with museum specimens (i.e., both left and rights were collected). This reflects the natural variability of the archaeological specimens so should not cause problems with the analyses. Three species of wild gazelles, two types of goats, and six types of sheep were examined. The varieties of species examined were selected to mirror the possible origin species for domestic animals and the assortment of gazelles found in the Near East.

Methods

Tooth Selection

Within the FMNH collections, upper and lower molars were selected for dietary reconstruction analysis. Either upper or lower second molars were used for microwear analysis (e.g., Merceron et al. 2004a, b; Ungar et al. 2007) while the same upper dentition is used for mesowear analysis (e.g., Franz-Odendaal and Kaiser 2003, Kaiser and Solounias 2003, Schubert 2007). As noted previously, the side chosen varied depending on preservation. Of note is the fact that previous dietary studies on sheep by Mainland (e.g., Mainland 1998a, b; 2003; Mainland and Halstead 2005) focused dental microwear examination on deciduous premolars rather than adult molars. Further, Mainland (2006) found differences in wear, specifically size of features, when looking at premolar versus molars. This should not be a problem here since

classification of breadth of features is not a variable scored using the newer method of dental microwear texture analyses, as opposed to quantifying features of images produced by scanning electron microscope (SEM), which Mainland used. In addition, microwear analyses of other ungulates, such as gazelles, traditionally examined molars (e.g., Merceron et al. 2004a, b; Scott 2012). Therefore, Mainland's protocol will not be followed here.

Age and Overall Wear: Several factors indicate the faunal material age (e.g., horn cores, dental eruption, epiphyseal fusion), but in archaeological material aging becomes difficult. For instance, variation in timing of life-cycle events occurs between individual indicators of age. If only one indicator is available to age an animal, this leads to the possibility of incorrectly aging the bone. These differences are amplified when comparing domestic to wild animals, which have different developmental trajectories (Bullock and Rackham 1982). Often teeth are relied upon, as they survive better in the archaeological record. Most dental aging methods rely on visual inspection (see Spinage 1973 for cementum line count). For instance, Deniz and Payne (1982), found in modern domesticated goats the first molar erupted around 3 months of age, but a large amount of variation occurred, including differences due to sex. Opposingly, Silver (1970) found the first molar erupted between 5 and 6 months while the second molar erupted at around a year of age. In sheep, Weinreb and Sharav (1964) also found eruption of the first molar around 3 months of age, with occlusion occurring around 9 months or 3-5 months following their eruption (Silver 1970). Wear rates varied between species and location, which caused difficulty in relating wear back to an animal's age (Deniz and Payne 1982). For instance, Fandos et al. (1993) found diet variation caused different wear rates for the same tooth between two species of goats. Kingswood and Blank (1996) reported eruption of the first and second permanent molars

around a year of age for gazelles with full eruption and wear occurring between a year and two years of age (Davis 1980). Although other aging methods have been utilized for gazelles (e.g., Munro et al. 2009, Twiss 2008a), all teeth were aged using overall occlusal dental wear for comparability purpose.

Animals selected for analysis possessed the second molar in wear, which means specimens were at least 1 year of age. This excludes young animals. Furthermore, due to the nature of mesowear and microwear analyses, teeth displaying no wear, very slight, or very high wear cannot be included within the analyses, as inclusion may alter results (e.g., Schubert 2007). To quantify the wear, Payne's scoring method was used (Payne 1973, 1987).

Mesowear Analysis Procedures

Visual inspection for mesowear data occurred after initial inspection for lack of taphonomic alterations and sufficient dental wear to allow for analyses (e.g., Rivals and Athanassiou 2008, Schubert 2007). Gazelle, goat, and sheep upper second molars were examined and surface relief characteristics recorded (cusp shape and occlusal relief) following methods described in Fortelius and Solounias (2000). Cusp relief (high or low) indicates the distance from the cusp tip to the area between the cusps, and provides information on abrasive wear within the diet. Cusp shape (sharp, rounded, or blunt) informs on whether diet created more attritional (sharp) or abrasion (rounded or blunt) wear (Figure 3.1) (Fortelius and Solounias 2000).

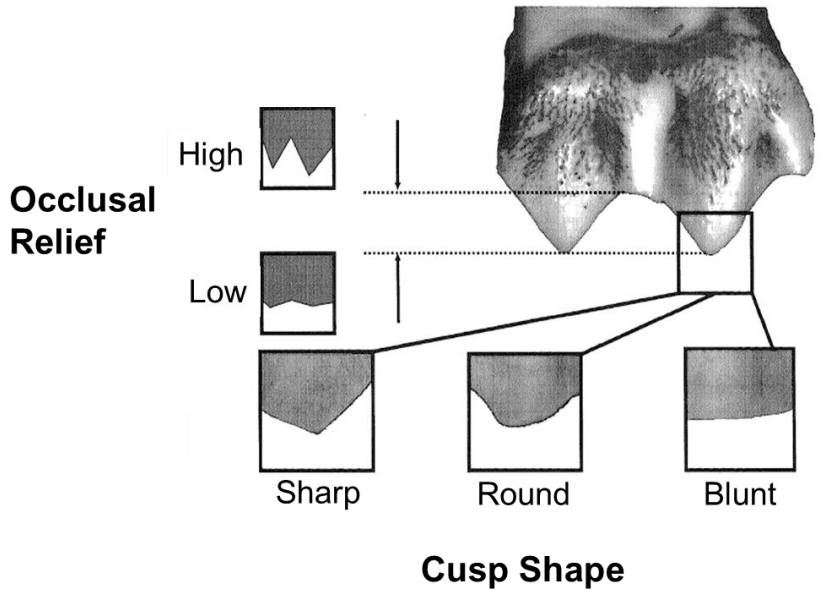

Figure 3.1. Image of an ungulate tooth's buccal surface where examination for mesowear analysis occurs. On the left side of the image, the measures of occlusal relief (high or low) are shown. On the bottom, the measures of cusp shape (sharp, round, or blunt) are illustrated (modified from Clauss et al. 2007). This measurement follows standard protocols established by Fortelius and Solounias (2000).

Molding and Casting

After examination for potential post-mortem damage (e.g., Teaford 1988), suitable molars were cleaned with alcohol and molded for microwear texture analysis. Molds were created by applying President's Jet, a high-resolution polyvinylsiloxane dental impression material (Coltène-Whaledent, Hudson, MA) to the occlusal surface of the second molar. The molding procedure was non-destructive, and created a precise, high-resolution impression of a tooth's surface (e.g., Beynon 1987, Teaford and Oyen 1989 b). President's two-part putty system (Coltène-Whaledent, Hudson, MA) shored up the molds so casts could be produced replicating the original enamel surface. Casts were created using Epotek 301 resin and hardener (Epoxy Technology Inc., Billerica, MA) following conventional procedures (e.g., Ungar 1996).

Microwear Texture Analysis Procedures

Previous researchers have examined sheep and goat wear (e.g., Mainland 1998a, 2003, 2006; Mainland and Halstead 2005). However, different methods were used for the current study that reflects changes in modern technology and standards established when examining ungulate microwear. For instance, Mainland analyzed the buccal-posterior cusp of the deciduous premolars. The current study instead follows Merceron et al. (2004a, b, 2005), Rivals and Deniaux (2003, 2005), Scott (2012), and Ungar et al. (2007), by using the lingual paracone[20] of the upper molars (Figure 3.2). As Gordon (1988) indicated, dental wear patterns are affected by more than just foods' dietary properties. Movement of the jaw, muscle pressures, and complexity of the occlusal surface influence wear patterns as well. This complexity was demonstrated by Mainland (2006) herself, who found size of features varied when looking at premolar versus molars. This may reflect differences in juvenile diet, variation of muscle affect along the tooth row, tooth shape, or a combination of influences. Molars[21], rather than premolars, will be used to remain consistent and comparable to the larger body of ungulate microwear research, which includes gazelles as well (e.g., Merceron et al. 2004a, b; Scott 2012). Therefore, Mainland's protocol will not be followed here.

Furthermore, this research uses dental microwear texture analysis (DMTA) to understand the microwear found on this facet as opposed to the SEM method of Mainland. DMTA has proven to be a faster method than SEM feature-based studies, and observer error in measurements is eliminated because surface characterization is automated. Instead of quantifying a tooth's surface by the number and size of pits and scratches, DMTA uses five

[20] The facet examined occludes during the shearing of the Phase I movement of the molars across the maxillary molar (Merceron et al. 2004a, b).

[21] Second molars are thought to provide a balanced view of dental wear and the variation that occurs between the molar teeth in the jaw (e.g., Merceron et al. 2004a).

variables to characterize overall surface texture (Scott et al. 2006). These variables relate to slightly different aspects of diet. Specifically, anisotropy and complexity have been shown to reflect dietary differences between species, including ruminants (Scott et al. 2005, Ungar et al. 2007). Higher anisotropy values tend to indicate a grazer diet while higher complexity is seen with a browse-based diet (Ungar et al. 2007). This methodology will provide a more nuanced approach to understand the vagaries of domestication, beyond what SEM studies are capable of doing.

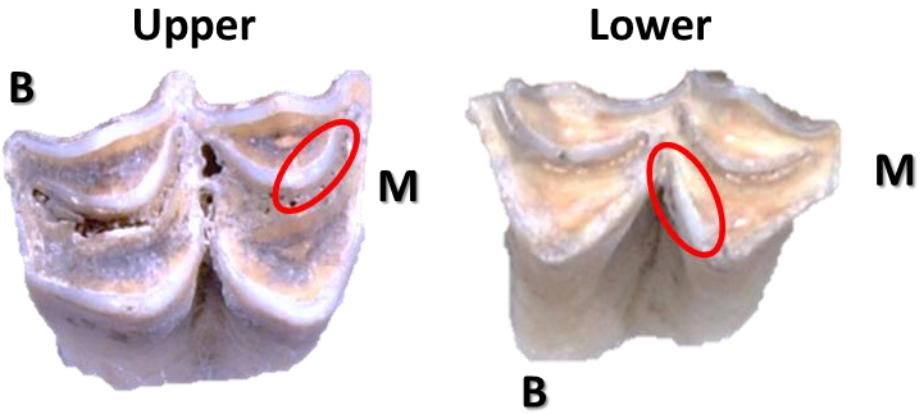

Figure 3.2. Location of Phase I shearing facets, indicated by red ovals, used for Dental Microwear Texture Analysis. Both teeth are archaeological samples from Gritille used within this analysis and are from the right side of the dentition (Mesial: M, Buccal: B). These areas were sampled following convention (references), as they have been shown again and again in the past to separate groups by diet. Photograph by M. Zolnierz.

A Sensofar Plμ white-light scanning confocal profiler (Solarius Development Inc., Sunnyvale, CA) was used to examine the microwear on the prescribed location of the casts[22] (Figure 3.2). The confocal profiler creates three-dimensional point-clouds of the tooth's surface with a lateral sampling interval of 0.18 μm and a resolution of 0.005 μm (with a 100x objective lens). Following convention, a series of four adjacent scans were used for a total scanned area of 276 X 204 μm (Scott et al. 2006). The resulting point clouds were analyzed in Solarmap Universal software (Solarius Development Inc., Sunnyvale, CA), wherein surfaces were normalized and leveled. Any defects remaining on the surface when the mold was created (e.g., dust or dirt) were erased electronically, and therefore excluded from the surface scan data. The point-cloud data were imported into Toothfrax and Sfrax software packages (www.surfract.com) for scale-sensitive fractal analyses. Scale-sensitive fractal analysis is based on the principle that apparent surface texture varies with scale of observation (Scott et al. 2006). Three algorithms are used in this study: the length-scale rotational algorithm, the area-scale tiling algorithm, and the volume filling versus scale square cuboid filling algorithm (see Scott et al., 2006 for a detailed explanation). These result in the generation of data for five texture variables used to categorize microwear surface (discussed below).

Anisotropy (*epLsar*): Exact proportion length-scale anisotropy of relief provides information on the directionality of the microwear texture based on the changes in observation due to orientation. A sampling interval of 5° was used in calculating this wear variable. Scale can affect this variable as well but is kept at 1.8 μm per the standard calculation established (see El-Zaatari 2007, Scott et al. 2006 for specifics on value calculations). This variable has been

[22] Since casts are an exact replica of the enamel surface of the original tooth, the facet location of the cast is in the same location as the original tooth.

used in ungulate-based studies to separate browsers and grazers. Grazers have more striated surfaces and therefore higher anisotropy values (Scott 2012, Ungar et al. 2007).

Complexity (*Asfc*): Complexity or area-scale fractal complexity indicates how the texture roughness changes with scale of observation. The calculation takes into account the idea that a coarse surface might not appear to have much, if any, visible texture roughness. By increasing the scale of observation, more and more wear features become visible. Therefore, a surface with overlapping features (e.g., various sized pits and scratches) will have a high complexity value (see El-Zaatari 2007, Scott et al. 2006 for specifics on value calculations). Complexity is another value focused on when examining ungulate microwear. Browsers will have higher complexity values due to their properties of browse and the movements of the jaws required to eat the food (Scott 2012, Ungar et al. 2007).

Heterogeneity (*HAsfc*): Heterogeneity of area-scale fractal complexity provides information on how the microwear texture (i.e., complexity) varies across each scanned microwear surface. A surface that has more variation (e.g., pits and scratches) across the wear surface will have a higher value than a surface with similar wear (e.g., just scratches) (El Zaatari 2007, Scott et al. 2006). The heterogeneity microwear texture variable is reported as two values, based on calculating the overall surface differently. This reporting follows standard protocol for DMTA analysis (e.g., Scott 2012). The first heterogeneity is based on dividing the surface into a 3x3 grid, giving rise to the 3x3-heterogeneity value or $Hasfc_9$. The second heterogeneity is based on a finer scale by dividing the surface into a 9x9 grid. This value is the 9x9-heterogeneity or $Hasfc_{81}$.

Scale of maximum complexity (*Smc*): The scale of maximum complexity relates to complexity, indicating at which scale the surface is the most complex. This microwear texture value is related to the size of the grit and other abrasives causing wear in the diet. The smaller the value, the finer the scale at which complexity is highest. Smaller values suggest both large and small features, while larger values suggest a lack of small features (Scott 2012, Scott et al. 2006).

Texture fill volume (*Tfv*): The texture fill volume is based on the idea a surface can be filled with boxes. Depending on the scale and shape, different numbers of boxes will fit. By taking values from a fine scale (2 μm) and subtracting the structural fill volume at 10 μm, the overall surface shape is removed, and leaves behind information on the wear. The larger the feature size, the higher the *Tfv* value will be (El Zaatari 2007, Scott et al. 2006).

Statistical Analysis

Mesowear

Mesowear analysis for the extant species followed calculations in Schubert (2004). Percentages for each mesowear variable were calculated (e.g., percent sharp, percent round, percent blunt, percent high, and percent low) based on the taxa and species. These percentages were imported into SYSTAT 13 (Systat Software, Inc., Chicago, IL) to allow for hierarchical cluster analysis. Cluster analysis was based on complete linkages and Euclidean distances following Schubert (2004, 2007).

Microwear

The results of scale-sensitive fractal analyses, calculated by Toothfrax and Sfrax software packages (www.surfract.com), were exported to Excel (Microsoft 2010) to allow further calculations. As stated previously in the microwear methods section, four contiguous scans of each wear facet were taken. However, instead of basing further analyses on each of these individual scans, the median values were calculated. The median value provides a more balanced view of the individual's wear surface and follows the protocol of previous microwear texture analyses (e.g., Scott et al. 2006, Ungar et al. 2007). In addition, the microwear texture data were rank-transformed, as the assumptions for normality in parametric tests may not be met (Conover and Iman 1981, Scott 2012). Ranked data were analyzed using multivariate analysis of variance (MANOVA) with SYSTAT 13 (Systat Software, Inc., Chicago, IL). The dependent variables were the microwear texture variables, while the animal groups served as the independent variable. If significance was found, individual analysis of variance (ANOVA) for the significant dependent variable was carried out along with pairwise comparisons to understand where the significance occurred. Pairwise comparisons included both Tukey's Honestly Significant Difference (Tukey's HSD) and Fisher's Least Significant Difference (Fisher's LSD) to balance the risk of Type I and Type II errors (Cook and Farewell 1996). In addition to running statistical analyses on rank-transformed data, the data also were transformed by Levene's transformation following Plavcan and Cope (2001). This data transformation provides information on the degree of variation between the specimens analyzed. Once transformed, a MANOVA was performed, following the same steps as the rank-transformed data.

Results

Mesowear

Hierarchical Cluster Analysis 1: Mesowear Variables by Taxon: A total of 6 cluster analyses were performed on the mesowear data based on either high or low cusp and the three shapes the tooth could have (sharp, round, blunt). Table 3.6 provides the data used for this hierarchical cluster analysis. Appendix 1 provides any other statistical charts and graphs for data analysis in Chapter 3 not given in the text, including the graphs showing the clustering pattern of the mesowear scores. All three cluster analyses based on percentage of high cusps separated the gazelles from the goats and sheep. In addition, when percent high and percent sharp and blunt were combined into one cluster analysis, the same pattern was observed. This same clustering pattern was also observed with percent low and percent round cusps and percent low and blunt cusps. The percent of high cusp is interesting since grazers undergo more abrasion. Percent sharp and percent blunt are also different from expected. This may indicate variation in Near Eastern species environment providing more browse or browse like qualities within the graze. The analysis based on percent low and percent sharp showed a different pattern with goats as the out-group. However, for this analysis, very little difference in distance was seen (along with the other two low cusp groupings). The cluster analysis based on taxa indicates that although there may be overlap within Iran, gazelles possess different dietary lifetime signatures than sheep and goats. Gazelles appear to suffer more from abrasive wear than the other two taxa. The abrasion may be due to excessive dietary grit as well as the material consumed.

Taxa	Number	% high	% low	% sharp	% round	% blunt
Goat	50	100	0	0.3	0.68	0.02
Gazelle	60	0.88	0.12	0.18	0.75	0.07
Sheep	84	100	0	0.18	0.80	0.02

Table 3.6. Percentage of each mesowear variable scored for each of the three taxa studied (goat, gazelle, and sheep). Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt.

Hierarchical Cluster Analysis 2: Mesowear by Species: Table 3.7 provides the data used for this hierarchical cluster analysis. Appendix 1 includes the graphs showing the clustering pattern of the mesowear scores. The percent high and percent sharp, percent high and percent blunt, and percent high and percent sharp and percent blunt combined follow the same pattern as the first cluster analysis. *Gazella dorcas dorcas* and *G. subgutturosa subgutturosa* separate from the rest of the animals examined. These animals live in much drier to desert areas, which probably provide more grit in the diet leading to wear that is more abrasive. The percent high and percent round separates *Ovis aries* sp., *O. a. aries,* and *O. a. urmiana* from the other animals. For these species of sheep, only round cusps were recorded. This finding indicates these animals may have abrasion and therefore more graze in the diet. A subgroup within the other cluster contains *G. d. dorcas* and *G. s. subgutturosa.* The percent low based clusters are less consistent. *Gazella dorcas dorcas, G. s. subgutturosa, G. gazella bennetti*, *Capra hircus hircus,* and *O. a. laristanica* separate out from the rest when percent low and percent sharp are examined. This pattern on the teeth may provide evidence of not only excess grit within the diet but the eating of browse, which would allow attrition to occur (keeping the cusps sharp). *Ovis aries* sp., *O. a.*

aries, and *O. a. urmiana* once again separate out for the percent round and percent low, just like the percent high. For the cluster analysis based on percent low and percent blunt, *C. h. hircus* once again separates out. Since there are only three *C. h. hircus* individuals examined, this may be indicating a difference in diet between the areas in which these specimens were collected.

Species	**Number**	**% high**	**% low**	**% sharp**	**% round**	**% blunt**
Capra hircus aegagrus	21	100	0	0.19	0.81	0
Capra hircus hircus	3	100	0	0.67	0.00	0.33
Gazella dorcas dorcas	12	0.83	0.17	0.75	0.17	0.08
Gazella gazella bennetti	6	100	0	0.5	0.5	0
Gazella subgutturosa subgutturosa	12	0.83	0.17	0.75	0.17	0.08
Ovis aries aries	4	100	0	0	100	0
Ovis aries gmelini	10	100	0	0	0.90	0.1
Ovis aries isphahanica	3	100	0	0.33	0.67	0
Ovis aries laristanica	4	100	0	0.5	0.50	0
Ovis aries sp.	6	100	0	0	100.00	0
Ovis aries urmiana	1	100	0	0	100.00	0
Ovis vignei dolgopolovi	11	100	0	0.09	0.91	0

Table 3.7. Percentage of each mesowear variable scored for each of the species studied (listed on the left). Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt.

Microwear

MANOVA 1: Examination of Wild Gazelles, Goats, and Sheep by Taxa: In this MANOVA, the microwear textures of the wild animals obtained from the FMNH were compared (Table 3.8). The animals were analyzed using the higher-taxonomic level distinguished as gazelle, goat, or sheep (regardless of species or subspecies). The MANOVA indicated both complexity (*Asfc*) and texture fill volume *(Tfv*) met the level of significance ($p < .05$) ($p = 0.030$ and < 0.001 respectively) (Table 3.9), and were examined further. All other variables provided no significant difference and therefore, no further testing occurred with these variables. Appendix 1 provides any other statistical charts and graphs for the MANOVA and follow-up ANOVA analyses not given in the text.

		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	**3x3*HAsfc* Median**	**9x9*HAsfc* Median**
Gazelle	Mean	2.233	.003	.887	12240.251	.419	.866
	N	29	29	29	29	29	29
	Std. Deviation	1.085	.001	3.300	3811.257	.095	.282
	Median	1.946	.003	.154	11731.732	.398	.776
	Skewness	.837	.204	5.307	-.374	.706	1.917
Goat	Mean	1.772	.004	.254	6600.180	.390	.812
	N	36	36	36	36	36	36
	Std. Deviation	1.068	.001	.192	4843.095	.116	.237
	Median	1.550	.004	.180	6517.120	.364	.761
	Skewness	1.284	.355	3.080	.064	1.051	2.080
Sheep	Mean	1.663	.003	5.803	7733.002	.419	.847
	N	70	70	70	70	70	70
	Std. Deviation	.902	.001	37.469	4907.395	.141	.340
	Median	1.489	.003	.208	7966.932	.380	.765
	Skewness	1.123	.370	8.251	-.029	1.539	1.833

Table 3.8. Table of general statistics for each microwear variable for each of the three taxa (gazelle, goat, and sheep) analyzed during MANOVA 1.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	10,568.966	2	5,284.483	3.587	0.030*
Error	194,451.034	132	1,473.114		
EPLSAR_MEDIAN	6,107.969	2	3,053.985	2.027	0.136
Error	198,912.031	132	1,506.909		
SMC_MEDIAN	1,497.936	2	748.968	0.486	0.616
Error	203,522.064	132	1,541.834		
TFV_MEDIAN	31,645.330	2	15,822.665	12.047	0.000*
Error	173,374.670	132	1,313.444		
_3X3HASFC_MEDIAN	3,939.233	2	1,969.617	1.293	0.278
Error	201,080.767	132	1,523.339		
_9X9HASFC_MEDIAN	1,373.652	2	686.826	0.445	0.642
Error	203,646.348	132	1,542.775		

Table 3.9. Results of the MANOVA run using the taxa (gazelle, goat, sheep) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 1).

For complexity, Tukey's HSD finds only gazelles and sheep complexity to be significant ($p = 0.025$). In addition, Fisher's LSD results suggested a significant difference between gazelles and goats ($p = 0.035$). The latter is taken as suggestive, or of marginal significance as the result was not significant in the Tukey's test comparison. Still, these differences are as expected given reported dietary differences between the three species. The difference between

Fisher's LSD and Tukey's HSD might reflect the fact that both gazelles and goats are more intermediate feeders or browsers while sheep prefer graze species. This feeding difference is reflected in the lower values for both goats and sheep, when compared to gazelles. Scott (2012) found species relying on browse have higher complexity values (Table 3.10). In this study, gazelles have the highest *Asfc* value, indicating a browse-based diet, which is what was indicated through the background literature.

	Asfc	***EpLsar***	***Smc***	***Tfv***	**3X3 *HAsfc***	**9X9 *HAsfc***
Obligate Grazer	0.985	0.0065	1.343	2306.9	0.387	0.698
Browser-Grazer Intermediate	2.063	0.0037	0.417	6248.3	0.497	0.866
Browser	3.611	0.0022	0.767	10975.1	0.622	0.951

Table 3.10. Median dental microwear texture values from Extant African bovids used to show dietary distinctions. Animals have been placed into general dietary categories of grazers, intermediate feeders, and browsers based on observation of modern diets (modified from Scott 2012).

The texture fill volume test result suggests significance between gazelles and goats ($p < 0.001$), and gazelles and sheep ($p < 0.001$) for both Tukey's HSD and Fisher's LSD post hoc tests. Scott's research (2012) indicated this variable is highest in browsers. In this research, the gazelle *Tfv* mean is double the mean for either goats or sheep. The properties of the food consumed by goats and sheep do not have as great an impact as on the occlusal surface of gazelles. Since complexity appeared to indicate gazelles and goats were eating a more browse-based diet, the foods these two species were relying on must have not overlapped. This separation makes sense, as eating different types of browse would allow the species to live in similar areas (Figure 3.3). Alternatively, the differences could reflect seasonal shifts in diet, as microwear only lasts a few days to weeks. The effects of season will be explored in a later MANOVA. Either of these theories would be supported by the mesowear analyses, which separated the goats from the gazelles. Over the animal's lifetime, different plant materials were consumed leading to diverse wear patterns on the buccal aspects of the upper molar teeth.

Figure 3.3. Current topographical map of Near East with sites wild animal specimens were collected. Species collected from the site are written off to the side. Due to limitations of size, not all specimens and collection sites are indicated (map created in Google Scribble Maps).

For the Levene's transformed data, the MANOVA indicated significant variation for the 9X9-heterogeneity variable (Table 3.11). However, Tukey's HSD found no significant pairwise comparisons between the variations in taxa group. Fisher's LSD found significant differences

between sheep and gazelles (p= 0.041), and sheep and goats (p= 0.032). The variation between sheep and the other groups may be due in part because of the wider variety of sheep samples (7 groups) than the goats and gazelles. Since these sheep were products of varying environments, this variation would follow. Still, the lack of significant variation evidenced in the Tukey's test comparisons suggests that these differences should be considered suggestive, or of marginal significance at best.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	0.041	2	0.020	0.167	0.846
Error	16.016	132	0.121		
LEVEPLSAR	0.368	2	0.184	2.319	0.102
Error	10.471	132	0.079		
LEVSMC	4.769	2	2.385	1.978	0.142
Error	159.114	132	1.205		
LEVTFV	13.380	2	6.690	1.073	0.345
Error	822.778	132	6.233		
LEV9HASFC	0.049	2	0.025	0.774	0.463
Error	4.222	132	0.032		
LEV81HASFC	0.269	2	0.135	3.410	0.036*
Error	5.211	132	0.039		

Table 3.11. Results of the MANOVA run using the taxa (gazelle, goat, sheep) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was p < 0.05. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 1).

MANOVA 2: Comparison of Wild Species by Individual Species: To understand in more depth the dental microwear texture differences between the wild taxa, a MANOVA was run with each species as an independent variable, while the dependent variable remained the microwear texture variables (Table 3.12). The results of this MANOVA indicate all microwear texture variables other than $Hasfc_9$ (3x3-heterogeneity) are significant (Table 3.13).

Scientific Name		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	***3x3HAsfc* Median**	**9x9*HAsfc* Median**
Capra hircus aegagrus	Mean	1.825	.004	.213	6571.404	.383	.819
	N	34	34	34	34	34	34
	Std. Deviation	1.074	.001	.088	4785.593	.111	.242
	Median	1.590	.004	.152	6517.120	.364	.774
	Skewness	1.230	-.077	1.991	.062	1.079	1.992
Capra hircus hircus	Mean	.870	.007	.942	7089.365	.500	.688
	N	2	2	2	2	2	2
	Std. Deviation	.321	.001	.174	8042.102	.210	.024
	Median	.870	.007	.942	7089.365	.500	.688
	Skewness	.	.	.	.	.	.

Table 3.12. Table of general statistics for each microwear variable for each of the species analyzed during MANOVA 2. Continued on next page.

Scientific Name		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	***3x3HAsfc* Median**	**9x9*HAsfc* Median**
Gazella dorcas dorcas	Mean	2.73	.002	1.791	14457.982	.421	.900
	N	11	11	11	11	11	11
	Std. Deviation	1.22	.001	5.364	2757.841	.126	.293
	Median	2.657	.003	.152	16046.348	.398	.797
	Skewness	.293	-.516	3.316	-.728	.833	1.706
Gazella gazella bennetti	Mean	1.702	.004	.250	9423.884	.431	.921
	N	7	7	7	7	7	7
	Std. Deviation	.711932394	.000	.170	3959.117	.106	.408
	Median	2.05	.004	.152	10205.320	.462	.816
	Skewness	-1.192	.053	2.129	.230	-.333	1.765
Gazella subgutturosa subgutturosa	Mean	2.067	.004	.387	11814.754	.409	.798
	N	11	11	11	11	11	11
	Std. Deviation	.990	.001	.496	3535.505	.051	.168
	Median	1.775	.003	.209	11696.905	.393	.735
	Skewness	1.503	.798	3.002	.027	1.243	1.625

Table 3.12 (Cont.). Table of general statistics for each microwear variable for each of the species analyzed during MANOVA 2. Continued on next page.

Scientific Name		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	***3x3HAsfc* Median**	**9x9*HAsf*c Median**
Ovis aries aries	Mean	1.071	.005	1.162	4901.076	.447	.729
	N	6	6	6	6	6	6
	Std. Deviation	.513	.001	2.277	5940.193	.197	.184
	Median	.970	.005	.267	2154.133	.371	.695
	Skewness	.355	-.830	2.447	1.191	2.027	.000
Ovis aries gmelini	Mean	1.009	.003	25.999	9545.523	.506	1.097
	N	15	15	15	15	15	15
	Std. Deviation	.531	.001	79.757	4853.036	.145	.456
	Median	.841	.002	3.815	10683.154	.502	.969
	Skewness	1.482	.832	3.831	-.224	.933	1.779
Ovis aries isphahanica	Mean	1.574	.004	.242	10893.446	.346	.662
	N	4	4	4	4	4	4
	Std. Deviation	.856	.001	.0824	3290.382	.048	.149
	Median	1.413	.005	.237	11489.637	.330	.656
	Skewness	1.076	-.833	.266	-1.013	1.450	.075

Table 3.12 (Cont.). Table of general statistics for each microwear variable for each of the species analyzed during MANOVA 2. Continued on next page.

Scientific Name		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	***3x3HAsfc* Median**	**9x9*HAsfc* Median**
Ovis aries laristanica	Mean	1.350	.004	.197	6743.204	.390	.682
	N	5	5	5	5	5	5
	Std. Deviation	.941	.001	.063	5677.302	.121	.146
	Median	.833	.003	.152	8192.398	.386	.655
	Skewness	1.585	.971	.608	.221	-.109	-.541
Ovis aries sp.	Mean	1.524	.005	.204	6601.020	.387	.703
	N	11	11	11	11	11	11
	Std. Deviation	.788	.001	.058	3995.961	.098	.274
	Median	1.480	.005	.208	5446.990	.360	.558
	Skewness	1.377	-.277	1.291	.263	2.293	1.410
Ovis aries urmiana	Mean	2.242	.002	.185	7917.635	.399	.894
	N	5	5	5	5	5	5
	Std. Deviation	.694	.001	.051	4748.642	.136	.266
	Median	2.540	.002	.151	9054.443	.354	.905
	Skewness	-.551	-.047	1.258	-1.557	.379	-1.265

Table 3.12 (Cont.). Table of general statistics for each microwear variable for each of the species analyzed during MANOVA 2. Continued on next page.

Scientific Name		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	***3x3HAsfc* Median**	**9x9*HAsfc* Median**
Ovis vignei dolgopolovi	Mean	2.243	.003	.173	7467.986	.394	.841
	N	24	24	24	24	24	24
	Std. Deviation	.884	.001	.040	5047.834	.144	.309
	Median	1.983	.002	.152	7214.855	.364	.752
	Skewness	1.723	.401	1.671	.054	2.189	1.206

Table 3.12 (Cont.). Table of general statistics for each microwear variable for each of the species analyzed during MANOVA 2.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	60,321.646	11	5,483.786	4.661	0.000*
Error	144,698.354	123	1,176.409		
EPLSAR_MEDIAN	52,337.951	11	4,757.996	3.833	0.000*
Error	152,682.049	123	1,241.317		
SMC_MEDIAN	56,997.025	11	5,181.548	4.306	0.000*
Error	148,022.975	123	1,203.439		
TFV_MEDIAN	47,698.515	11	4,336.229	3.390	0.000*
Error	157,321.485	123	1,279.036		
_3X3HASFC_MEDIAN	22,040.398	11	2,003.673	1.347	0.207
Error	182,979.602	123	1,487.639		
_9X9HASFC_MEDIAN	29,649.718	11	2,695.429	1.891	0.047*
Error	175,370.282	123	1,425.775		

Table 3.13. Results of the MANOVA run using the individual animal species as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was p < 0.05. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 1).

In comparing species using Tukey's HSD pairwise comparison with the complexity variable, *Capra hircus aegagrus* differed from *Ovis aries gmelini* (p= 0.038). *Gazella dorcas dorcas* is significantly different from both *O. a. aries* (p= 0.020) and *O. a. gmelini* (p< 0.001). *Gazella subgutturosa subgutturosa* is also significantly different from *O. a. gmelini* (p= 0.018). *Ovis aries aries* texture is different from *O. vignei dolgopolovi* (p=0.030). *Ovis aries gmelini* is

different from both *O. a. urmiana* (p= 0.035) and *O. v. dolgopolovi* (p=0.000). Fisher's LSD found significant differences too, which are provided in Appendix 1. As expected from MANOVA 1, complexity separates species of gazelles, goats, and sheep from each other. Of note are differences among the sheep species. When the actual values of these animals are examined, we find the highest complexity values lie with *O. a. urmiana* and *O. v. dolgopolovi*. In Scott (2012), the values of these animals would place them in the generalist/ browser-grazer category. The lowest complexity values, associated with grazers, are found with *O. a. aries* and *O. a. gmelini*. When comparing these animals to the location they were collected, a pattern based on environment emerges. *Ovis aries urmiana* and *O. v. dolgopolovi* come from drier conditions such as Shahrud and Khvoy (see Table 3.5, Figure 3.3). *Ovis aries aries* and *O. a. gmelini* derive from locations close to water sources and not as dry (e.g., Maku).

For the anisotropy variable, Fisher's LSD found 25 significant pairings between the wild species for this variable. These differences include differences between each taxon. Again, these are of marginal significance. Tukey's HSD finds only one significant pairing, *Ovis aries* sp. and *O. vignei dolgopolovi* (p= 0.047). Although both species are sheep, the locations in which they were collected are vastly different, which probably affects dietary grit levels. *Ovis aries.* sp. was collected in a much wetter area than *O. v. dolgopolovi*. The *epLsar* value falls within the variable grazer range according to Scott (2012). The latter specimens were collected in a much drier, flatter area of Iran. The anisotropy values fall within the browser-grazer range. The variable suggests that the location of *O. a.* sp. provided these sheep with more sources of graze than *O. v. dolgopolovi,* which required eating of browse species in the diet as well.

When the ANOVA was run for the scale of maximum complexity (*SMC*), the Fisher's LSD pairwise comparison found 19 significant pairings while Tukey's HSD found five. The

significant comparisons all involved *Ovis aries gmelini*. When compared with *Capra hircus aegagrus* significance was p< 0.001, with *Gazella dorcas dorcas* p= 0.002, *O. aries* sp. p= 0.005, *O. a. urmiana* p= 0.013, and *O. vignei dolgopolovi* p< 0.001. *Ovis aries gmelini* have higher *SMC* values than other species. Having a high *Smc* value is a trait Scott (2012) found in obligate grazers. The mean scale of maximum value is incredibly high, even higher than mean values reported by Scott (2012). The inflated values may be providing an incorrect comparison with the other species, or could indicate that *O. a. gmelini* ate only a graze-based diet.

When examining the texture fill volume (*Tfv*), 13 significant pairings were found with Fisher's LSD. Turning to Tukey's HSD, four significant pairs were found, all of which involve *Gazella dorcas dorcas*. The significant comparisons for the dorcas gazelles include *Capra hircus aegagrus* (p= 0.000), *Ovis aries aries* (p= 0.005), *O. aries sp.* (p= 0.006), *O. vignei dolgopolovi* (p= 0.003). The dorcas gazelles have high values for *Tfv* indicating a browse-based diet expected when living in desert areas. The texture fill volume is nearly double that of the species found significant in this test. This significant result follows what was seen in MANOVA 1.

When the pairwise comparison for 9x9-heterogeneity ($HAsfc_{81}$) was examined, no significant pairings were found using the Tukey's HSD test. However, Fisher's LSD found four pairings. *Capra hircus aegagrus* just met the level of significance with *Ovis aries gmelini* and *O. a.* sp. (p= 0.045, 0.047 respectively). *Gazella subgutturosa subgutturosa* paired significantly with the same two sheep species, *O. a. gmelini* and *O. a.* sp. (p= 0.017, p= 0.017). Given the results found in Scott (2012) for heterogeneity, browsing species have the highest values. Based on the results of the MANOVA 1 and the other ANOVAs, *C. h. aegagrus* and *G. s. subgutturosa* should have the highest heterogeneity. However, *O. a. gmelini* has a higher range of values than

either gazelles or goats. This high heterogeneity value places *O. a. gmelini* within the browser category, which is seemingly inconsistent with its classification based on *Smc.* This opposing signal combined with lack of significance in MANOVA 1 may indicate that heterogeneity may not parse out the diets of animals living in these environmental conditions.

The MANOVA using the Levene's transformed data only found significance in the *Smc* and *Tfv* variables (Table 3.14). In both cases, Fisher's LSD identified 10 significant pairings. For scale of maximum complexity, Tukey's HSD found that *Ovis aries gmelini* was significantly different from goats (*Capra hircus aegagrus*), all species of gazelles, and several sheep species (*Ovis a. aries, O. a. isphahanica, O. a. laristanica, O. a. urmiana, O. a.* sp., *O. v. dolgopolovi*) ($p<0.001$ for all cases). Similar to what we saw with the traditional MANOVA analysis, the standard deviation for *O. a. gmelini* is at least 9 times that of the other animals examined. For *Tfv, O. a. urmiana* was significantly different in dispersion from goats (*C. h. aegagrus*), all species of gazelles, and *O. a. gmelini, O. a. isphahanica, O. a.* sp., and *O. v. dolgopolovi*. Possibly living near salt flats provided a different type dietary variety, providing *O. a. urmiana* a unique range in its texture fill volume.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	1.629	11	0.148	1.263	0.254
Error	14.427	123	0.117		
LEVEPLSAR	1.468	11	0.133	1.751	0.070
Error	9.371	123	0.076		
LEVSMC	71.906	11	6.537	8.742	0.000*
Error	91.977	123	0.748		
LEVTFV	129.483	11	11.771	2.049	0.029*
Error	706.674	123	5.745		
LEV9HASFC	0.386	11	0.035	1.110	0.359
Error	3.886	123	0.032		
LEV81HASFC	0.507	11	0.046	1.139	0.337
Error	4.974	123	0.040		

Table 3.14. Results of the MANOVA run individual animal species as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 1).

MANOVA 3: Examination of Taxa by Season: To understand whether season played a role in diet, a MANOVA was run with the microwear texture variables as the dependent variables, and taxon and season as the independent ones. The table listing the general statistics is found in Appendix 1. This test allowed for examination of the interaction between the two independent factors. Since microwear turnover is rapid, the season at the time of death should

represent the dietary pattern for that period. The results indicated complexity, anisotropy, and texture fill volume were significant (Table 3.15).

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
AFSC	30,064.429	11	2,733.130	2.068	0.028*
Error	157,250.571	119	1,321.433		
EPLSAR	34,608.832	11	3,146.257	2.454	0.008*
Error	152,584.168	119	1,282.220		
SMC	18,386.416	11	1,671.492	1.355	0.203
Error	146,784.584	119	1,233.484		
TFV	47,262.428	11	4,296.584	3.650	0.000*
Error	140,067.572	119	1,177.038		
HASFC9	9,541.273	11	867.388	0.582	0.841
Error	177,475.227	119	1,491.388		
HASFC81	17,803.596	11	1,618.509	1.137	0.339
Error	169,431.904	119	1,423.798		

Table 3.15. Results of the MANOVA run individual animal species and season as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 1).

The ANOVA for complexity indicated both taxon and the interaction between taxon and season was significant ($p= 0.005$, $p=0.034$ respectively) (Appendix 1). The significance found with complexity is understandable given the results of the first MANOVA. Tukey's HSD does not indicate any significant pairings between the taxon/ season interactions. Fisher's LSD, gazelles by season are significantly different from the other taxon by season. The only same taxon significant pairings occurred with fall and summer goats ($p=0.043$), and fall and spring sheep ($p= 0.034$). Since these results are found with Fisher's LSD and not Tukey's HSD, the interactions are only suggestive and may indicate some dietary sifts based on seasonal availability of resources.

For anisotropy, the ANOVA did not return significant results for taxon, season, nor the interaction between the two. The ANOVA for texture fill volume indicated taxon ($p< 0.001$) and the interaction between taxon and season ($p = 0.020$) were significant. Again, the significance difference in texture fill volume for taxon was seen already in MANOVA 1. Fisher's LSD found many interactions between taxon and season significant. Tukey's HSD identified fall gazelles and fall goats ($p= 0.004$), spring gazelles and fall goats ($p< 0.001$), spring gazelles and spring sheep ($p= 0.029$), spring gazelles and summer sheep ($p= 0.047$), and summer gazelles and fall goat ($p= 0.020$). It appears that gazelles' texture fill volume has significant differences in all seasons except winter. This finding is interesting as during the winter, gazelle species often migrate, which may bring these animals into areas where sheep and goats are.

Levene's transformed data indicated no significant differences in the variation of the microwear texture variables when taxa and season were the independent factors (Table 3.16). Therefore, no further analyses were done with Levene's transformed data.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	0.815	11	0.074	0.599	0.826
Error	14.724	119	0.124		
LEVEPLSAR	0.891	11	0.081	0.993	0.457
Error	9.705	119	0.082		
LEVSMC	12.597	11	1.145	1.286	0.240
Error	105.943	119	0.890		
LEVTFV	38.294	11	3.481	0.520	0.886
Error	796.263	119	6.691		
LEVHASFC9	0.167	11	0.015	0.450	0.930
Error	4.026	119	0.034		
LEVHASFC81	0.531	11	0.048	1.196	0.297
Error	4.805	119	0.040		

Table 3.16. Results of the MANOVA run individual animal species and season as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. No variable met this criterion.

Conclusion

Based on the results of the mesowear and microwear analyses, the null hypothesis can be rejected (H_0 no dietary difference between species: no change in central tendencies for mesowear and microwear variables between the different species taxa or individual species). Significant differences were seen within the dietary reconstructions.

H_{A1} dietary differences: differences in mesowear and microwear are seen reflecting dietary preference. Gazelles and goats should provide a browser-based signal while sheep should indicate a grazer-based diet. This hypothesis was supported with both the mesowear and microwear. For mesowear, gazelles most often fell out from the other groups, presumably reflecting their coarse, abrasive diets. Gazelles also stood out from sheep and goats, in microwear variables, as seen in MANOVA 1. Specifically gazelles separated from these animals with complexity, which was already established in separating ungulate dietary type (e.g., Scott 2012, Ungar et al. 2007). Texture fill volume also was much higher in gazelles, indicating more occlusal enamel was removed through dietary properties.

H_{A2} dietary habitat differences: In comparing the location of collection for the species, differences in microwear textures between collection sites should occur. Animals living in settings that are more arid should have wear signatures reflecting a diet including more grit. Mesowear and microwear analyses indicate that this is the case. Mesowear hierarchical analyses were able to separate species living in drier environments from other species. This pattern is also seen in the microwear analysis. For instance, *Ovis aries gmelini* lived in much wetter environments than the other species, such as gazelles. This provided a diet enriched with graze, which the microwear variables support.

H_{A3} dietary seasonal differences: In comparing the season of collection for the species, differences between seasons can occur. For instance, grazing animals collected in the spring should indicate a dietary signal towards graze. Animals collected when plants are no longer in

their prime or not available will reflect diet shifts. Mesowear analyses were not performed for this variable as mesowear indicates diet over a lifetime. As such, seasonal date of collection should not affect the mesowear signature. Microwear analyses indicated anisotropy, complexity, and texture fill volume were valuable in separating samples by season. Sheep, traditionally associated with graze, showed shifts in complexity. Since complexity has shown dietary differences in the past (e.g., Scott 2012, Ungar et al. 2007), this result suggests that animals either shifted diet based on seasonal resource changes or included resources with more grit.

Chapter Four: Neolithic

The Neolithic Revolution marked dramatic changes in human subsistence practices. In order to explain these changes, we must understand the motive forces behind them. Researchers have proposed many different stimuli, with most theories invoking environmental dynamics, human population density increases beyond environmental carrying capacity, and the natural outgrowth of human and plant/animal interactions. However, unanswered questions remain concerning the mechanics of animal domestication. Traditional studies of changing faunal morphology and skeletal population profiles offer some clues, but such research has had limited success identifying stages intermediate between wild and domesticated forms. This inability to distinguish subtle changes leads to difficulty in discerning initial animal control attempts, and in understanding fully this revolutionary process. This proposed study will bring the tools of dental mesowear and microwear to bear on the issue of animal domestication at the Neolithic site of Gritille (see below). Dental mesowear and dental microwear of zooarcheological materials from the site should allow us to identify diet changes related to husbandry (control of movement and penning animals), and to determine whether the process was gradual or abrupt. This in turn will lead to a better understanding of the causes and mechanics of animal domestication during the Neolithic Revolution.

This chapter will begin by briefly covering the history and subsistence strategies of the Near Eastern Neolithic and the cultural periods surrounding the Neolithic as well. This will be followed by an examination of theories developed to explain Neolithic domestication. The archaeological methods used to support domestication theories will also be covered. The methods and issues resulting from the use of strategies will be discussed, as these issues provide

impetus for using dietary reconstruction within this research. Since some researchers believe pastoralism played a role in domestication, theories and archaeology of pastoralism will be surveyed as well. Following this background information, the materials and methods used to analyze Neolithic Gritille materials will be discussed.

Near East History

The following sections provide a summary of Near Eastern history during the Neolithic as well as the cultural periods immediately before and following the Neolithic. In addition to providing a brief summary of societal structure, the sections provide information on subsistence practices during each period. Dates ascribed to Near Eastern cultures vary between studies due to margins of error in dating techniques, cultural constructs, and attribution of sites (e.g., Bar-Yosef 1989). Therefore, to remain consistent within this paper, cultural periods follow approximations by Kuijt and Goring-Morris (2002), derived from radiocarbon analyses from sites in the southern Levant.

Natufian (ca. 15,000- 12,000 B.P.)

Settlement and Society: Garrod (1932) defined the Natufian in reference to a novel microlithic technology (stone tools) not matching previous, traditional Palestine Mesolithic industries. Some researchers believe differences between the core Mediterranean Natufian sites and those in the north are more than what one cultural classification can encompass. Therefore, the term Epipalaeolithic is used in place of the Natufian for sites in northern Levant, such as Syria (Bar-Yosef and Belfer-Cohen 1989b, Goring-Morris 1995, Moore 1991, see Weninger et al. 2009 illustrative map of cultural periods). For consistency and to avoid confusion with other

uses of Epipalaeolithic, Natufian will be used in this dissertation for all sites regardless of geographic location. The Natufian occurred at the end of the Pleistocene epoch. The period divides into Early and Late Natufian phases based upon differences in cultural and material practices (Figure 4.1) (Akkermans and Schwartz 2003, Bar-Yosef and Belfer-Cohen 1992, Belfer-Cohen and Bar-Yosef 2000).

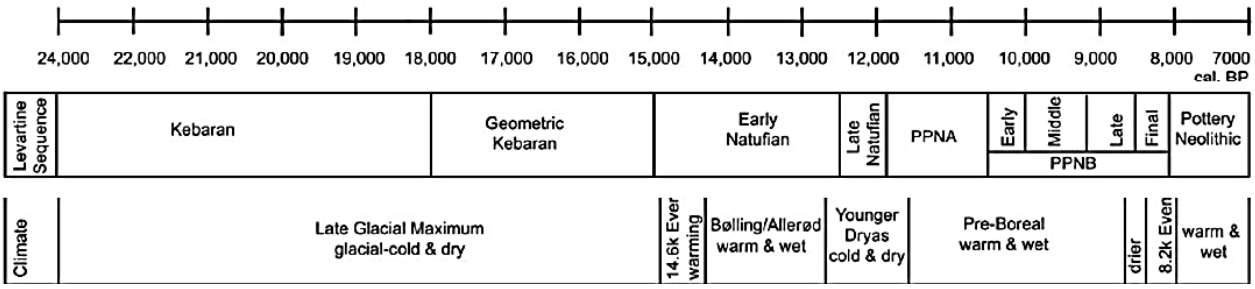

Figure 4.1. This chart indicates how Near Eastern chronology (calibrated dates on the top) corresponds to cultural sequence discussed in the text (middle), and reconstructed environmental conditions (bottom) (modified from Zeder 2011: S223).

Belfer-Cohen and Bar-Yosef (2000) indicated the Natufian bridged the gap between Epipalaeolithic hunter-gatherer lifestyle to sedentary agriculturalists of the Neolithic. Within the Levant, diverse environments supported distinct lifestyles, from hunting and gathering to sedentism. Natufians in marginal areas (e.g., steppes) were more mobile, practicing logistical mobility by travelling from base camps to specialized areas for seasonal resource procurement (Goring-Morris and Belfer-Cohen 2011, Lieberman 1993). For example, small cave sites have been discovered at higher elevations. Faunal remains attested to these sites used in the spring and summer to access game migrating to cooler temperatures (see Chapter 3) (Akkermans and Schwartz 2003, see also Bar-Oz 2004). Shorelines supported a sedentary lifestyle (i.e., permanent settlement at a site), as resource availability remained favorable throughout the year (Goring-Morris and Belfer-Cohen 2011). Natufians often settled where several environmental zones met, such as the intersection of steppes and forests. These diverse environments provided Natufians with a wide resource base (e.g., cereals and oak/ pistachio trees respectively) (Bar-Yosef 1998a, Byrd 2005). During the Late Natufian, occupations expanded into desert areas, possibly the result of density dependent or independent pressures discussed later (Tchernov 1991).

Although Natufians practiced various lifestyles, trade routes existed that connected Natufians throughout the Near East. Trade items have been recovered far from their original sources, such as shells at desert sites or northern-sourced flint in southern Levant. Items traded included not only shells, flint, and beads, but also carved pieces of bone and stone, which feature humans, animals, and abstract designs. Exchange systems consisted ostensibly not only of goods, but also of ideas (Akkermans and Schwartz 2003, Byrd 2005, Mellaart 1975). The overall number of trade objects decreased towards the end of the Natufian, attesting to Natufians

undergoing new pressures, which caused a cultural shift possibly leading to the Neolithic Revolution (Cauvin 2000).

Not all researchers believe the Natufians were fully sedentary. Edwards (1989a) postulated that the Natufians were semi-mobile, moving between fixed residence points seasonally to ensure the best resources. Whether Natufians were fully sedentary or not, archaeological evidence indicates their communities were complex with permanent architecture (Lieberman 1993). Structures include wood or stone circular or semi-circular pit houses. Rebuilt buildings, indicated by multiple house debris layers overlying each other, suggest seasonal movement (Akkermans and Schwartz 2003, Bar-Yosef 1998a, Valla 1995, see also Flannery 1972 who reviewed house structure and society). Recovery of house mice (*Mus musculus domesticus*), sparrows (*Passer domesticus*), and rats (*Rattus* sp.) signal prolonged human occupation or sedentism at Natufian sites. These species are considered commensal, relying on human environment for survival and the apparatus for speciation (Bar-Yosef and Belfer-Cohen 1989b; Tchernov 1984, 1991, 1993). Furthermore, cemeteries indicate connection to the land, with burials occurring within settlement confines. Often burials occurred under the floors of houses, though differences occur between communities (Lieberman 1993, Valla 1995). Orme (1977) discussed reasons for sedentary lifestyles, including overcoming competition with animals by protecting specific food locations. Sedentism also secured prosperous territories from other Natufians, and provided the opportunity to modify the land for better returns (e.g., burning of brush) (McCorritson and Hole 1991). By creating a stable life, Natufians amassed resources for social activities[23], and accumulated material goods and wealth. Sedentism

[23] Archaeological indicators for status activities include large cooking or processing apparatuses, remnants of large animals like cows, and unusual animals or materials (Orme 1977, Twiss 2007a, b).

decreased the amount of individual maternal time needed to care for children (e.g., neighbors could watch them), which allowed for more offspring and workers for the land (i.e., increased population) (Orme 1977). The sedentary lifestyle allowed other novel activities to follow, such as domestication.

However, Maher (2010) suggested that people living earlier in the Pleistocene also possessed social complexity and understood the landscape like the Natufian or later Neolithic people. Consequently, ideas thought to be novel in these later periods (i.e., agriculture and animal domestication) may be a continuation or modification of earlier practices. For instance, many Levantine archaeological sites, such as ‘Ain Ghazal (Jordan) (Figure 4.2), had domesticated dogs (Quintero and Köhler-Rollefson 1997, Tchernov and Valla 1997 and references therein). The dog contributed significantly to daily Natufian life as evidenced by human/ dog burials, a practice not performed with other animals (Belfer-Cohen 1991). Dayan (1994) proposed dog domestication developed prior to the Natufian in the Near East after examining tooth morphology from small foxes. Bökönyi (1978) found archaeological indicators for dog domestication in Iran during the Upper Pleistocene. Maher’s hypothesis of earlier knowledge of domestication was supported through genetic evidence pointing to domesticated dogs in the Upper Pleistocene in Belgium (Germonpré et al. 2009). Although dogs' genetic origins are complicated due to the relative newness of many breeds and interbreeding with wolves (Larson et al. 2012, vonHoldt et al. 2010), recent genetic studies show early domestic dogs’ genotypes allowed for starch digestion, an ability wolves do not possess. This genetic change indicates the cohabitation between humans and dogs started early in the dog lineage (Axelsson et al. 2013, see Callaway 2013 and references therein for differing opinions on dog DNA). Therefore, given the archaeological evidence indicating an evolved relationship in the

Natufian, the domestication process was known much earlier in the Pleistocene. Later, large-scale domestication adoption may attest to factors that previous lifeway could no longer support.

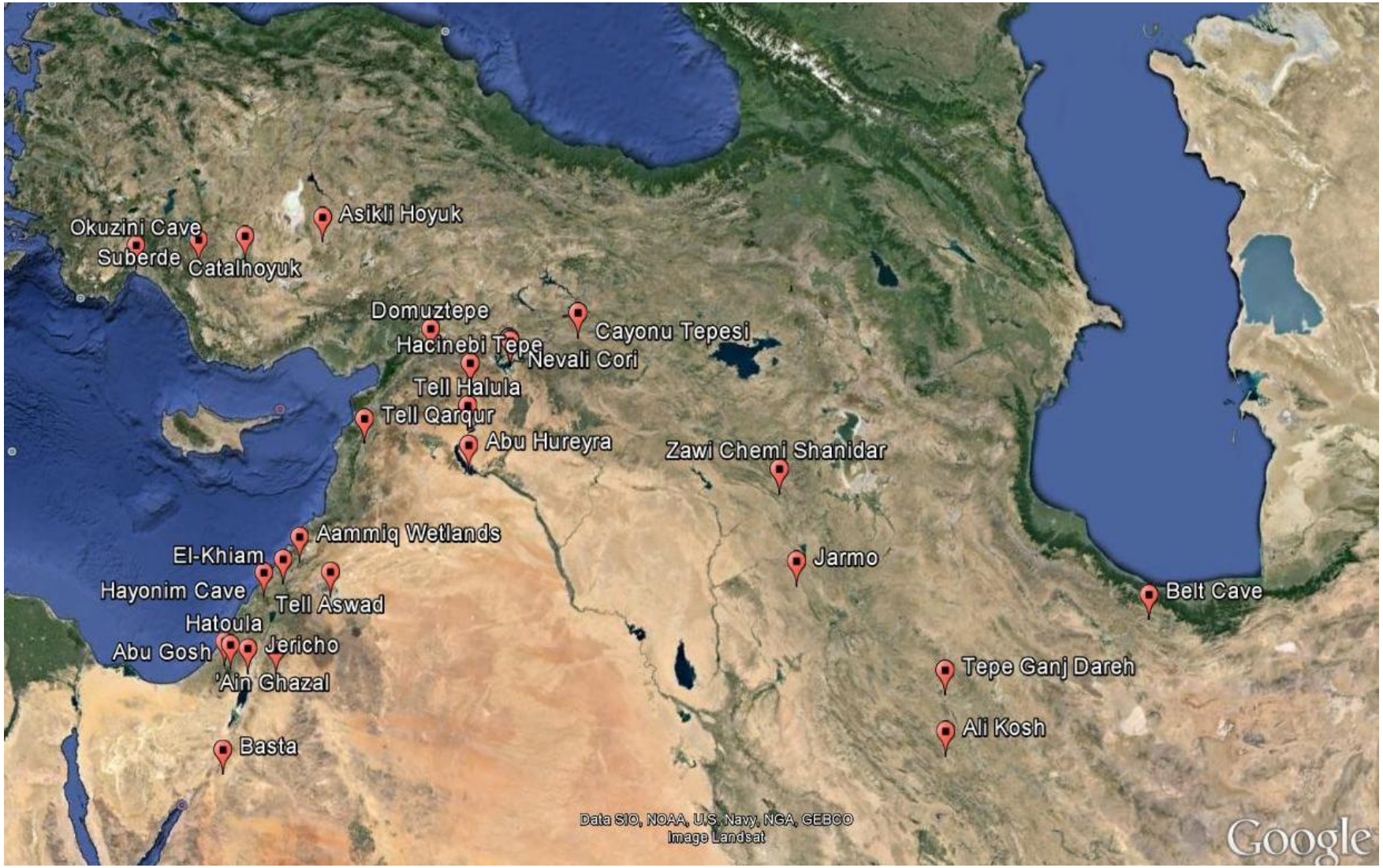

Figure 4.2. Map of archaeological sites discussed in the text. Some sites provided are discussed in other chapters. Created in Google World.

Subsistence: Natufian subsistence included a variety of dietary staples, featuring both plants and animals (Bar-Yosef 1983, Bar-Yosef and Belfer-Cohen 1991). Plant resources included cereals (e.g., einkorn wheat, emmer wheat, and barley), legumes (i.e., beans), nuts, and fruits (Kislev et al. 1992). Archaeologists have recovered indicators for grain processing, such as grinding stones and sickle blades, from numerous Natufian sites (Lieberman 1993). Grinding tool (e.g., mortars, pestles, and grinding stones) use increased from the previous Kebran[24] period (see Adams 1999, Kraybill 1977 for explanation of grinding tools). These grinding tools were used to prepare a wide variety of food including crushing bone to reveal the marrow cavity, preparing foods containing toxins (e.g., acorns), and preparing food for young or old individuals (Hayden 1981, Bar-Oz 2004). Use-wear analyses of Natufian grinding tools indicated cereal and legume processing (Dubreuil 2004, Valla 1995). Source materials for grinding stones were part of the Natufian trade network, as one basalt tool was discovered 100km away from its source (Byrd 2005). Although development of grinding tools occurred prior to the Natufian, sickle blades appeared then for the first time. Sickle blades allowed Natufians to maximize harvest efficiency by threshing, permitting quick grain collection (Bar-Yosef 1998a, Bar-Yosef and Belfer-Cohen 1992, Belfer-Cohen 1991, Byrd 2005). Increased harvest levels led to some Natufian homes featuring storage areas or lined storage pits (Akkermans and Schwartz 2003, Bar-Yosef 1998a, Henry 1991, Valla 1995). However, Redding (2005) postulated the storage areas facilitated early animal keeping. In either case, storage areas attest to increased resource returns and developing agricultural activities.

In addition to finding archaeological evidence for grain processing, human dietary

[24]Carter (1977) states the first grinding stones date back 100,000 years ago. In the Old World, evidence for grinding occurs at 40,000 years (Carter 1977, see also Kraybill 1977 for other dates).

reconstructions, such as dental microwear analysis, indicate an increased role of grain in Natufian diet (Anderson 1991, Smith 1991, Smith et al. 1984, see Sillen and Lee-Thorp 1991 for opposing isotopic information). Debates continue as to whether grains consumed were wild, cultivated, or domesticated. At the Natufian-Neolithic site of Abu Hureyra (Syria), researchers discovered domestic rye grains from Natufian levels (Hillman et al. 2001). However, many researchers do not agree with this conclusion due to the limited number of rye grains found and their stratigraphic context (Hillman et al. 1989, Kislev et al.1992, Willcox 2004). Willcox et al. (2009) found seeds morphologically similar to seeds from domesticated plants developed after the Younger Dryas, indicating domestication occurred after the Natufian. Opposingly, Rossignol-Strick (1995) suggested these morphological changes after the Younger Dryas resulted not from domestication but from plants adapting to the cool, dry conditions. On the other hand, morphological changes to domestic grains may have lagged behind the actual domestication event (Willcox and Savard 2011). If morphological changes trailed behind, plant domestication may have transpired prior to the Younger Dryas or even the Natufian. There is currently no consensus on when plant domestication arose. Belfer-Cohen (1991) indicate the Natufians were the first farmers, Bar-Yosef (1998a, 2011) consider them proto-farmers (i.e., cultivators), and other researchers (e.g., Akkermans and Schwartz 2003) believe farming began during the Neolithic period after sedentism occurred. These differences in ideas can be applied to animal husbandry/ domestication as well.

Meat entered into the Natufian diet through specialized hunting and collecting techniques. For example, hooks and net weights denote Natufian fishing, and arrowheads attest to distance hunting (Mellaart 1975, Cauvin 2000). Desert kites helped capture ungulates (e.g., gazelles, goats, and sheep). Animals were funneled into a fenced in area and jumped over a wall

to their death. The cooperation required to use kites hints at Natufian society's development and growth, possibly laying down the foundation for later cultural developments (Capana and Crabtree 1990, McCorriston and Hole 1991, Moore 1991, see Edwards 1991 for interpretation critique). Cope (1991) examined Natufian gazelle (*Gazella* sp.) bones using traditional zooarchaeological techniques (discussed later), and determined proto-domestication[25] resulted from Natufian specialized hunting techniques (i.e., desert kites) (see Mendelssohn 1974, Rosen and Perevolotsky 1998 for opposing desert kite view). Bender (1975), Bökönyi (1976), Legge (1972), Moore (1982), Noy et al. (1973), Vita-Finzi and Higgs (1970), and Zeuner (1955) also suggested ungulate management by Natufians. However, Simmons and Ilany (1975), who conducted field research on gazelles in Israel, countered the idea of gazelle domestication. They concluded the Natufians understood the predictable gazelle behavior. Therefore, purported gazelle domestication indicators stemmed from this knowledge, such as increased male kills due to hunters following all-male bachelor herds as opposed to male culling (Simmons and Ilany 1975, see also Sapir-Hen et al. 2009). Furthermore, Dayan and Simberloff (1995) reexamined Cope's data and found no statistically significant trait difference occurred between the Natufian and other periods.

Whether or not Natufians managed gazelles, gazelle remains dominate core Mediterranean sites' faunal remains. Sheep, goat, and equid numbers were greater in peripheral areas (Legge 1972, Moore 1991). Birds, fish, and other land animal exploitation was not as common either (Byrd 1989). However, animal frequencies varied between sites due to different environments, a trend found into the Neolithic as well. For example, in southern Levantine sites,

[25] Proto-domestication developed from loss of female choice as Natufians killed the males. This hunting selection reduced the gene pool, leading to morphological changes to the herd similar to domestication (e.g., reduced size) (Cope 1991).

goats dominate faunal remains, while sheep are a rare occurrence until the Pre-Pottery Neolithic B. The sheep assimilated into the subsistence strategy as domesticates, originating in northern Levant (Horwitz and Ducos 1998). Northern sites displayed the opposite pattern, with sheep outnumbering goats until after large-scale domestication occurred during the Neolithic (e.g., Abu Hureyra) (Moore et al. 2000). As noted earlier, each population partook in different subsistence strategies, allowing individuals to survive their local environment (i.e., adapt) (Bökönyi 1978, Byrd 2005, Legge 1980, Moore 1991, Seguí 2000, Valla 1995). Therefore, animals utilized appear to vary with the environment in which the Natufians lived. This idea is especially important towards the end of the Natufian period (e.g., Younger Dryas).

Through the course of the Natufian, animal frequencies within sites changed too. Over time, higher quality resources were depleted through density dependent factors (e.g., population growth), independent factors (e.g., environment), or a combination of both dependent and independent elements. These factors led to increased use of lower quality, labor-intensive foods, such as acorns that required substantial processing before consumption. Fast, small animals, which were difficult to catch and provided little meat, became more common (Figure 4.3) (Horwitz and Tchernov 2000; Lieberman 1993; Munro 2003, 2009a, b; Valla 1995). Archaeological indicators for Natufians undergoing these pressures included increased bone processing (e.g., extracting marrow). Processing comprised of bones previously not exploited, due to either low nutrition levels or high effort required to obtain the resource. For instance, gazelle phalanges contain very small marrow amounts. This processing for marrow displayed increased need to obtain the most return from resources (Davis 1982; Munro 2009a, b). Subsistence stress markers in the archaeological record also included increased numbers of young animals, such as gazelles. Increased hunting removes normal biological population

constraints due to limited food supplies, and the population attempts to maintain itself through increased reproduction. Therefore, more juvenile animals created the overall population and available animal resources (Munro 2009a).

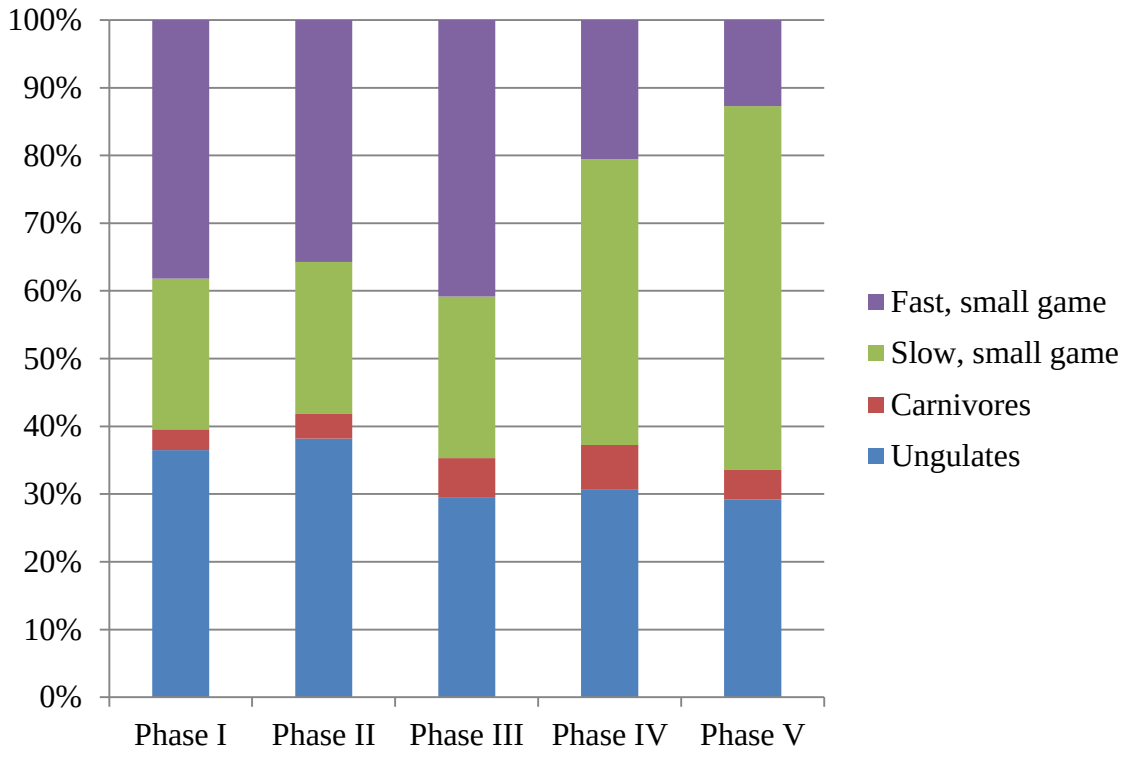

Figure 4.3. The faunal distribution demonstrating shifts in animal preference during the Natufian phases from Hayonim Cave (Israel). The early Natufian is represented by phases I - III, and the late Natufian by phases IV and V (adapted from Stiner and Munro 2002).

The main environmental stressor for the Natufians was the Younger Dryas event, which brought colder, dryer conditions to the Near East (Munro 2003)[26]. The natural vegetation changed, leading to animal population shifts. The resource changes forced the Natufians to modify subsistence strategies (Lieberman 1993, Munro and Atici 2009). Natufians either remained sedentary and began the initial planting of cereals, or returned to a mobile way of life (Bar-Yosef and Belfer-Cohen 2002). Information on the Younger Dryas and its effects come predominantly from southern archaeological sites. However, what occurred in the south may not be the same as what happened in the north, or provide an accurate subsistence model for the whole Near Eastern Natufian (Kuijt and Goring-Morris 2002, Simmons 2000). For example, Rindos (1984) found that the increased use of less desirable animals was not due to stressors. Instead, Natufians settled in high resource dense areas and found a more effective (less-energy cost) method of obtaining resources. Natufians used the entire range of animals within their settlement (optimal foraging strategy) (Rindos 1984). This strategy would provide similar archaeological profiles as other explanations for faunal shifts. Regardless of root cause, the late Natufians adjusted their subsistence to utilize a wide range of resources. This broad-spectrum subsistence strategy continued into the next Near Eastern cultural period.

Pre-Pottery Neolithic A (ca. 11,700-10,500 B.P.)

Settlement and Society: The term Pre-Pottery Neolithic (PPN) stems from Kathleen Kenyon's 1950s work at Jericho (Palestine). Assemblages recovered followed the established definitions for Neolithic archaeological phase except they lacked pottery. Therefore, Kenyon

[26] The Younger Dryas is in opposition to what occurred previously, the Bølling-Allerod climate change. During this period, the temperatures were warmer and wetter (Byrd 1989, 2005; Munro 2004, 2009a).

coined the term Pre-Pottery Neolithic. Most Near Eastern researchers accept and use PPN, and this cultural designation will be used here as well. The cultural divisions within the PPN (A, B, and C) are not as widely accepted due to northern versus southern cultural differences (e.g., Final PPNB used in place of PPNC) (Akkermans and Schwartz 2003).

The Pre-Pottery Neolithic A (PPNA), the first PPN cultural phase, followed the Natufian. The majority of PPNA sites were located in the Mediterranean Levant especially the Jordan Valley, Damascus Basin, and around the Euphrates and Tigris Rivers (Byrd 2005, Kuijt and Goring-Morris 2002). The number of settlement occupations increased in southern Turkey and into northeastern Levant. The spreading of sites may relate to climate amelioration following the Younger Dryas (Preboreal climate phase), opening up more land capable of supporting human settlements due to warmer and wetter conditions (Byrd 2005, Willcox and Savard 2011). Typically, PPNA sites developed close to water resources (Byrd 2005). Within settlements, the number of structures grew, indicating increased sedentism (Kuijt and Goring-Morris 2002). The archaeological record supports year-round sites through faunal remains (e.g., animals recovered from all age ranges) (Bar-Yosef and Meadow 1995). Furthermore, house structure shape changed, with circular homes replaced by square ones (Bıçakçı 1998). At Jericho, inhabitants constructed an 8-meter tall stone tower and wall, moving beyond domestic structures into communal. However, the reason behind this monumental structure is unknown, although hypotheses put forth include settlement defense, a barrier from flooding, and ritual space (Munro 2003, Goring-Morris and Belfer-Cohen 2011).

Subsistence: During the PPNA, resource exploitation focused on local resources (e.g., waterfowl) (Bar-Yosef and Belfer-Cohen 1992, Byrd 2005, Kuijt and Goring-Morris 2002). The

small game index for PPNA indicated an increased level of small, fast animal exploitation, higher than the Early Natufian. This resource exploitation close to sites suggested the need to stay close to cultivated land (Legge 1980, Munro 2003). In addition, Byrd (2005) noted changes in subsistence strategies increased the importance of family units, as the family unit was linked to food production. The increased faunal exploitation may have initiated animal domestication to meet the population's meat needs (Bar-Yosef and Meadow 1995, Legge 1980). Trade networks included food as well as knowledge across the Levant (Bar-Yosef and Belfer-Cohen 1992).

The PPNA also provides evidence for incipient cereal and legume cultivation (or an intensive use) along with continued hunting and gathering (e.g., wild game, fish, birds, reptiles, fruits, and seeds) (Bar-Yosef 1991, Belfer-Cohen and Bar-Yosef 2000, Cauvin 2000). The amount of cultivated versus wild resources incorporated within the diet is unknown. For instance, Twiss (2007) found cultivated plants only supplemented gathered resources, while Byrd (1992) reported a modest reliance on cultivated plants. Silos found at sites indicated surplus crops (Goring-Morris and Belfer-Cohen 2011). Importance was placed on these resources as modifications to granaries kept rodents out, allowed air circulation, and provided areas for grain processing (Kuijt and Finlayson 2009). As compared to the Natufians, people during the PPNA exhibited higher incidences of dental caries, periodontal disease, and antemortem tooth loss. These dental pathologies reflect increased dependence on carbohydrates (i.e., grains), and food processing without pottery (Smith et al. 1984, see Eshed et al. 2006 for opposing view on these findings). For instance, Bar-Yosef and Belfer-Cohen (1991) noted increased amounts of fire-cracked rock, indicating a change in food preparation. Heated rocks allowed individuals to boil food. This heating technique rendered toxins out of plants. In the

case of meat, fats and other nutrient rich parts became accessible (Hayden 1981). Molleson and Jones' (1991) dental microwear analyses on Abu Hureyra inhabitants indicated a shift as well. They concluded Natufian diet was composed of more roots while PPNA individuals ate more grains (see also Mahoney 2006, Molleson et al. 1993 for microwear examination). The overall dental wear rates also changed between the periods. Natufians exhibited flat occlusal wear while Neolithic people possessed angled wear. This dental wear change probably reflects a decrease in dietary toughness or a change in the food processing (e.g., fire-cracked rocks, grinding instruments) (Belfer-Cohen and Hovers 2005, Eshed et al. 2006). PPNA grinding tools were transitional between the Natufian mortars and pestles (pounding instruments) and Neolithic querns and hand stones (grinding instruments) (Belfer-Cohen and Hovers 2005, Kuijt and Goring-Morris 2002).

Pre-Pottery Neolithic B (ca. 10,500-8,700 B.P.)

Settlement and Society: The Pre-Pottery Neolithic B (PPNB) divides into Early, Middle, and Late, based on changes in lithic technology. The PPNB followed different trajectories within the Levant (Bar-Yosef and Meadow 1995). In the north, PPNA cultures transitioned to PPNB. Archaeological evidence points to successful, growing populations (Goring-Morris and Belfer-Cohen 2011, Legge 1980). However, in the southern Levant, there was an abrupt end to the PPNA sequence, as sites were deserted and reestablished in other geographic areas. New sites shifted eastward into marginal desert zones (Kuijt and Goring-Morris 2002). The reason for site abandonment is not known, although hypotheses range from climate change, to disease, overexploitation/ reduction of resources, or inter/ intra-site conflict (Bandy 2004, Belfer-Cohen and Goring-Morris 2011, Goring-Morris and Belfer-Cohen 2011). The PPNB resumed in the

south after approximately 400 years, when the middle PPNB occurred in northern Levant (Belfer-Cohen and Goring-Morris 2011, Goring-Morris and Belfer-Cohen 2011).

As the Near Eastern PPNB progressed, the number of sites increased. Settlements varied in size, form, and location, reflecting a cultural shift towards agriculture (Akkermans and Schwartz 2003, Harris 2002). Material culture also reflected a shift, with Natufian animal figurines replaced by female figures, conceivably reflecting fertility (Bar-Yosef and Belfer-Cohen 1989b, Bar-Yosef and Meadow 1995). Like the past periods, resources, ideas, and people were not localized. Large sites, such as Abu Hureyra, served as exchange posts for objects. For instance, continued seasonal use of desert kites occurred, allowing people to gather a large amount of meat with little effort. This meat then could be used within the exchange networks (Bar-Yosef and Belfer-Cohen 1989a, b; Legge and Rowley-Conwy 1987; Rosen and Perevolotsky 1998).

Water continued to play a pivotal role in settlement location, but arid areas also supported occupations. The latter were predominantly seasonal hunting camps, used only when animals were present (e.g., during migration) (see Chapter 3) (Kuijt and Goring-Morris 2002). Within settlements, houses continued to be rectangular. Rooms became compartmentalized, indicating specialized function was ascribed. For instance in rooms utilized for crop storage, lime plaster, a PPNB innovation, lined the floors (Akkermans and Schwartz 2003, Harris 2002, Kuijt and Goring-Morris 2002, Rollefson 1996). These house designs continued through many generations, with new houses rebuilt over old ones following the same plan (Akkermans and Schwartz 2003). Hodder and Cessford (2004) believed this reconstruction practice created social memory/ rules and helped synchronize daily practice. In addition to residences, non-residential architecture became more common (Kuijt and Morris 2002). For instance, at Ç atalhöyük

(Turkey), communal architecture included pens around the site's periphery. Pens provided a place to store animals when not being herded, or during the winter, when animals needed to be foddered (Atalay and Hastorf 2006). Increased feasting provides evidence for the importance of community, serving as an integration mechanism for populations (Twiss 2008b). Charnel houses indicate another communal activity, where remains of many individuals were placed in one location (Bellwood 2005). This increased focus on community reflects a level of resources available to sustain numbers beyond the family unit, and foster a culture beyond basic adaptation to subsistence.

Subsistence: By the PPNB, the "Neolithic Revolution" had occurred, with the adoption of agriculture (domesticated plants and animals), although hunting and foraging still transpired (Akkermans and Schwartz 2003, Horwitz and Tchernov 1998). Not all scholars believe the Neolithic Revolution was a true revolution, especially since incipient agriculture had taken place prior to the Neolithic, and domestication ideas had occurred as early as the late Paleolithic (discussed previously) (e.g., Maher 2010). Instead, the Neolithic Revolution may be better defined as a change in the intensity/scale of agriculture, bringing about archaeological indicators for large-scale agriculture (Tudge 1999). The adoption of domesticated products and the use of wild resources varied between sites (Ingold 1986, Monahan 2000, Rollefson 2001) (Figure 4.4). In fact, some sites did not adopt domesticates during the PPNB, as evidenced by archaeological faunal remains still indicating hunting of wild animals (Ducos 1969, Kuijt and Goring-Morris 2002, Lösch et al. 2006, Moore 1982, Willcox and Savard 2011). For example, at Nevalı Ç ori (Turkey) isotopic analyses indicates that although inhabitants possessed domesticated animals, they did not rely on their stock for subsistence. Instead, isotopes reveal a vegetarian diet with

protein provided by pulses (legumes), as indicated by nitrogen isotope levels (Lösch et al. 2006). Seasons influenced the use of domesticated goods as well. At Gritille (Turkey), hunting increased during the winter because of the uncertainty of the winter and spring. In the winter, penning of animals placed them in crowded, harsh conditions where diseases quickly spread. Further, the farmer did not know whether spring rains and favorable growing conditions would occur[27]. Therefore, residents preserved domesticated resources by utilizing wild animals migrating to lowlands around the site (Stein 1989). Because of the vast supply of wild resources at Ç ayönü (Turkey), full adoption of a domestic-based economy took 1,000 years after initial use of husband animals (Hongo et al. 2002).

[27] Researchers believe that Neolithic farmers planted crops during the winter months (October to December) and harvested them during April and June (Akkermans and Schwartz 2003).

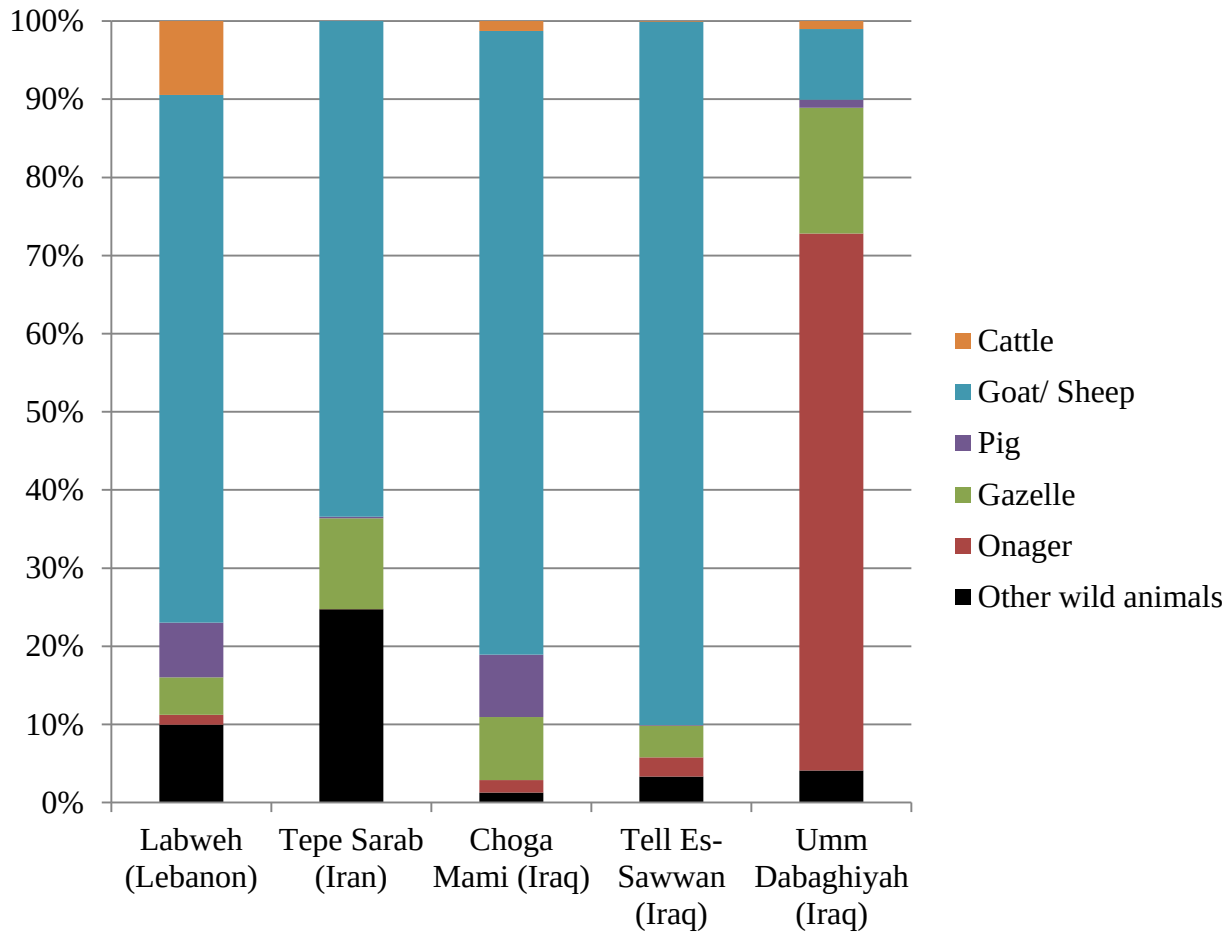

Figure 4.4. Graph indicating the animal usage from sites around the Near East. Animals on the graph include the main domestic animals of the Neolithic (cattle, sheep, goat, and pig) and wild animals (onager, gazelle, other) (modified from Bökönyi 1978).

Different plants and animals were domesticated at different times and places in the ancient Near East. The first domesticated plants included einkorn wheat (*Triticum monococcum*), emmer wheat (*Triticum turgidum dicoccum*), barley (*Hordeum bulgare*), lentils (*Lens culinaris*), peas (*Pisum sativum*), chickpeas (*Cicer arietinum*), bitter vetch (*Vicia ervilia*), and flax (*Linum usitatissimum*) (Weiss and Zohary 2011, Zohary 1996, see also Abbo et al. 2013). Querns became more common during the PPNB. These lighter grinding stones provided a larger surface area for efficient processing of materials (Belfer-Cohen and Hovers 2005, Kuijt

and Goring-Morris 2002, Wright 1994). Smaller instruments indicate a shift away from communal processing towards family production (Belfer-Cohen and Hovers 2005, Kuijt and Goring-Morris 2002). Mortars are rare in the record, although archaeologists have recovered numerous hand stones used for both pounding and grinding (Kuijt and Goring-Morris 2002).

Researchers have proposed that crop by-products were provided to the animals as feed (Weiss and Zohary 2011). Domesticated animals comprised of cows (*Bos taurus),* goats (*Capra hircus*), pigs (*Sus scrofa*), and sheep (*Ovis aries*) (Bogaard 2005, Legge 1996, Weiss and Zohary 2011, Wasse 2001, Zeder 2011). Sheep and goats were domesticated prior to pigs and cattle (Akkermans and Schwartz 2003, see Redding and Rosenberg 1998 for different pattern). Previous thought maintained plants were domesticated 1,000 years before animals (e.g., Braidwood et al. 1981, Bar-Yosef 2000, Bar-Yosef and Meadow 1995, Price and Bar-Yosef 2011). However, current archaeological and genetic evidence suggest domestication of plants and animals occurred around the same time. For instance, domesticated animals and plants were brought to Cyprus, an island in the Mediterranean, at the same time from Turkey. This evidence indicates that during the PPNB or earlier, both animals and plants were together as an agricultural construct (Bogaard 2005, Vigne et al. 2011, Wasse 2001 and references therein, Zeder 2011).

Pre-Pottery Neolithic C (ca. 8,600-8,250 B.P.)

Settlement and Society: Near Eastern locations experienced the end of the Pre-Pottery Neolithic differently due to a variety of factors (e.g., environment) (Rollefson 1998, 2001; Simmons 2000). This inconsistency affects the designation of the last PPN period. Some researchers believe not enough significant cultural change transpired to warrant a separate

designation (PPNC). Instead, the term Final PPNB is preferred (Bar-Yosef and Meadows 1995). This dissertation utilizes Pre-Pottery Neolithic C (PPNC) to avoid the nuanced divisions within the debate.

Regardless of designation, changes occurred between the middle and end of the PPN. Settlement patterns and building construction changed from the PPNB, such as a decrease in the use of lime-plastered floors. Human health worsened, as evidenced by an increase in infectious disease markers in preserved skeletal remains (Angel 1984). Burial patterns also change, with an increased number of secondary burials (i.e., remains removed from their original burial locations and reburied elsewhere). During the PPNC, some archaeological indicators signal environmental deterioration, specifically another cool, dry event (Berger and Guilaine 2009, Bıçakçı 1998, Eshed et al 2010, Goring-Morris and Belfer Cohen 2010, Köhler-Rollefson 1988, Kuijt and Goring-Morris 2002). In the Mediterranean core area, the human population contracted in space, with only a handful of sites continuing into the Pottery Neolithic (Kuijt and Goring-Morris 2002). Even long occupied settlements, such as Jericho, were abandoned (Rollefson 1998, 2001). Explanations for settlement changes include families moving closer to the land they worked to meet increased agricultural need. On the other hand, increased social hierarchy in the PPNB, or other social issues, may have caused too much strain within the society, which could also explain the collapse (Twiss 2007b). Archaeological indicators for feasting (e.g., faunal remains) decrease during the PPNC, supporting this idea (Twiss 2008b). Another explanation includes over-exploitation of farming and grazing lands along with deforestation[28]. These agricultural practices degraded the environment, especially in the southern Levant. The land

[28] Wood served a variety of purposes in the Neolithic. Wood was used in building, plaster production, and even animal fodder (Rasmussen 1989, Rollefson and Köhler-Rollefson 1989). During the PPNC, house structures were modified to reduce wood structural supports (i.e., no post-holes) (Rollefson and Köhler-Rollefson 1989).

could not support the population using non-sustainable agricultural practices (Flannery 1969, Goring-Morris and Belfer-Cohen 2010, see Campbell 2010 for opposing view of farming practices). Köhler-Rollefson (1988, 1992) believes sheep husbandry in the north allowed settlements to continue. The south relied on goats, a destructive animal to both crops and wild resources, leading to sites' downfall (e.g., 'Ain Ghazal) (Köhler-Rollefson and Rollefson 1990). Climate change may have aggravated the already stressful conditions (Berger and Guilaine 2009, Goring-Morris and Belfer-Cohen 2010, Köhler-Rollefson 1988). This is especially true in marginal areas (e.g., semi-desert steppes) where slight environmental or synthetic changes have huge impacts on resources (i.e., change steppe vegetation into desert) (Köhler-Rollefson 1992). However, deserts exhibited continued occupation, hinting at the development of pastoralism (Kuijt and Goring-Morris 2002, Harris 2002, Twiss 2007b). Pastoral economy provides separation of destructive herd animals from crop resources, while maintaining the needed protein resources (Köhler-Rollefson 1992, Köhler-Rollefson and Rollefson 1990). Whatever the reason, the end of the PPN provides evidence for the Neolithic populations adjusting their adaptations to survive new cultural circumstances.

Subsistence: Domesticate usage increased during the PPNC at the expense of wild species (Kuijt and Goring-Morris 2002). At 'Ain Ghazal the exploited species number decreased from 52 at the beginning of the Neolithic to only 12. Of these, four species were domesticated while eight were wild. The majority of the wild species were steppe or desert adapted, indicating that the environment around 'Ain Ghazal changed. Either the species around the site shifted, or hunters had to go further to procure wild animals (Rollefson and Köhler-Rollefson 1989). Cattle and pig numbers rose, due to the later domestication date, their ability to meet new agricultural

needs (e.g., plowing), or the use of these animals in ritual contexts (Kuijt and Goring-Morris 2002). In addition, preference of ovicaprids (i.e., sheep and goats) changed, from goats to sheep. Goats destroy vegetation, creating a need to separate agricultural interests (Rollefson 1996, 2001). Bogaard (2005) postulates sheep were favored due to their better ability to graze on farmers' fields, and leave behind profitable manure. However, the viability of this practice may not overcome environmental issues, like soil erosion and the weather (Simmons 2000). Within the archaeological record, grain-grinding stones are scarce (Rollefson and Köhler-Rollefson 1989). Whatever the reason behind subsistence changes, innovations emerged to provide a profitable economy and framework for the Pottery Neolithic.

Pottery Neolithic (8,250-7,300 BP)

The Pottery Neolithic (PN) followed the PPNC. Fired pottery, for utilitarian (e.g., food) and symbolic use, marked the period. Phases within the PN are based on local ceramic traditions. For instance in Jordan, the first PN period is called the Yarmoukian. This pottery style, found in northern Jordan only, used a banded herringbone impression (Rollefson 2001). The Amuq culture occurred elsewhere in the Levant. During the middle PN, Halaf culture spread from the west and replaced the Amuq tradition. Like other cultural periods in the Near East, the Halaf period abruptly ended. The Ubaid culture from the east replaced much of the cultural and technological advancements (Mellaart 1975).

Technology for pottery creation came from previous PPN innovations, such as mud bricks and plaster. Plaster had a wide range of functions, including lining rooms for storage, figurines, creating plaster skulls, and beads (Bar-Yosef and Meadow 1995, Kingery et al. 1988, Rollefson 1996, 2001). Other technology in the PN included spindle whorls, showing expansion

of animal exploitation for products beyond meat (e.g., using wool) (Gopher 1995). Further genetic changes occurred to domestic animals to fulfill these secondary roles, such as retention of year-round wool (Sherratt 1983, see Vigne and Helmer 2007 who postulated milk played a role in domestication). For example, wild animals do not lactate excessively beyond their young's requirement. Therefore, the ability to lactate to provide milk had to be selected for over many generations (Davis 1987, Sherratt 1981). Animals used for wool production were selected to retain juvenile coat features[29] throughout life (Isaac 1970).

Domestication Theories

Many definitions for domestication have been proposed (see Chapter 1), based upon many differing theoretical viewpoints. Similarly, there are numerous hypotheses as to why domestication occurred in the first place. While domestication has been studied for years, no one hypothesis has been universally accepted (Gebauer and Price 1992). The brief summation below examines reasons why domestication occurred, highlighting main ideas proposed. We may ultimately find all of these hypotheses initiated domestication, a combination of some, or perhaps something entirely novel.

Carrying Capacity and Population Increase

Some researchers postulated that population increase was the driving force behind domestication (Boserup 1965, Cohen 1977a, Dumond 1965, Herre and Röhrs 1977). Increasing populations reached beyond the land's carrying capacity, bringing about a decline in the amount

[29] Specifically, these features included the removal of the outer kemp layer, which exposed finer wool, and ending spring molting had to occur in order to use hair for spinning (Davis 1987, Redman 1982, Ryder 1969).

and quality of food available to feed populations. Several methods can prevent people from reaching the land's carrying capacity, including population control (e.g., birth control). Increasing the exploited territory augments resources, but requires more time and effort to obtain resources. Returning to a more mobile lifestyle may be required. On the other hand, the population may rely on less desirable resources for nourishment. These solutions all have a natural limit until they too are too costly to maintain. The population then must turn to new methods for increasing available resource yields (i.e., domestication) (Bar-Oz 2004; Cohen 1975, 1977a, b; Davis 1991, 2005; Earle 1980). Earle (1980) suggested that agriculture did not accrue limiting costs as quickly, allowing intensification to handle society's needs. Cohen (1975, 1977a, b) believed that because population growth was universal, continuous population growth could be a basis for domestication.

Redding (1988) presented a four-step process for the origin of agriculture that was based on the biological concepts of *r*- and *K*-selection[30] and population growth models. Step one occurred when a hunter-gatherer group first moved into an area. Because no growth limits were present, the population would reach the land's carrying capacity. When resources declined, natural population regulation occurred or step two took place. In step two, the group diversified utilized resources, such as increased use of fast-moving animals (as discussed earlier for Natufian and PPNA periods). The population again either regulated itself through natural controls, or transitioned to step three. In step three, new technology and storage techniques were used. If the population did not regulate itself successfully and continued to grow, step four began with manipulation of resources and ended in domestication (Redding 1988). When

[30] The *K*- and *r*- selection are biological concepts relating to parental investment within a population. Humans are *K*-selected, placing significant amounts of resources and energy into offspring production and survival (Redding 1988).

examining the archaeological population, one finds health decreased when people turned to farming. However, domesticated crops supplied enough nutrition that women were still able to reproduce. Although skeletal remains indicate childhood was difficult, children survived beyond childhood and reproduced. Later technological advancements allowed populations to achieve better health (Angel 1984).

Binford (1968) found that populations naturally stayed under the land's carrying capacity by examining ethnographic evidence. If population changes occurred, the culture would adapt. However, if another population came into an already populated area, the natural equilibrium was upset, as the new group relied on the same resources. In order to continue in marginal environs (e.g., steppes), people turned to new adaptations, like domestication. This so-called "tension zone" hypothesis also explains domestication around the world, since tension zones occurred in any environmental area (Binford 1968). Following Binford (1968), the "broad-spectrum revolution" occurred in marginal zones. Disequilibrium was caused by non-natural population growth, such as new people entering the community. All resources around the community were collected, including seasonal resources (similar to Redding (1988) step 2). Animal domestication was a method to "bank" a resource more stable than plants, which were easily affected by environmental changes (Flannery 1969). Davis (2005) called the heavy exploitation of resources the "demographic pressure hypothesis". To support this idea, Davis points to increased number of juvenile remains (e.g., gazelles) in the archaeological record. More juveniles reflect population turnover due to overhunting (Davis 2005, see also Rosen and Rivera-Collazo 2012, Stiner et al. 2000). Domestication then would be the natural outgrowth of this increased use of all available resources in the area (Diamond 2002).

Issues: Although ethnographic examples play an important role in developing ideas, they may not precisely replicate the past. When modern populations choose sedentism, structures are in place for consistent food supplies and care for individuals. In the Neolithic, food was not a guarantee so population growth may not have occurred (Bender 1978, Asouti and Fairbairn 2010, see Cohen 1975, 1977b for differing view). Further, modern hunter-gatherer populations maintain population levels even during times of stress without turning to domestication (Hayden 1981, Wilkinson 1981). Hassan (1975) noted a delicate balance existed between a population's size and the amount of land that could be exploited before issues arose. Through population and cultural controls, a natural check was placed upon the population limiting growth (Hassan 1975). As Hassan (Hassan and Sengal 1973) emphasized, population growth only occurs after there are more than enough resources available to feed a growing population (e.g., more protein sources for women to support birth). Wilkinson (1981) also questioned population pressure causing domestication since developing domesticated crops requires time. The population would starve before domestication resources could be successfully developed. Development of trade, domestication, and other inventions were an outgrowth of natural attempts to sustain and provide security to populations (Wilkinson 1981).

Domestication occurred independently in several areas (Americas, Asia, and Near East). However, these societies maintained different population levels, let alone resources (Hayden 1981). Cauvin believed that population growth and resource reduction were not a logical explanation for agriculture by examining PPNA site distribution and size. Sites during this period do not appear overpopulated or stressed (Cauvin 2000). However, Henry (1989) noted that later factors like dam building obscured the archaeological landscape. Modern landscape changes then may obscure greater populations than known through sites. Binford questioned his

"tension zone" hypothesis years later. He cautioned that domestication theories centering on specific resource diminishment, as other parts of the world had the same resource but did not domesticate. Cultures only change when no longer able to adapt to their situation (Binford 2002).

Neeley and Clark (1993) ran a computer simulation, and found the broad-spectrum revolution was supported by archaeological evidence. Their experiment and results were contra Edwards (1989b) and Henry (1989), who found animal exploitation did not increase during the Natufian and Neolithic periods. Instead, Edwards and Henry believed that animal exploitation remained constant, all the way back to Neanderthals. The archaeological record appears differently because refuse builds up in sedentary occupations rather than spreading across the landscape (Edwards 1989a). Henry (1989) questioned recovery methods when comparing sites as well, as excavation collection procedures vary. In addition, he noted that even if small animals were used, their small size contributed minimally to diet. Even with the increase of smaller animals, larger animals still provides the bulk of the diet (Henry 1989).

Climatic Change

Worsening environmental conditions are often cited as the force behind domestication. Hunter-gatherers had several options when climate change occurred at the end of the Natufian. One option was to increase mobility, either by increased travel distance to gather resources or move between favorable resources. On the other hand, sedentism allowed populations to defend limited natural resources from others. This strategy brought about innovations[31] to aid in increasing resource yields and ultimately domestication (McCorriston and Hole 1991).

[31] Inventions noted in the archaeological record included sickle blades and animal corrals (Bar-Yosef 2011, Bar-Yosef and Belfer-Cohen 1992).

Similarly, Henry (1989) and Bar-Yosef (2000, 2011) suggested that domestication was an outgrowth of experiences. Natufians learned to utilize fully the resources of the land during favorable climate conditions. When climate changed (worsened), further adaptations occurred to maintain the populations building upon past experiences, which led to domestication (Bar-Yosef 2000, 2011; Henry 1989). Penning of wild animals served as assurance for meat and other materials, such as hides (Bar-Yosef 2000). Rosen and Rivera-Collazo (2012) noted that Natufian domestication ideas were part of the social memory of past periods of climatic trouble, and not due to trying to make the most out of favorable climatic conditions.

A variety of environmental triggers have been put forth by researchers. Duerst (1908) believed that desiccation caused animals to flock to oases. The intersection of humans with animals provided humans the opportunity to domesticate animals, as humans protected food animals from predators (Childe 1939, 1957; Duerst 1908). As climate worsened, humans adopted herd remnants, which provided male, female, old, and young animals to create stocks (Childe 1939). Byrne (1987) believed that climatic change (intense seasonal temperature and precipitation fluctuations) affected plants and animals, as previously noted. This forced new subsistence strategies to meet dietary needs, such as increasing the use of annuals[32] (Byrne 1987). In a similar vein, McCorriston and Hole (1991) found that as climate deteriorated, water levels dropped. Natufians became settled in areas with stable water supplies. However, plants were affected by the climatic change, and new varieties began to grow around the settlements. A change in plants brought about a change in the fauna that fed off the plants (McCorriston and Hole 1991). Animal domestication then was an outgrowth of maintaining favored animals. Hole (1996) postulated that domestication started by humans taking control of nursery herds (i.e.,

[32] Annuals were adapted to grow in the Mediterranean climate: revised growth for the short winter season, large seeds to supply dormancy through the long summer (Bellwood 2005).

mothers and infants). Hunter-gatherers might then have placed these animals along their hunting/ gathering routes. Hole speculated that the herds would then have stayed where they were placed, as natural migration paths were no longer available due to environmental changes. These stranded herds would have provided humans with a reliable meat supply during their transhumance (Hole 1996). Bar-Yosef (2000[33], 2011), and Wasse (2001) cited the Younger Dryas as the main climatic change stimulating domestication. Belfer-Cohen and Goring-Morris (2011) suggested that climatic change caused a bottleneck. The bottleneck served as a catalyst for people to not only adapt to the changing environment but society as well. Different outcomes were produced, because not all populations were the same (northern Levant vs. southern, Natufian vs. PPNA) (Belfer-Cohen and Goring-Morris 2011).

Issues: Benz (2010) questions the duration of the climatic stress. Since the Younger Dryas event was purported to last generations, hunter-gatherers would have undergone stress the first year. However, after several years of stress, people would die, starve, or move. Ethnographic accounts of hunter-gatherers indicate that societal structure creates a situation where movement is not easy during times of stress. Instead, the people living at the beginning of the Holocene had to develop new methods of survival: storage, trade, and investment in resources (domestication) (Benz 2010).

Braidwood (1960), Harris (1977)[34], and Hayden (1981) suggested that climatic change was an insufficient explanation for domestication since climatic changes had occurred

[33] Bar-Yosef (2000) mentioned that decreasing levels of CO^2 in the air influenced not only climatic change but plant growth as well (see also Richerson et al 2001, Sage 1995).
[34] Harris does cite climate change, specifically the Younger Dryas, as the reason behind plant domestication as well as trade networks. Harris finds animal domestication lagged behind plant domestication by at least 1,000 years (Harris 2002).

previously. People adapted to these prior environments, but domestication was not the result. The end of the Pleistocene was not novel in its conditions. Therefore, something else must have happened to spawn domestication (Hayden 1981). Furthermore, climate changes alter resource distribution across the landscape, but resources do not disappear completely. Resources retreat, in most cases, to favorable areas called "refuge areas" (Cohen 1977a). Willcox (2005) believed that vegetation shifts were not very dramatic at the end of the Pleistocene. According to this author, Natufians did not modify their collection methods greatly in order to gather preferred plants. Exchange networks allowed desired plants to be passed among groups. The desirability of certain plants led to purposeful planting and domestication (Willcox 2005). Reed (1960) also noted that humans undergoing a harsh climate shift would not likely have been worried about conserving resources. Instead, humans would have exterminated whatever they came across in order to survive (Reed 1960). Therefore, domestication would not be a result of climate change.

Araus et al. (1999) question what is really known about Near Eastern climate during the period domestication developed. Different reconstruction methods provide diverse environmental models (discussed in Chapter 3). In addition, how humans and animals influenced the environment is not understood (e.g., clearing or grazing the land) (Araus et al. 1999). Ducos (1969) questioned the idea of drying causing domestication. He suggested that animal reduction reflected forest reduction after examining archaeological sites in Palestine. However, other species increased during the same period, such as cows and ovicaprids. These ruminants rely on water supplies, which reflect moisture not dryness (Ducos 1969). Baruch (1994) examined pollen cores from northern and southern Levant, and found different climatic trajectories indicated by the cores. It seems unlikely that climate change alone was the impetus for domestication in both northern and southern Levant if the areas experienced different

climates (Peters et al. 1999). This follows the discussion presented earlier that cultural periods were not uniform throughout the Near East (e.g., PPNC or Final PPNB).

Evolution of Relationships

Budiansky (1992), Galton (1865) and Reed (1959, 1971, 1984) believe that humans did not initially set out to domesticate animals. Instead, domestication developed out of the benefits humans and animals provided one another (Rindos 1984). Symbiotic relationships included keeping animals as pets, using animals as hunting decoys, imprinting of abandoned young onto humans by humans serving as wet nurses, and the use of animals for entertainment, sport, and religious purposes (Galton 1865, Köhler-Rollefson and Rollefson 2002, Reed 1959, 1971). For example, Braidwood (1960) believed that people observed the world around them and developed proclivities. Domestication came about by human desire to have certain animals as pets (Braidwood 1960, Serpell 1989 and references therein). The human/ animal relationship also developed through hunting (Braidwood 1960, Peters et al. 2005, Zeder and Hesse 2000). Hatt (1953) suggested that hunters used tamed animals as decoys, setting the stage for domestication. Harris (1977) and Hesse (1984) suggested that before domestication, humans provided animals salt around fields to obtain animals' dung for fertilizer. Sheep and goats congregated around fields, eating leftovers inedible by humans. Humans provided protection from predators. Humans built on this relationship by copying natural behaviors, and became natural leaders within their dominance hierarchy structure (Budiansky 1992, see also Uerpmann 1996). Reed (1960) and Zeuner (1963) also believed that domestication was a natural, slow outgrowth of human and animal interactions, such as hunting and pet keeping. Herre (1970) supports the idea of hunters being the initial domesticators because current evidence points to dogs being the first

domesticates.

Initial domestication did not take place in one location, because the relationships discussed above occur everywhere. Several areas developed domestication, and the knowledge passed through trade routes. Features, including tameness and ease of handling, would be selected for within the captive population, allowing these traits to flourish over time (Reed 1971, see Budiansky 1992 for opposing view). Higgs and Jarman (1972) preferred not to mark a certain point, such as the Neolithic, for domestication origins (see also Zeuner 1963). Instead, domestication developed as humans adapted, with animals and plants moving into and out of husbandry depending on human need. Therefore, researchers should not focus on place to understand domestication. Instead, domestication research should focus on the economy that occurred, which brought about animal and plant husbandry (Higgs and Jarman1972).

Issues*:* A problem with relationship-based hypotheses stems from preys' natural avoidance of their predator. In this case, humans would have difficulty making connections and gaining the trust of wild animals (Uerpmann 1996). As Curwen (1953) pointed out, although domesticated animal bones were often found at the earliest agricultural sites, this did not mean animals were raised there. Hunters or other nomadic people could have traded their animals for domesticated crops (Curwen 1953). This possible trade movement makes understanding development of relationships more difficult, as origins cannot be placed.

Religion

It has been suggested animals and plants were purposefully selected for domestication because of their role in religious ceremonies. Features selected for in animals included horns and

milk production (Isaac 1962, 1970, see Rodrigue 1992 for opposing view). Isaac (1962, 1970) reported that the first domestic cattle were selected for to recreate the myth of the lunar fertility goddess, which followed ideas put forth by Eduard Hahn. Skin color may also have played a role in selection. Animals were selected for desired features that led to controlled breeding and domestication (Isaac 1962, 1970).

Issues: The main issue most have with religion-based hypotheses is the focus on cattle. Cattle were domesticated later than other animals, like dogs, sheep, and goats (Herre 1970). However, Sauer (1969) noted historical sources in which goats and sheep played a religious role. This role's origin may have extended to prehistoric times (Sauer 1969). These are also entirely untestable ideas.

Sedentism

Sedentism provided opportunities for novel developments towards domestication, such as new technology for storage and obtaining resources. Social structures evolved to maintain a growing community, and people began keeping animals. Redman (1977, 1982) believed that initial animal husbandry was based around herding animals and protecting them from predators. Selected animal breeding, and feeding of non-edible human resources to animals (e.g., harvest remnants) were practiced later (Redman 1977, 1982; see Van Soest 1994: Table 2.7 for plant digestibility between mammals and ruminants). Buitenhuis (1990) and Tchernov (1993) also suggested that sedentism was the catalyst in changing subsistence patterns. Domestication was created to supplement the deficit brought about by hunting and overexploitation of wild resources and environmental degradation brought about by sedentism (Buitenhuis 1990,

Tchernov 1993). This need is recognized in the archaeological record by the quick adoption of sheep and goats outside their normal home ranges (Buitenhuis 1990). Domestication then was a natural outgrowth of human/ animal relationship beginning with sedentism (Tchernov 1998).

Chaplin (1969) and Garrard (1984) suggested that animal domestication was an outgrowth of already established plant agriculture. Perhaps, sheep and goats originally were seen as pests, but, if placed under human control, they benefited farmers (Chaplin 1969). Humans kept animals as a meat reservoir or for prestige. Other uses were found once animals were integrated into the subsistence economy, such as manure for fields, transportation, and secondary products (e.g., wool or milk) (Garrard 1984, see Vigne and Helmer 2007 for different view on secondary products). For instance, legume seeds are more likely to germinate after ingestion by sheep (Russi et al 1992). Halstead (2006) believed that sheep were used as part of crop management as well. Farmers obtained better yields by allowing sheep to graze in certain areas, as sheep provided weed control and checks on crop overgrowth (Halstead 2006, Peters et al. 2005). Landscape degradation was reduced by penning (Harris 1977). Alvard and Kuznar (2001) postulated that animal husbandry was a method of prey conservation, as domestication required a delay in benefits. Sedentism brought about population increase, which in turn caused pressure on resources. Initially, sheep and goats were selected due to their reproductive ability. Both large and small animals were hunted to bridge population needs (Alvard and Kuznar 2001).

Issues*:* Bender (1978) questioned domestication hypotheses that were based on sedentism, as a sedentary lifestyle could not be established without surplus resources. Physical structures needed to be built for storage, animal keeping, etc., requiring large labor pools. In addition, established social structures needed to be present to organize these projects (Bender

1978). Bandy (2004) and Bender (1978) noted that without the correct social structure, groups would break up over conflict. Ducos (1969) discussed the fact that sedentary villages existed prior to evidence for domestication. Therefore, sedentism was not a sufficient reason for domestication (Ducos 1969). Higgs and Jarman (1969) echoed this perspective by noting evidence of plant husbandry without domestication in the New World. Redding and Rosenberg (1998) also felt that sedentism and environmental degradation were not sufficient reasons for domestication. They believed animals were first used as stores. People kept a few animals while maintaining a hunter-gatherer lifestyle (Redding and Rosenberg 1998).

Society/ Culture

Domestication may have developed as an outgrowth to an evolving social/ cultural system (Peters et al. 1999, see also Shaler 1895). Inequalities between community members started when the shift to complex hunting and gathering occurred (Natufian period). Hayden (1990) believes that economic antagonism led to competitive feasting, which required a ready supply of animals. Halstead (2006) also suggested that feasting played a role in domesticating animals. Social systems infiltrated political, economic, and familial aspects of life, allowing people to live and work together. Resources needed to be manipulated in order for sedentary people to accumulate goods and avoid overreaching the land's carrying capacity, (Bender 1978). The society structure then allowed for specialization and domestication of plants and animals (Bender 1975). During the Natufian, communal hunting was practiced (e.g., kites) as discussed previously. Community members had to come together in order to execute this hunting strategy. Therefore, societal structure was needed prior to large societies or agriculture. Agriculture was adopted after communities had hierarchies (Campana and Crabtree 1990).

Cauvin (2000) points to changing artistic symbolism between the Natufian and PPNA as an indicator of pressure on society. Stress could have been due to environmental changes or other factors. The female figurine and bull appear, likened to the mother goddess and a male partner. It is believed these new symbols were part of a new religious movement to provide relief to what was transpiring in society. This societal change brought about other changes, such as people aggregating in larger communities. Larger communities provided a mode of work distribution, allowing domestication to flourish during the Neolithic (Cauvin 2000). On the other hand, Caldwell (1977) believed that although alternative means of survival would be sought during times of stress (e.g., environmental, population), no drive to develop domestication occurred (see also Carter 1977). Instead, what was known was exploited. Following this logic, and as discussed previously, hunter-gatherers prior to the Neolithic practiced a form of agriculture. This social memory would be exploited in the correct cultural setting when issues arose. Cultural support was important, as once domestication started, the population's lifeway changed (Caldwell 1977, see also Johnson 1982). This view was followed by Hassan (1977) who suggested that although many different stresses occurred (e.g., environmental change, population growth, etc.) in ethnographic accounts, society's internal structure (or culture), led to adaptive strategies.

Issues: Edwards (1991) opposed the hunting/ society structure interpretation, as the numbers needed to work a kite cannot be inferred, which may mean no societal contribution was needed to work a kite. Further, the timing of bone accumulation at kites cannot be reconstructed. Edwards believed community hunting occurred earlier in the Pleistocene and did not bring about domestication. Furthermore, this explanation for domestication is not universal (Edwards 1991).

Technology

Fire has been proposed as a mode to domestication. Burning allows new plant species to invade the landscape. For instance, wooded areas can transition to grasslands after burning. Animal species also change through the increased diversity and amount of flora in an area. However, a solution had to be found during the Neolithic to maintain plant levels since sheep and goats are dependent on specific plants (Lewis 1972). In 1981, Hayden proposed a slightly different hypothesis on how domestication came about from what was discussed above[35]. He recognized that populations would undergo some stress regardless, such as population stress or environmental stress. Therefore, humans tried to increase resource reliability by modifying the technology used. One method was to domesticate animals in areas people often underwent stress, allowing the exploitation of resources to the fullest (Hayden 1981).

Combined Theories

Bökönyi (1969) proposed that domestication was spurred on during incipient animal keeping due to increasing populations no longer finding enough resources through hunting. Several years later, Bökönyi (1976) stated that the principal force behind domestication was environmental change, brought about by the Younger Dryas. However, increased population played a crucial role too. Bökönyi recognized another push towards domestication occurred when Neolithic people realized the importance of wealth, which was gained through animals (Bökönyi 1969, 1976). He believed that Neolithic people had to attain certain societal and economic constructs before domestication occurred (Bökönyi 1976, 1993). Bellwood (2005)

[35] In this article, Hayden (1981) notes social pressures were not a main force in driving domestication.

stated that unstable climate conditions set forth a cultural stage that favored sedentism and developing resources. This stage then allowed population growth and competition between neighboring people. This competition drove agricultural development, which was rooted in the natural human/ animal relationships. Therefore, no one real cause could be attributed as the reason behind domestication (Bellwood 2005). Maisels (1998) suggested that domestication was a result of accumulating steps similar to Bellwood (2005). People were adapting based on their past and current conditions (Maisels 1998). Wright (1992) also suggested that domestication was an adaptive survival strategy when both population increase and environmental change occurred. Bronson (1977) suggested that domestication was an adaptive life strategy to a whole host of factors from sedentism, disease, environment, technology, society, subsistence, warfare, and population size. Redding (2005) and Rosenberg and Redding (1998) echoed the complex nature of domestication and how several factors interconnected to foster domestication development (e.g., sedentism, broad-spectrum use of products). Domestication may not have been the end goal set forth from the onset, but an outcome of subsistence experiments with other constituent parts and failures (Redding 2005).

Gebauer and Price (1992) suggested that many previous hypotheses were rooted on incorrect assumptions. The authors identified conditions necessary for domestication to occur based on archaeological evidence. First, human populations have to be large, as archaeological evidence emerges with signals for large groups. Second, the population must be constrained. People were restricted to a certain area, and no longer able to move around to avoid conflict with others. This conflict is seen in the archeological record through evidence of violence. Third, the area in which the population lives must possess a large, natural resource base. Indicators of domestication were not found in areas where plant and animal varieties were minimal. As such,

according to Gebauer and Price (1992), the adoption of domestication and agriculture stemmed from internal society factors, not external.

Archaeological Reconstruction Methods for Domestication

Animal Characteristics for Domestication

Why some animals were not domesticated while sheep and goats were stems from certain inherent characteristics of these breeds, such as ability to adapt to husbandry conditions (Price 1984, see also Clutton-Brock 1999). For example, although gazelles, goats, and sheep are polygamous, gazelles tend not to mix with the opposite sex until mating season. Sheep and goats, on the other hand, form mixed sex herds allowing these animals to be kept comfortably together (Baharav 1974b, Garrard 1984, Simmons and Ilany 1975). Further, gazelles spook easily, and possess the ability to escape more quickly than sheep or goats (Clutton-Brock 1999). Therefore, gazelles would be more difficult to keep under human control and domesticate (Diamond 2002, see Reed 1977a for opposing view). Galton (1865) suggested that many animals may have been kept as pets, but only a few animals possessed qualities favorable for domestication. These characteristics included being hardy (e.g., able to successfully survive in different environs), and able to thrive under human-made conditions. Being able to breed without mate selection and have profitable growth rate were also factors favorable for domestication (Darwin 1875b, Diamond 2002, Garrard 1984, Seguí 2000). Accepting humans as master or part of their social hierarchy allows animals to be herded (Galton 1865, Price 1984). This trait is important since domestic species need to live in large herds with humans taking the lead role to allow herding (Budiansky 1992, Darwin 1875b, Diamond 2002, Garrard 1984, Hemmer 1990). Territorial animals do not domesticate well because fighting ensues when

dominant animals are mixed in with lower-ranked animals (Garrard 1984, see Bottema 1989 and Wilkinson 1972 for opposing view). Domesticated animals also have to provide a return, either a product or comfort (e.g., pet)(Galton 1865, Price 1984). Animals who form persistent groupings were selected so early farmers would not lose their livestock to wild herds when out to pasture (Darwin 1875b, Diamond 2002, Garrard 1984, Seguí 2000).

Archaeological Indicators for Domestication

This section will focus on archaeological indicators that indicate domestication in archaeology. The focus will be on sheep and goats, which make up the majority of the archaeological specimens used in this research (see Chapter 3 for methods on separating goats and sheep).

In the archaeological record, certain indicators are recognized as signals for human husbandry. These signs include demographic profiles not found in the wild, presence outside the natural range, morphological changes, artwork, and other cultural articles associated with animal keeping (Bökönyi 1969, Davis 1987, Grigson 1989, Herre 1970, Horwitz 1989, Legge 1996, Meadow 1989, Stein 1988, Zeder 2006b). Unfortunately, transitional animals, which possess features of wild and domestic types, are not found. This absence leaves a gap in our knowledge of the domestication process (Bökönyi 1969). This could be due to domestication procedures, lack of ability to identify transitional forms, or taphonomic processes influencing the recovery of bones (Table 4.1) (Davis 1987, Grigson 1969, O'Connor 2000). Unfortunately, early Near Eastern excavations did not reliably collect zoological specimens (e.g., collected only picture perfect specimens), which impeded understanding as well (Stampfli 1983).

Taphonomic Processes	Definition	Example
Biotic	Pre-death process (environmental and human husbandry) that bring animal assemblages together	Seasonal change which brings about vegetation change which attracts both humans and animals to a certain location
Thanatic	The process in which the animal is killed and remains are deposited at an archaeological site	Humans kill and butcher animals feeding on the desirable vegetation. Only specific parts of the meat are kept with the rest of the carcass left behind
Perthotaxic	Movement and destruction of bones prior to final deposition in the ground	A scavenger comes along and takes parts of the carcass or a flood comes and moves the remains down river
Taphic	Physical and chemical changes to the bones after deposition (i.e., taphonomy or diagenesis)	The chemistry of the soil causes a breakdown of the bone matrix
Anataxic	Re-exposure of bones to other taphonomic processes	Flood occurs in the area which causes some of the bones to be brought to the surface and allowed to weather while others remain intact
Sullegic	Archaeological process that impacts recovery of bones	Archaeologist selects random meter sections to excavate which may not fully encompass the spread of the bones after the flood
Trephic	Curatorial and post-excavation research decisions on the remains	Animal remains are placed off to the side and not examined by anyone

Table 4.1. Taphonomic process influencing recovery of archaeozoological bone (left column). The center column provides a textbook definition, while the right column provides real-life examples of the taphonomic process (modified from O'Connor 2000).

Cultural Indicators: Culture reflects what occurs within a society. Therefore, if domestication takes place, cultural indicators of domestication should be present. However,

Near Eastern researchers have recovered little cultural evidence for domestication. For example, Meadow (1984) reports two burials from Mehrgarh (Pakistan) that include five baby goats arranged around a human. Russell and Düring (2006) discuss a human burial at Ç atalhö yük (Turkey) that includes a sheep on its back. These deliberate animal burials show the apparent connection people had with domestic livestock and their importance. Other Near Eastern burials include puppies (dogs), which may indicate a different animal/ human relationship since dogs are thought to be raised as human aides (e.g., hunting) (Davis 1987, 1991; Russell and Düring 2006 and references therein). The importance of animals to humans can also be seen when archaeozoologists discover pathological changes in domestic bone, such as arthritis or dental wear due to the use of harnesses (Crabtree 1993, Davis 1987, Horwitz 1989, Rollefson 2000). In the wild, lame or injured animals would be killed quickly by predators. Domestic animals, on the other hand, are protected from predators and provisioned with food, which allows animals to live to an older age (Davis 1987, Köhler-Rollefson 1997, Zohary et al. 1998). Artistic animal depictions evidence animal husbandry as well. For instance, at ‘Ain Ghazal (Jordan), clay figurines contain impressions of rope (i.e., control devices) on the animals. These figures could be toys or ritualistic, as evidenced by several cattle figures “killed” with a blade then placed under a house floor (Rollefson 2000).

Issues: Cultural images of animals do not prove domestication at an archaeological site (Ducos 1969). These figurines could simply signify wild animals or be part of a ritualistic activity. In regards to the animal remains, studies on arthritis and normal bone pathologies of wild animals have not been conducted to allow educated use of this method to mark domestication (Crabtree 1993). Furthermore, Baker and Brothwell (1980) noted that some

researchers assign the diagnosis of arthritis any time exocytoses are present. Other etiologies produce these phenomena beside arthritis. Therefore, other indicators for joint osteoarthritis need to be found for the correct diagnosis (Baker and Brothwell 1980).

Demographic Profiles: Archaeologists reconstruct demographic profiles (the age and sex distribution of a particular species) directly from bones recovered to understand what occurred at the site. This reconstruction method has become the more favored reconstruction method for archaeozoologists (e.g., Arbuckle and Atici 2013). Various reconstruction methods are utilized to determine age and sex, including dental wear, bone measurements, and statistical analyses (Bar-Oz 2004, Ducos 1969, see Collier and White 1976 for refutation). It has been proposed that butchered remains' age and sex profiles vary depending on the context of the slaughter (hunted or domestic) (Figure 4.5) (Albarella et al. 2006, see Martin 2000 for age/ sex cautions). One expects hunted animal profiles to include a majority of older, adult remains (older than 36 months), while husbandry should contain more juvenile bones due to culling (between 12-36 months) (Arbuckle 2008, Wright and Miller 1976, see Munson 2000 for contradictions to these ages). Several factors are considered when creating these profiles. Survivorship differs between wild and domestic groups (Wright and Miller 1976). For instance, young survivorship in the wild will differ when compared to animals under human protection (Bökönyi 1969).

Sex ratios are also thought to differ due to death context. The sex ratio from hunting is likely to be close to 1:1 (male: female) (Bökönyi 1969), although deviations occur due to season and hunting strategy (Davis 1982, Seguí 2000, Wilkinson 1976, Wright and Miller 1976). For instance, hunters have different preferences when hunting goats versus gazelles. This preference or strategy produces different demographics (Horwitz 1989). For domestic animals, assorted

models have been proposed to describe the specific animal product obtained (Stein 1988, see Sherratt 1981 for a history of domesticated animal use, Cribb 1984 for computer models). If animals are raised solely for meat, more males are slaughtered at a young age. Specifically, the age that provides the most meat with the least economic burden to the farmer, usually between 18 and 30 months. The majority of females survive into adulthood to procreate the herd (Arbuckle et al. 2009, Chaplin 1969, Köhler-Rollefson 1997, Payne 1973, Sherratt 1981). Other models describe animals used for other products, such as milk and wool. One finds a larger number of surplus lambs and kids within the faunal remains in a milk-based economy, as humans retained their mother's milk for themselves (Arbuckle et al. 2009, Payne 1973, Sherratt 1981, Vigne and Helmer 2007). Of course, not all sites follow these prescribed models. For example, at the PPN site of Suberde (Turkey), original examination by Perkins and Daly (1968) indicated animals were wild based on size. Newer demographic profiles show sheep and goats were selected for slaughter by age not sex, which does not correspond to any established profile. Suberde occupants maintained a unique husbandry system, established to meet their needs (Arbuckle 2008).

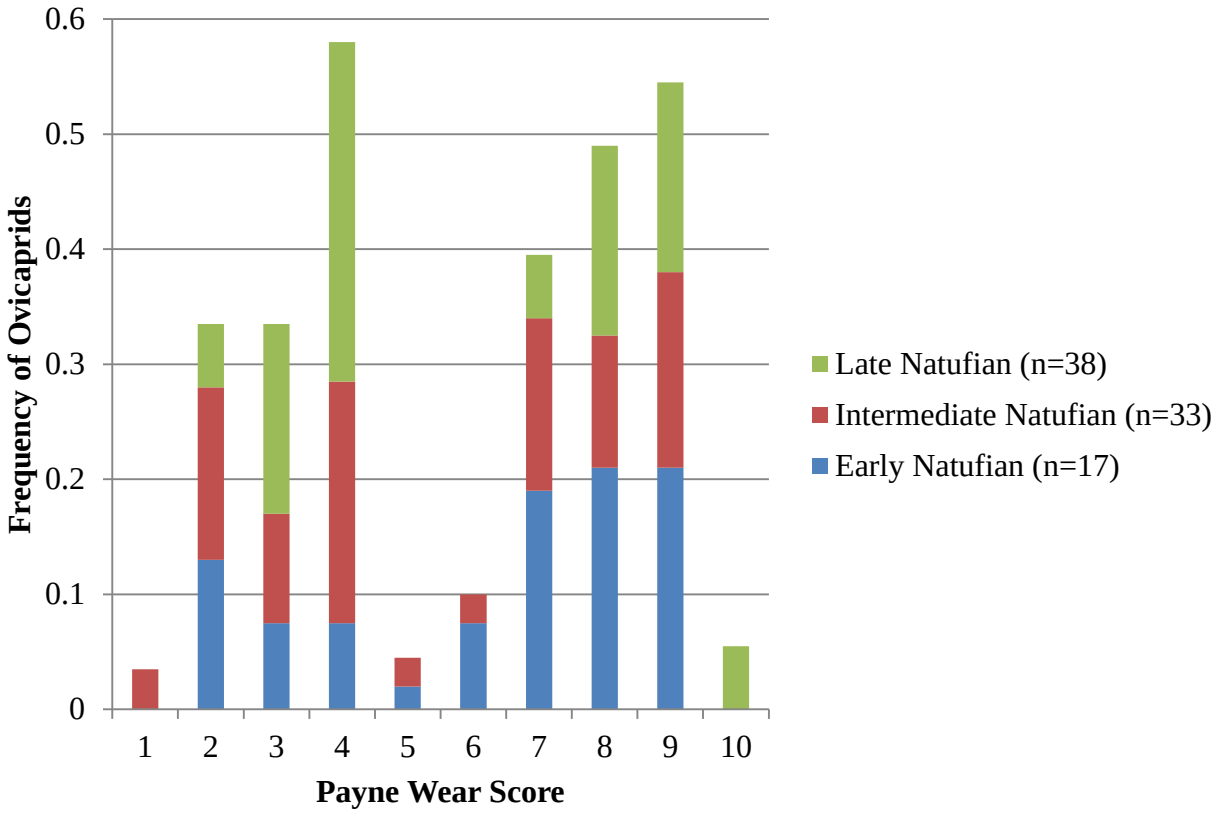

Figure 4.5. Ovicaprine mortality profile from the site Öküzini Cave (Turkey) over the Natufian (blue: early Natufian, red: middle, and green: late). Age at death was based on Payne dental wear scores, indicated by column numbers, on the fourth lower and upper premolars (modified from Atici and Stutz 2002).

Separating goat from sheep remains provides informative demographic trends as well (see Chapter 3 for separation methods and how these animals differ). For example, when Neolithic sites in Turkey are examined, goat profiles remain consistent, indicating goats played a reliable economic role. Sheep profiles differ greatly between sites, indicating that sheep were used to meet distinct economic needs for individual sites (Arbuckle et al. 2009).

Issues: Researchers have tried to find methods to overcome issues with demographics since their conception, as understanding the dynamics at archaeological sites provides direct

evidence in animal handling (e.g., Bocherens et al. 2006, Zeder 2008). The assumptions used in creating and comparing profiles leads to many issues with this method. Collier and White (1976), Cribb (1987), Martin (2000), and Munson (2000) warn about the creation of and use of demographic profiles in stating the purpose of archaeozoological remains. Difficulties stemming from bone recovery, meat processing, and herd dynamics, such as natural deaths, all pose problems in recreating the proper model (Deevey 1947). Another drawback in modeling is that models are often based on an unrealistic dichotomy (e.g., the herd was used for meat or it was not). Herds may have played a role in several economic activities, skewing the model's results (Martin 1987). For instance, Cribb (1987) used computer modeling to reconstruct kill-off patterns based on archaeological and ethnographic data. Profiles from archaeological sites do not always reconstruct a viable herd. This is problematic if Neolithic people were raising animals for their livelihood but could not maintain their herds (Cribb 1987). Arbuckle and Atici (2013) found after surveying sites from around the Near East that male culling was not within the norm during initial husbandry practices. This finding indicates initial husbandry practices varied between locations with different strategies applied at locations. Not until after morphological distinctions occurred do more sites possess male culling, indicating this was an effect of breeding better-adapted animals, advancing husbandry strategies, and increasing herd sizes (Arbuckle and Atici 2013).

Aging bone is also not a precise science. For example, dental eruption and epiphyseal fusion are affected by nutrition. These characteristics vary naturally between animals, and could be affected during early husbandry attempts. Researchers compare archaeological bones to modern, known age samples to determine age. This comparison has several inherent problems, such as assuming the same growth trends between evolved modern herds and animals in the past.

Some studies compare archaeological bones to radiographic images to determine age. However, this method is problematic, as bone appearing to be fused or end-stage fusion may break off in archaeological contexts, which then reconstructs to a different age (Payne 1972).

Another problem using demographic profiles is that we do not have an understanding of hunting strategies used to establish past hunting profiles. Further, we lack evidence for a standard wild animal population. Animal herds' composition depends on the natural environment, which, during the Neolithic, could be affected by humans. These environmental influences change yearly, which affects the herd structure for that year (e.g., drought that decreases resources, temperature). Seasonality also influences what types of animal groupings hunters encounter (Arbuckle et al. 2009, Jarman and Wilkinson 1972). Furthermore, even hunters today do not know what will be encountered while hunting, making a normal ratio difficult to ascertain (Jarman and Wilkinson 1972, Meadow 1993, Payne 1972, Seguí 2000). For instance, animals do not always associate in mixed sex herds (i.e., bachelor bands, females and children). Hunting profiles therefore can be skewed based on what type of herd structure is encountered (Herre and Röhrs 1977, Jarman and Wilkinson 1972, Legge 1996). Preference for sex might occur depending on season. Females are avoided during birthing season and males are avoided during rut, because of the weight reduction during these times (Bar-Oz 2004). Finally, diseases affect wild herd structures, a factor researchers cannot easily reconstruct. The same problem applies to domestic herds, where animals are penned, allowing illness to spread more quickly. Disease conditions create a different profile from the normal models (Jarman and Wilkinson 1972).

Butchering plays an important role in bone recovery. Hunted or sick animals could either have been brought to the settlement whole or butchered at the kill-site. If the latter occurred,

only the meat parts were brought back to the site, affecting what bones entered the archaeological record (Bar-Oz 2004, Bender 1975, Buitenhuis 1996, Madrigal and Holt 2002, Perkins and Daly 1968, see also Lyman 1987 for butchery patterns). Further, Bar-Oz (2004) noted that smaller animals were more likely returned whole to a site, while larger animals were butchered at the kill site. In addition, both intrinsic and extrinsic factors play a role in bone recovery. For instance, bone density is not consistent throughout the skeleton, with less dense bones breaking down faster (Binford and Bertram 1977). This fact is especially true with juveniles. Epiphyseal ends fare differently in the ground than adult bones (Bar-Oz 2004, Davis 1983, Payne 1972). Bar-Oz (2004) showed that when comparing data based on epiphyseal fusion to that of dental wear and eruption data, different demographic profiles are obtained. On the other hand, adult bones may have been used for cultural objects, removing them from the archaeological record (Payne 1972). Differences in treatment (e.g., cooking, left on the surface to weather, scavenged by dogs) also influenced whether animal remains survived in the archaeological record (Bar-Oz 2004, Binford and Bertram 1977, Munson 2000, Payne 1972). Becker (1998) demonstrated that profiles might be misleading. Using traditional bone counts, 70% of the faunal remains from Basta (Jordan) come from domestic animals. However, by weighing the animal bones[36], which correlates to the amount of animal meat, domestic animals drop to 54%. The bone weight indicates that although herding occurred, wild meat supplied half the dietary protein needs (Becker 1998).

Furthermore, domestic handling methods are not understood. Köhler-Rollefson (1997) discusses how young animals are sensitive to cold temperatures, and need to be kept in protective

[36] The method of using bone weight to determine the amount of meat utilized at a site (i.e., Wiegemethode) has been questioned as to whether the results are accurate based on the assumptions that must be made in order to calculate (Casteel 1978, see also Lyman 1994 for discussion of measurement meanings).

enclosures as done in modern ethnographic examples. Herders need to provide fodder to these protected animals. This system could be used during the day to ensure mothers returned to the site at night (Köhler-Rollefson 1997, see also Redding 2005 for similar methodology for pigs). Whether this occurred and how apt the ethnographic examples for reconstructing Neolithic practices are not known. For example, Cranstone (1969) pointed out that males are not necessarily butchered when they reach a certain age in modern herding societies. Instead, males are castrated or undergo other breeding control methods. These methods may have been used in the past, affecting the sex ratios seen at archaeological sites, as castrated males would not develop like normal males (Cranstone 1969).

Genetics: Domestication occurred in several areas around the world, although mitochondrial (mtDNA) analyses indicate original goat and sheep domestication occurred in the Near East and then spread. However, our ability to pinpoint exact locations through genetics is hampered by trade, migration, and allowing wild animals to breed with domestic animals (Bradley 2006). For instance, secondary domestication occurs when domesticated animals are brought into an area with a wild population present. Either wild young are brought into the herd, or females interbreed with wild males. This allows genetic admixture, with domestic animals acquiring new traits from the wild herd. It may thus appear like local domestication occurred, an incorrect conclusion without careful examination of evidence (Hemmer 1990). Further, complete genetic understanding may never be realized since all wild and domestic populations are not known. This unknowing could be due to early domestic populations or wild progenitors dying off early in domestication history (Bradley 2006, Jarman and Wilkinson 1972).

Separation and keeping in isolation the animals that initially underwent domestication

were crucial factors. The use of penning would remove natural selective pressures, and therefore, genetic change would occur even before selective breeding was started (Köhler-Rollefson and Rollefson 2002). Human selection included genotypes not favorable to wild animals including body size, docility, and response to predators (Darwin 1875a, b; Price 1984). Further, animals had to adapt to survive human-made conditions (Higgs and Jarman 1972, Price 1984). The domestication process led to genetic changes, seen in the archaeological record as morphological and metric changes (discussed later) (Higgs and Jarman 1972). Domesticated animals display wider characteristic variations than what is found in the wild (Hemmer 1990). For instance, all domestic sheep possess both face and foot glands. However, in wild animals, one, both, or no glands are found. Further, if present, these glands are more developed in wild populations (Epstein 1971). Differences in physiology and appearance of domestic animals are due to animals adapting to specific environments (Darwin 1875a, see also Terrill 1968). However, whether complete isolation actually occurred during incipient domestication is unknown. Modern ethnographic studies show that some pastoralists allow their herds to interbreed with wild populations. If this occurred in the past, the domestication process would have been very slow with a great amount of time passing to accumulate enough genetic changes to show morphologically. Population examination (i.e., demography, dietary reconstruction) may provide evidence for human control better than genetic changes (Higgs and Jarman 1972 see also Larson 2011 about questions on interpretations of DNA).

Goat Genetics: The domestic goat has 2n= 60 chromosomes. Several wild goat species have this same number, allowing them to interbreed successfully (Mason 1984, Payne 1968). The most likely ancestor for domestic goats (*Capra hircus*) is *C. aegagrus* but some have

reported *C. falconeri* (Markhor goat) contributed in East Asian domestication (Fernández et al. 2005, Luikart et al. 2006). Naderi et al. (2008) mtDNA studies indicate six initial domestic maternal lineages coming from the eastern Taurus Mountains, southern Zagros Mountains, and the Iranian plateau (Zeder 2011). Naderi et al. (2008) identified haplogroup C [37], from the Zagros region, the most likely candidate for incipient domestication. Another domestication center occurred in Anatolia (Turkey), represented by the A haplogroup. Based on the number of A haplogroup animals compared to those possessing C, the C did not prosper like those in Anatolia. The Anatolian animals provided greater genetic contributions to modern goats (Naderi et al. 2008).

Sheep Genetics: Chromosome number varies between sheep species, from 2n= 54 to 2n= 58 (Shackleton and Lovari 1997). Sheep genetics are complicated due to lack of agreement in the number/ division between species (Geist 1971). Like goats, sheep genetics are complicated by species ability to interbreed, making genetic and breed information difficult to parse (Bruford and Townsend 2006, Guo et al. 2005, Payne 1968, Reed 1960). Hybridization occurs when different species interbreed, creating viable, reproducing offspring. Species nomenclature then is rejected by researchers due to their possible hybrid origins. For example, *Ovis orientalis* and *O. gmelini* both denote the mouflon, with *O. gmelini* preferred by researchers believing the species is a hybrid (Shackleton and Lovari 1997, see Bunch et al. 1976 for discussion on chromosome number). Seven wild sheep breeds have been recognized as candidates for initial domestication, giving rise to domestic sheep (*O. aries*). Bruford and Townsend (2006) report that *O. orientalis*

[37] "A haplotype is a package of genetic material that incorporates multiple variable sites or markers, and which can be considered as a unitary, heritable package that is uncomplicated by recombination through the generations" (Bradley2006: 273).

(Asiatic mouflon) appears to be the most likely ancestor, based on genetic evidence. However, Guo et al. (2005) state that the urial (*O. vignei*) is the original ancestor. Hiendleder et al. (1998, 2002) report two different maternal sources for domestic sheep using mtDNA analysis, one the mouflon and the other an unknown species that is no longer living (Meadows et al. 2011).

Originally three haplogroups were identified (A, B, C) based on mtDNA analyses of domestic sheep (Bruford and Townsend 2006, Guo et al. 2005, Pedrosa et al. 2005). Today, five haplogroups have been identified (D, E), indicating a more complex sheep domestication process than previously realized (Bruford and Townsend 2006). Increased genetic variability occurs in the Near East, suggesting the origin of domestic sheep. Variations within cytochrome *b* region of mtDNA indicate that each domesticated population originated from a different mouflon subspecies. For instance, an *Ovis* species interbred with a mouflon becoming the domestic progenitor at one site, while domestication at another site had a different mouflon or hybrid starter (Bruford and Townsend 2006). Kijas et al. (2012), using single nucleotide polymorphisms (SNP), found a "highly heterogeneous" progenitor population as well. These authors suspect the strongest selective pressure humans placed on sheep was for horn loss. Other selective factors on domestic sheep were coloration, body size and morphology, and reproduction (Kijas et al. 2012).

Guo et al. (2005) estimate lineage A originated between 84,000-100,000 years ago, and B occurred 112,000-134,000 years ago given the mutation rate in the mtDNA. Meadows et al. (2011) found that haplogroups C and E separated 26,000 years ago, reflecting a domestication event within the Near East. These results, reported with cautions on timing estimate correctness, indicate a much earlier beginning to Near Eastern sheep domestication. Ho and Larson (2006) discuss reasons behind an early date, including incorrect calibration points, incorrect substitution

rates, and the analysis picking up wild population splits. However, in studies that controlled for the latter possibility, early dating (prior to the Neolithic Revolution) remain (Ho and Larson 2006).

Issues: Comparability problems exist between ancient DNA (aDNA) analysis and mtDNA. More markers are needed in analyses to understand fully what occurred during domestication. This situation is complicated by the fact that aDNA does not preserve as well as mtDNA, making additional studies impossible to do (Bradley 2006). Berry (1969) noted that the domestication process itself did not lead to phenotype changes, based on domestication attempts with Norway rats. The domestic changes seen were based instead on human selection. Early farmers selected desirable traits (e.g., docility), or traits allowing animals to live in human-made environments (Belyaev 1979, Berry 1969, Price 1998). Belyaev (1979) termed this "destabilizing selection". The selection of behavior, like docility, leads to changes in the neurological systems. These changes bring about changes in the regulation, timing of genes, and expression (discussed below in morphology).

Location*:* Although researchers know domestication started in the Near East, exactly where domestication occurred is not known. Animals are thought to have been domesticated if found at a site not within the animals' natural range (see Chapter 3) (Albarella et al. 2006, Legge 1996). For example, at 'Ain Ghazal (Jordan), the local environment supports goats. Goats are recovered throughout the settlement, both wild and domesticated. A large number of sheep appear within the archaeological record during the middle PPNB, indicating a shift in animal husbandry to the adoption of domestic sheep (Wasse 2002, see also Moore et al. 2000).

Issues: This criterion is not straightforward, as many natural factors influence animal distribution (e.g., drought, fires, rain, snow, temperature changes). Humans also influence animal distribution, such as using animals' natural ranges for agricultural development. Therefore, present day distributions may not reflect past distributions (Zeder 2006a, b). Furthermore, the archaeological record contains gaps that create problems in reconstructing wild populations' ranges (Payne 1968). Therefore, species appearance, especially in the absence of other criteria, is not enough to warrant domesticated status (Harris 1996). Concerns about this indicator also include animals following humans to new areas in order to exploit manufactured resources (e.g., pigs, dogs). These animals were not under human control, and viewed as pests. In addition, humans have transported animals to new locations, such as islands for the sport of hunting, making this criterion very dependent on background information prior to using appearance as a marker for domestication (Albarella et al. 2006).

Metric Analysis: Metric analysis provides information on species, how individuals compare to the rest of the population, and population change over time and space. Metrics can distinguish between sexes and domestication status, as under domestication animals tend to reduce in size compared to their wild counterparts (Boessneck and von den Driesch 1978, Stampfli 1983, Zeuner 1963). For instance, domesticated animals' brain sizes decreased. This decrease results in changes to not only the size but morphology of the skull as well (e.g., reduction in the dimensions of molar teeth[38]) (Albarella et al. 2006, Darwin 1875b, Flannery

[38] Stampfli (1983) notes tooth size decrease does not happen at the same rate as skull size reduction. Instead, the dentition changes at a slower pace. The skull reduction caused dental crowding, a feature used as a mark of domestication (Stampfli 1983). However, Higgs and

1983, Groves 1989, Hemmer 1990, Zeuner 1963). Furthermore, variation was reduced under human control, as sexual dimorphism characteristics were no longer required (i.e., sexual selection no longer occurs). For metric analysis, a standard animal is selected, to which the archaeological specimens are compared. However, complications arise as domesticated males may overlap wild female size, making it critical to use full bones for analysis (Boessneck and von den Driesch 1978, Grigson 1969, Legge 1996).

Issues: Metrical analysis standards have been around since the early 1900s (e.g., Duerst 1926), although adoption has been hampered due to language barriers (Uerpmann 1978, Meadow 1999). Further, archaeozoological reports are not often published with site reports, making comparisons or results between sites difficult (Uerpmann 1978). No current comparison standard is agreed upon to determine measurements indicating wild or domestic animals. This situation is due to numerous factors affecting size, and the amount of size overlap that naturally occurs (Becker 1998, Boessneck and von den Driesch 1978, Meadow 1999). In addition, no comparison database is available that contains wild Near Eastern animal measurements (Peters et al. 1999, Reed 1960). This knowledge is especially important for initial animal husbandry changes, as domestic animals would have not undergone much, if any, size change (Peters et al. 2005). Another caveat is where the modern comparative samples arise, as whether or not comparison animals are truly wild or have been improved (e.g., used to be domesticated, mix of domestic and wild, or managed by humans), and to what conditions the animals were adapting (e.g., stress) all impact measurements (Horwitz 1989, Jarman and Wilkinson 1972, Zeder 2006b). Boessneck and von den Driesch (1978) suggest that the most reliable way to understand

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Jarman (1972) note dental crowding is also found in wild populations.

animal husbandry is through animal measurements period by period. Berry (1969) also stated that domestication should only be claimed if continuous change was observed. This observation is especially important since one does not know the animals' source. For instance, phase X animals may measure larger than later phase Z animals, and indicate domestication. However, phase X and Z animals may have originated from different wild populations, trade, or undergone a natural size transition (see below) (Payne 1972). Furthermore, during the process of domestication, size and other changes became "fluid", making a distinct distinction between domestic and wild size difficult (Bökönyi 1989, Herre 1970). Marked distinction between wild and domestic only occur after domestication has had time to develop (Bökönyi 1989). Zeder (2001) questions relying solely on size when determining domestication at a site. Zeder found no appreciable size change occurred after reexamining material from Near Eastern archaeological sites. Instead, decreased size is falsely created by the increased number of females, who are naturally smaller. Therefore, size decrease may be misinterpreted if sex and demography are not accounted for. Further bias may arise from not including both complete and unfused bones within analysis (Buckley et al. 2010, Legge 1996, Zeder 2001).

Age and sex are issues in metrics as well. Females tend to be smaller than males; however, under domestication, males reduce more in size than females. Grigson (1989) and Zeder (2006b) report little variation between domesticated and wild species measurements due to overlap. Most sex-based size variation is found in the postcrania (Albarella et al. 2006, Bender 1975). Humans initially selected juvenile animals for ease of handling (e.g., smaller size, docility). This led to animals retaining juvenile morphological features (Albarella et al. 2006, see also Budiansky 1992). For instance, Bottema (1989) discussed how modern geese domesticators chose animals one year or younger. This selection benefits the domestication

process in several ways. Since geese pair bond, at this age bonding has not occurred, which allows a young female to be placed with another male and bred. Further, imprinting on the natural environment has not occurred. Therefore, especially for the female, rearing of young can occur in human-constructed surroundings successfully (Bottema 1989). Another issue of concern when reconstructing domestication is placing size change within the context of juvenile culling. Since males were culled at an early age, there were not many males left to reconstruct a proper understanding of male size change. Often, juvenile bones are not included in reconstructions. Complete understanding then is lost when males are left out of the calculations (Köhler-Rollefson 1989). Therefore, multiple tests should be done in order to understand what occurred during the Neolithic (e.g., Redding 2005).

Herre (1970) and Jarman and Wilkinson (1972) questioned whether size change truly was an outcome of domestication or an outcome of living conditions. A correlation between husbandry and size change does not imply causation. Humans may have selected for small size for handling or docility (Davis 1981, 1987; Herre 1970, Tchernov and Horwitz 1991). However, Higgs and Jarman (1972) explored the idea that smaller animals were more docile by examining cattle species. Some larger cattle species are actually more docile than smaller species. Both young, small animals and large animals can come under human husbandry, as seen in modern experiments (Higgs and Jarman 1972). Smaller animals may have been selected by earlier farmers simply due to economic reasons. Agriculturalists could maximize their animal numbers when maintaining a larger herd of small animals, as a smaller herd of larger animals need a greater resource base to survive. The increased number provided more resources for survival if difficulties arose (Jarman and Wilkinson 1972). Humans' interference could have caused a shift in reproductive strategies, from *K*-selective to *r*-selection. This shift in reproductive strategy

then caused a decrease in body size and less maternal care requirements (Tchernov and Horwitz 1991).

Size reduction could have occurred if animals were not fed properly (Albarella et al. 2006, Bender 1975, Davis 1981, 1987; Herre 1970; Herre and Röhrs 1977; Leach 2007; Tchernov and Horwitz 1991). Researchers found that reduced protein diets (5% protein) cause animals' growth to slow. This decrease results in smaller animals when compared to animals fed normal or increased protein diets (Ambrose 2000). Nutrition factors have also been critiqued. Jarman and Wilkinson (1972) questioned why people who were successful hunters would bother raising smaller, possibly sick animals. Furthermore, the critical time in an animal's life is right after birth. If humans were gathering animals for their domestic flocks or raising young, their ignorance of proper nutrition would have caused quick death for the animals (Jarman and Wilkinson 1972). Domestication would not prosper without understanding dietary needs.

Size change can stem from the environment as well. Size reductions happen to animals isolated on islands, and those living in overcrowded conditions[39] (Albarella et al. 2006, Bender 1975). Isolation size differences may be natural or human sourced. Animal groups could be separated naturally through geography or environment. In these cases, the genetic pool is limited, causing natural variation between species (Grigson 1969). However, this natural environmental variation is not a simple process to understand (Albarella et al. 2006, Davis 1981, Hafez 1968, Jarman and Wilkinson 1972). Bro-Jørgensen (2008) discusses several hypotheses regarding natural size variation. For instance, Bergmann's Law finds animals in colder environments will be larger than the same species in a warm environment. This size change reduces the amount of heat loss from the body because the surface to mass ratio increases

[39] Overcrowding can lead to sudden death through adrenal stress, a condition called Selye's syndrome (Fox 1968).

(Bender 1975, Bro-Jørgensen 2008, Hafez 1968, Zeder 2005, see Dayan et al. 1991 and McNab 2010 for cautions). Natural differences occur due to food choice (Bro-Jørgensen 2008). If two animal species rely on the same food source, natural selection favors animal size change so both species can survive on the given amount of resources (Davis 1981, McNab 2010, Bro-Jørgensen 2008). Sexual selection may also play a role in body size. In open habitats, larger, more noticeable animals (e.g., horns) are preferred, leading to the entire herd increasing in size. Opposingly, maneuverability needs produce changes in body size. Smaller body size is selected for in denser environments, because animals are able to move, escape predators, and access food and hiding spots more easily than a larger animal in the same environment (Bro-Jørgensen 2008, Davis 1981). In comparing studies examining animals during the Natufian when the Younger Dryas (cold, and dry) took place, the assumed environmental effects are not consistent among all species. Some species show size reduction predicted by Bergmann's Law. However, the timing of size change is not consistent between species (Bar-Oz 2004, Davis 1981). Furthermore, Levantine gazelles increase in size, indicating other natural and possibly human created forces influenced size (e.g., over-hunting or more resources due to human cultivation) (Bar-Oz 2004). Changes in size may have environmental, husbandry, or genetic reasons behind them, and of course, these causes are not mutually exclusive.

Since so many factors influence the size of an animal, using just metrics to determine domestication is not feasible (Higgs and Jarman 1969, Zeder 2005). In addition, certain environmental conditions must be met in order for successful domestication (Arbuckle 2005, Bökönyi 1989, Herre and Röhrs 1977). Animal sensitivity has been demonstrated by many documented historical and modern domestication attempt failures (Budiansky 1992). In nature, the environment plays an integral role within animals' daily life, and animals adapt to their

specific environments (e.g., shelter from predators). Domestic animals must adapt to conditions they are not used to. Undesirable results are seen when animals no longer rely on natural instincts. For instance, mothers cannibalize young due to either the stress of being confined and/or lack of mate support. Further domestic animals die in severe weather because they no longer possess instincts to find natural shelters (Darwin 1875a, Price and King 1968). Ducos (1969) and Herre and Röhrs (1977) add that genetic changes within a population are not uniform, due to genetic traits occurring separately from one another on a chromosome. The better an animal is able to survive under domestication, the more likely it reproduces and passes on the favorable genes to the next generation (Price 1998). However, other factors can cause major stress and even death as domestic animals become adapted to living conditions controlled by man. These stressors can be as simple as changes in routines or changes in the food supply (Fox 1968).

Arbuckle (2005) found in modern domestication attempts that when humans selected for reduced aggression, hormones and other regulatory devices in the brain changed (e.g., Belyaev 1979, Trut 1999). Specifically, changes occur to animal behavior, reproduction, nervous and endocrine systems; and new morphological traits arise as a result (Arbuckle 2005, Belyaev 1969, Hemmer 1990). Reductions occur in sensory perception, such as olfactory, vision, and hearing. These reductions occur in the sense structures themselves and the related brain areas, as adaptation to human-made environments free animals from needing to sense predators (Albarella et al. 2006, Arbuckle 2005, Kruska 1988). Ebinger (1975) hypothesized that the reduction in the visual apparatus was due to domesticates no longer living in the wild and needing to visually orientate themselves to the herd and environs (see Gustafsson et al. 1999 for foraging strategy research). In addition, the limbic system, which is responsible for emotional responses such as

aggression, also reduces (Arbuckle 2005, Kruska 1988). However, body size is not reduced in modern experiments. Therefore, other factors took place in the domestication environment that drove morphological changes. These factors may range from nutrition, maternal care, over-crowding, disease, to stress as discussed previously (Arbuckle 2005, Legge 1996, Hemmer 1990, Zeder 2006a). However, Crockford (2002) relates heterochronic changes (e.g., size, color, behaviors) to changes in thyroxin levels, a thyroid hormone. Changes in this hormone allow animals to adapt quickly to the environment, including captivity. The idea is that these animals would have thrived under domestication, allowing rapid heterochronic changes such as size, coloration, and behavior, to occur (Crockford 2002; see also Clark and Galef 1980, Richter 1949).

The timing of the domestication change is a mystery, since conditions during the Neolithic are not well understood. The process of domestication may have happened differently in various areas. A major challenge arises in attempting to reconstruct domestication with lab experiments, as they may not accurately replicate what truly occurred during the Neolithic. Most likely domestication occurred slower than modern experiments indicate (Bökönyi 1989, Price 1998, see Wilkinson 1972 for experiment summary). For instance, in favorable environments, experimental studies with small animals show domestication occurs within 30 generations. Larger animals with increased maturity periods take 100 generations (Arbuckle 2005, Bökönyi 1989). Of course, modern domestication experiments do not mirror the situation of the past when the process was challenging and success was not assured (Budiansky 1992). Darwin (1875b) suggested that domestication was arduous since changes were created through selection. In each generation, slight improvements occurred. Animals possessing the desired feature must be bred to maintain and continue the selective process. Both unconscious and conscious

selection processes must have been "insensibly slow" (Darwin 1875b: 231). For instance, horn shapes found in the archaeological record reflect a gradual domestication process, much longer than 30 generations (Bökönyi 1989, Zeder 2006b). Zeder (2008) reports that traditional size change markers occur 1,000 years after husbandry started based on demographic profiles. Haber and Dayan (2004) believe that animals possess different levels of susceptibility for domestication. Animals more "pre-adapted" to domestication display morphological and metric changes sooner as these animals are easily bred. Those animals not "pre-adapted" will undergo longer pre-domestication stages. This situation is visible through demographic profiles, with hunters still capturing wild animals to maintain herds (Haber and Dayan 2004). However, Crockford (2002) and Horwitz (1989) hypothesized that morphological changes should appear rapidly in the archaeological record. Kohane and Parsons (1988) provide support for this hypothesis through lab experiments. Small populations undergoing domestication stress would rapidly adapt. Behaviors change first followed by genetic changes due to recombination and mutations (Kohane and Parsons 1988). Buitenhuis (1990) cited archaeological evidence, specifically the quick adoption of sheep and goats, to show the speed of domestication. Animals moved into several areas at the same time. If the process took longer, Buitenhuis expects more variation in location and dating of occurrences (Buitenhuis 1990).

The diversity of estimates regarding the amount of time domestication took, and the possibility early domesticates were not metrically different from wild animals requires other indicators for domestication establishment (Horwitz 1989, Reed 1959). For instance, Ervynck et al. (2001) used both traditional methods along with linear enamel hypoplasia (LEH) analysis[40]

[40] Stress events disrupt the process of enamel formation, causing horizontal depressions across the adult tooth. By taking measurements of where LEH are on a tooth, the time of the formation and therefore the stress event can be recreated (Dobney and Ervynck 2000).

(see Chapter 2 for discussion) to find pigs at Çayönü Tepesi (Turkey) underwent a slow, gradual process of domestication. Arbuckle et al. (2009) discusses how at the site of Aşıklı (Turkey) demographic profiles suggested human management of caprines. However, no morphological changes occurred within the site's 400-year occupation. The authors suggest that animals interbred with wild populations, which hampered the genetic isolation needed for domestic changes (Arbuckle et al. 2009).

Morphology: Morphological changes also occur in domestic animals, although not all morphological changes are preserved in the archaeological record (e.g., coat color[41]) (Zeuner 1963). For instance, the morphology of horn cores provides information on domestication status, species, and sex (Becker 1991, Zeder 2006b). Changes in horn shape may be due to human selection or reduction of competition (e.g., no longer needed for dominance displays related to mate selection) (Zeder 2006b). The horn core changes along with the change in the horn shape. For instance, in the domestic goat, horns change from large, scimitar-shaped to small and upright shape. Bone horn cores are found underneath the keratin horns, and often remain in the archaeological record (Bender 1975). Not all horn cores are represented equally in the archaeological record however. As such, over- or under-representation and skewed demographic profiles occur when based solely on horn cores. Female goats have more durable horn cores than males. Female sheep lack horns, both in the wild and under domestication (Bender 1975). Further, horns are not a genetically stable feature. Therefore, changes seen in horns may be due

[41] Different hypotheses are offered to explain coat color change. These include genetic changes (e.g., Crockford 2002), selection for religious ceremonies (e.g., Isaac 1970), or through human selection to differentiate domesticated animals from wild animals (Clutton-Brock 1994). Human husbandry methods protected unusual coat color and other conditions normally making animals vulnerable to predators (Zohary et al. 1998).

to domestication or the result of other natural influences. Even animals within the same population have different sized and shaped horns, underlying the need to understand the morphological variation occurring in modern populations (Stampfli 1983).

Issues: Problems arise using morphology to determine domestication in the archaeological record. To begin, wild animals have continued to evolve since domesticated ones were separated from their progenitor species. Therefore, modern animals may not possess representative features of animals living thousands of years ago (Harris 1996, Price 1998). Price (1998) notes that this difference is especially underscored in genetics, as modern populations may not represent the genetic diversity of the past. Similar to metric changes, morphological changes may not correspond with domestication onset (Reed 1971, Zeder 2011). Zeder (2011) notes that morphological distinctions between wild and domesticated animals occurred 1,000 years after animal management started. Further, some animal ancestors are not known, so what animal should be used as a standard comparison is not clear. In addition, some groups may have died out making morphology comparison very difficult (Jarman and Wilkinson 1972, Price 1998).

Goats in the Archaeological Record: Goats were once thought to be the first domesticated ungulate (Isaac 1970). Wild and domestic goats are difficult to tell apart morphologically. Traditionally, horns are relied upon as the only reliable indicator. The first domesticated status based on this horn criterion was reported at Neolithic Jericho (Isaac 1970, Reed 1983, Zeuner 1963), and Jarmo (Curwen 1953, Isaac 1970, Reed 1983, Zeuner 1963). However, questions about the domesticated status of these animals have been raised by Clutton-

Brock and Uerpmann (1974). These researchers found that domesticated goats were only present during the PPNB based on other domestication indicators (Clutton-Brock and Uerpmann 1974). At the Mesolithic site of El-Khiam (Palestine), researchers believe goats, along with cattle and pigs, were domesticated (Legge 1972, Zeuner 1963). At Belt Cave (Iran), another Mesolithic site, evidence points to goat and dog domestication. Researchers concluded goat domestication occurred prior to agriculture, with goats providing meat and skin to the inhabitants (Coon 1951). However, Zeuner (1963) and Legge (1972) reinvestigated both sites and found the original interpretations not correct (i.e., domestication had not occurred). At El-Khiam, Legge (1972) noted that the sample of bones was not large enough to determine whether goats there were domesticated. Asiab (Iran), dating to 10,000 BP, provides evidence of early goat domestication. This classification is based on twisted horn cores, and high percentage of mature male bones recovered (Bökönyi 1976). At the nearby site of Ganj Dareh (Iran), dating to 9,500 BP, goat domestication is evidenced by footprints[42] left in mud bricks (Hesse 1984, Perkins 1973). It is thought only domesticated animals would maneuver close to human occupations. Further, goats would not normally be present at the site (Crabtree 1993, Perkins 1973). Horn cores recovered also support domestication (Hesse 1984, Perkins 1973). At the site of Ali Kosh (Iran) (9,000 BP), mortality profiles indicate goat domestication (Higgs and Jarman 1972). Wasse (2001) believed that goats were domesticated early in the PPNB, based on the presence of goats at the site of Tell Aswad (Syria). The location of the site is not within the natural wild goats' range (Wasse 2001).

Sheep in the Archaeological Record: The earliest reported domestic sheep were found at

[42] Hesse (1984) notes these footprints could have come from sheep.

Zawi Chemi Shanidar (Iraq), dating to 11,000 BP. Perkins (1964, 1973) based domestication status on demographic profiles, age (high number of juveniles), and species presence (sheep over goats) (Higgs and Jarman 1972, Perkins 1964, 1973). Crabtree (1993) questioned these results due to small sample size and lack of statistical analysis. Crabtree's statistical analysis indicates an increase in juveniles, but this mirrored an earlier Pleistocene period (Mousterian) as well, a culture not believed to have domestic animals (e.g., Neanderthals) (Crabtree 1993). Bökönyi (1976) believed that the high number of mature, male sheep denoted domestication at the site of Asiab (Iran) around 10,000 BP. However, Zeder (1999, 2011) questioned this assessment based on other sites' demographic profiles. Zeuner (1963) reported domestication at Belt Cave (Iran) and Jarmo (Iraq). Like with goats, these results are questionable (Zeuner 1963).

Pastoralism

General Pastoralism

Spooner (1972) defined pastoralism as a subsistence strategy reliant on adapting to the environment in which herdsmen lived. Levy (1992) defined pastoralism as holding domestic animals as property with economic value, and being dependent on these animals. Chang and Koster (1986) and Abdi (2003) shared this view of pastoralism as well. Khazanov (1994) saw pastoralism as an economic food production system in which the majority of the population practiced a migratory pattern to sustain animal herds. Pastoralism can be subdivided into more nuanced types. For instance, Abdi (2003) discusses three types: mobile, transhumant, and nomadic. Mobile pastoralism is moving herd animals just beyond agricultural fields. Herders travel a few days walking distance from the settlement. Transhumant pastoralism reflects a response to environmental changes. Herders, and possibly whole settlements, move locations

based on seasonal conditions (e.g., move to highlands in summer and lowlands in the winter). Finally, nomadic pastoralism is the traditional view of pastoral life. Herders constantly move across the landscape, looking for pastures (Abdi 2003, Bar-Yosef and Khazanov 1992, Cranstone 1969, Khazanov 1994). Modern Bedouin societies indicate movement is regulated by several factors. For instance, animals' water needs contribute to movements. Sheep require water every day to two days while goats need water every four days. Location for night camps and the type and pasture quality influence movements. Pasture quality is especially important during the birthing season, as mothers need extra resources during pregnancies and after birth (Levy 1992). Other movements are based on relationships with not only other pastoralists but agriculturalists as well. For example, modern pastoral societies maintain movement patterns in relation to agriculture crops. Pastoralists move their animals to harvested fields to allow animals to feast on the harvest debris. This strategy provides farmers with fertilizer for their fields (Khazanov 1994). Due to these factors, movements are not predictable and may alter with altitude as well (Khazanov 1994, Levy 1992).

Modern pastoral populations vary from one another in their means of movement, settlement, and self-reliance (Spooner 1972). Subsistence varies with some pastoralists hunting and gathering wild resources (Bernus 1988, Casimir 1988). Meat use depends on the circumstances within the society. For instance, some rely more on vegetable resources as the major source of food. Herds are reserved for economic gain (Cranstone 1969). Further, secondary resources, such as wool and milk products, differ in use and production (Degen 2007, Khazanov 1994). A concise definition of pastoral life was difficult to obtain, because of the variation in pastoral practices (Spooner 1972). Therefore, understanding what occurred in past, (e.g., how pastoralism started, society structure and relationship with other people, the amount of

movement, etc.), is difficult to ascertain, as there may have been as much variation as there is today.

Bar-Yosef and Khazanov (1992) believed, based on modern ethnographic examples, a pure pastoralist economy did not exist during the Neolithic. Reasons for this belief include lack of mounted animals to control both herds and other people. Further, the size of herds needed for trade and dietary resources could not be met during inception of pastoralism/ domestication. For instance, if secondary products (e.g., milk) had not been developed within animals yet, people may have struggled to meet their own immediate needs let alone develop the herd for economic benefit (Bar-Yosef and Khazanov 1992). Khazanov (1994) later recognized incipient pastoralism (semi-nomadism or distant-pasture husbandry/ yaylag) existed after the Neolithic Revolution. These early stages did not require large herds or control animals to proliferate (Khazanov 1994). Hole (1978) noted that early pastoralists living in resource-rich areas did not have as difficult a life as modern pastoralists living in marginal ones do today. Adaptations to desert-steppe and desert areas are not apt then for reconstructing the past (Hole 1978). However, not much other evidence is available to reconstruct pastoral origins. Archaeological indicators are difficult to ascertain due to the nature of nomadism, although some markers do exist, such as structures and indicators of animal penning (Chang and Koster 1986).

Pastoralism Origins

The origins of pastoralism are not well understood. No single hypothesis for pastoral origins has been accepted. Further, like the adoption of domestic animals, herding development may not have occurred at the same time and for the same reasons around the Near East (Abdi 2003, Hole 1978, Rosen 1988). Some early researchers believed animal domestication/

pastoralism occurred prior to plant domestication since herders just maintain animals, while agriculturalists had both plants and animals. Other researchers believed plant domestication occurred first, providing food for animals (Wright 1992). Chang and Koster (1986) suggested that pastoralism developed during the Neolithic at the same time as agriculture. Pastoralism was adopted as an alternative subsistence method. Because pastoralism and agriculture mesh in a beneficial way, it appears their social structures developed together (Chang and Koster 1986, Layton et al. 1991). Hole (1978) suggested that pastoralism did not necessarily need agriculture to develop into a subsistence system. However, more success came when the two systems worked together (Hole 1978).

Climatic Change: Bar-Yosef (1984) suggested that once agriculture was adopted in the Near East, those living on the periphery (marginal areas) were more susceptible to changing climate, water resources, and game movement. Therefore, they adopted pastoralism, allowing maintainable life in arid areas (Bar-Yosef 1984). Curwen (1953), following Childe (1939, 1957), suggested that desiccation caused hunters to develop into herdsman in order to maintain and protect animals they depended on. Curwen also provided another explanation in which a single group developed both domesticated plants and animals. This hypothesis is supported by the presence of domesticated animals at agricultural sites. However, these remains might simply have been the remnants of trade between agriculturalists and pastoralists (Curwen 1953). Khazanov (1994) also believed that climate played a role in the establishment of pastoralism. However, he suggested climate was not the only player, as cultural and economic factors had to be established first before climate triggered pastoralism (Khazanov 1994). Simmons (1997) believed that monsoonal rains and their aftermath triggered the shift in subsistence. Farming and

herding greatly degraded the lands and could no longer meet the needs of growing populations. Debris, such as cobbles, washed into farming lands after rain and posed farming issues. Rains decreased by the end of the PPNB/ beginning of the PN, but the damage had been done and many farming sites failed (Simmons 1997).

Evolution of Relationships: Many early ideas on pastoral origins evolved from the idea that pastoralism began before agriculture. The nomadic way of life was a natural outgrowth of the relationship between hunters and the herds they followed (Khazanov 1994). For instance, Hatt (1953) credited pastoralism originating with hunters using tamed animals for decoys. Later, other uses, such as transportation or milking, developed to increase animals' profitability. Krader (1959) proposed two ideas based on animals' seasonal movements. Pastoralism was either an outgrowth from humans watching wild animals' movement and continuing this pattern to maintain their herds, or simply allowing domestic flocks to follow their natural migration instinct. In either case, pastoralism developed to mimic animals' natural ability to survive (Krader 1959).

On the other hand, pastoral development could have stemmed from division of labor, which existed after the Neolithic Revolution. This development relied upon the circumstances within society (e.g., what the people needed), and what cultural structure was in place to meet those needs (Khazanov 1994). Therefore, pastoralism developed during early village life in which herding occurred. As group need increased and herders moved further away for pastures, herders may have grouped together. This development led to a transhumance-based and then nomadic-based pastoralism (Abdi 2003).

Issues: Typically, ideas of pastoralism originating from the evolution of relationships are based on ethnographic accounts of reindeer herders. Khazanov (1994) questions this analogy, as early humans would have had difficulty following wild herds (no horses or other animals to keep up with herd pace). Nomads lacked fodder resources needed with herd control. Furthermore, natural herds separated and combined, increasing the difficulty in domesticating wild herds (Khazanov 1994).

Exploration: Cauvin (2000) used evidence from Neolithic nomadic sites around the Near East to contradict the idea that pastoralism came about because of arid conditions. Further, he argued that nomadism did not develop due to herders or animals being social pariahs resulting from environmental degradation. He found pastoral sites located in a wide range of ecological areas, not just the desert. In addition, pastoral practices occurred earlier than traditionally thought. He opined that pastoralism allowed Neolithic people to travel and explore new areas while still relying on their preferred food supply (Cauvin 2000).

Population Increase: Alternatively, pressure for resources may have driven agriculturalists to force herders away from valuable land. Pastoral people were driven away from any potential agriculture lands to marginal or arid lands, as populations grew (Khazanov 1994; Levy 1983, 1992; Sauer 1969). If so, community fissioning would have become more common until herders established new communities centered on herding. Agriculture then would have become only a minor subsistence strategy within these societies (Bar-Yosef and Khazanov 1992). Lees and Bates (1974) believed that the breaking point between agriculture and herding occurred when farmers started relying less on rain-fed agriculture (i.e., growing

crops utilizing rain and the groundwater it supplies), and started building irrigation canals. Irrigation allowed farmers to spread out across the landscape, and required herders to increase their distance to avoid crops (Lees and Bates 1974).

Other: Spooner (1971) described pastoralism as an adaptation to the conditions in which people lived. Bonte (1981) suggested that there were multiple factors behind pastoral acquisition, each contributing differently based on the specific area's needs. Pastoral growth and spread depended on profitability. This profitability increased by expanding mobility and changing societal structures (e.g., building relationships between sedentary and more mobile people) (Bonte 1981). Similarly, Rosen (1988) believed that environmental, social, and technological factors all led to pastoral economy.

Martin (1999) discussed the fact that during the initial stages of herding, hunting of animals still occurred. The faunal demographic profiles recovered from the archaeological record do not point to a specific husbandry strategy (e.g., milk productions). Martin therefore suggests sheep and goats are instead part social status indicators, with sheep and goats used for gifts, exchange, or prestige indicators (Martin 1999).

Materials

The study proposed here will examine ovicaprines from the archaeological site of Gritille (Turkey) to test hypotheses regarding domestication and handling of animals during the Neolithic. In this research, dental mesowear and microwear analyses will be used to understand diet during this critical period. Both these methods utilize the amount of enamel wear present on the teeth to reconstruct dietary patterns, as dental wear provides important insight into an

animal's life. During life, dental wear guides dietary choices, the amount of food eaten, and in extreme cases of dental senescence, leads to starvation and death (Jurado et al. 2008). Dental mesowear and microwear analyses provide a way to understand diet through different aspects of wear, gross and microscopic. When comparing archaeological animals from the Neolithic to wild animals, understanding of how human control modified wild dietary types can be understood.

Gritille Höyük (Turkey)

The 1.5-hectare site of Gritille was located on a bluff on the right bank of the Euphrates River. This Karababa Basin site is currently covered by water due to the Ataturk Dam construction (Figure 4.6) (Ellis and Voigt 1982, Monahan 2000, Stein 1988, 1989). Excavations were limited to several field seasons in the early 1980s under the direction of Richard S. Ellis from Bryn Mawr College as part of the Lower Euphrates Salvage Project (Monahan 2000, Stein 1989). The site has discontinuous occupations dating to the Neolithic, Bronze, and Byzantine-Seljuk cultural phases (Ellis and Voigt 1982). The Medieval period is the largest and best preserved (Voigt 1988). Gritille's location on the Euphrates floodplain provided farmable land to its occupants over its history of settlement (Ellis and Voight 1982). The modern climate consists of hot summers and mild, moister winters, which can produce snow at higher elevations (Ellis and Voigt 1982, Monahan 2000). Enough rain fell during the winter to support dry farming, with mean yearly rainfall between 400-600mm (Stein 1986a, 1988, 1989). Furthermore, three environments surround the site, providing a range of resources. The Mediterranean woodlands are comprised of deciduous trees and pines at higher elevations, the Irano-Turanian steppe-desert consists of shrubs and wild cereals, and the Kurdo-Zagrosian

vegetation located in the uplands consists of oak-pistachio forests. Animals in these zones include gazelles, hyenas, foxes, deer, and brown bears (Monahan 2007, Stein 1988). Specifically within the Kurdo-Zagrosian environs, one can find sheep and goats. Sheep live in the foothills while the goats prefer the mountains (Monahan 2000). Further, its location between the Euphrates and Mediterranean, places Gritille in a natural crossroads for trade (Ellis and Voigt 1982).

Figure 4.6. Map of Near East archaeological sites used within this research imposed on a current topographical map. The main archaeological site of Gritille is marked in red balloon while the comparison sites (Hacınebi and Tell Qarqur) are indicated by blue (map created in Google Scribble Maps).

Great care was taken in material recovery from Gritille (e.g., wet and dry screening) in order to be able to understand the site's economy. Most of the archaeological materials were filtered through .5cm meshed screen. The material not dry screened went through a wet screening process (Stein 1988). The majority of flora and faunal material recovered came from fire or storage pits and secondary trash deposits. This consistency in recovery allows the

material between phases to be compared without having to deal with contextual issues (Monahan 2000, 2007). Gritille's Neolithic botanical remains indicate a shift in agricultural resources over the period associated with domestication. A decrease in pulses occurred over time (65% pulses to only 20% in the late PPNB). Concurrently, an increase in cereals (two-row barley, einkorn, emmer, and wheat) took place, with barley contributing the highest portion of cereals (Miller 2001). Another shift was seen at Gritille in fuel, from wood to dung. This switch in fuel resource indicates possible change in the environment around the site, especially towards the end of the Pre-Pottery Neolithic occupation (Miller 1996). This change may have been due to farming or herding practices (e.g., Rollefson and Köhler-Rollefson 1989) or some other environmental or climatic change (Monahan 2000).

The lowest stratigraphic layer recovered from Gritille dates to Pre-Pottery Neolithic B, based on radiocarbon dating. Within the 4 meter Neolithic layer, over 80,000 animal remain fragments were recovered (Stein 1886a, 1988). The Neolithic occupations occurred in four distinct stratigraphic layers. Layers A and B were from the upper Neolithic (i.e., later) and C and D represented the earlier occupations (Monahan 2000). The basal layer indicated the widest variety of animal use, but even at this time, initial steps towards sheep and goat domestication could have occurred (Monahan 2000). The majority of identifiable bones throughout the Neolithic occupation came from caprines (Stein 1986a, 1988). Although bone ratios indicated sheep and goats were represented equally in faunal remains, over time, sheep became the preferred stock animal (Monahan 2000). This preference changed during Phase A when an increase in cattle and pig use occurred (Monahan 2007). Later, during the Medieval occupation, goats outnumbered sheep (Monahan 2000). Other animals recovered from the Neolithic occupation included pigs, cattle, gazelles, deer, and dogs. Although located near water, aquatic

resources did not appear to contribute greatly to the subsistence base (Stein 1986a). Further, due to the amount of meat provided, cattle may have had a greater dietary impact than sheep and goats (Monahan 2000).

The Neolithic fauna used in this research arise from three of the four sub-phases (C-A). The earliest Phase (D) was not used due to lack of identified material from this phase (Monahan 2007, Voigt 1988). Sheep and goats appear throughout the sequence as discussed above, but only the later phases (Phase B) suggest domestication through traditional indicators, such as morphology. Caprine sizes began to decrease during Phase C but did not reach a consistent size change until Phase B. This signal suggests that initial husbandry began during Phase C, but either interbreeding still occurred or hunting of wild animals continued throughout this occupational level (Monahan 2000). Demographic reconstruction indicates juvenile cull occurred prior to Phase B, but it was not until Phase B that male cull was observed (Monahan 2000, 2007). Stein (1986a) reported the cull pattern followed the meat model as discussed previously. Most likely domesticated animals were relied on during the spring and autumn months. Wild animals were used during the winter, when their migrations brought them close to the site, and provided abundant subsistence resource (Stein 1986a).

Approximately 3,000 years passed between the Neolithic occupation and the next occupation at Gritille (Stein 1988). During the Early Bronze Age, Gritille was a large village connected to the larger urban centers around the region. Approximately 5,000 animal fragments were recovered from this period, with caprines making up over 50% of the remains (pigs 17%, cows 9%). Like the Neolithic, sheep predominated the assemblage. However, based on the demographic profile, no specific subsistence strategy appears. Instead, the animals were used to meet local needs. During the Medieval period, Gritille evolved into a fortified site, with three

distinct occupational areas. Over 12,000 animal fragments were recovered. The majority of these fragments are pig (49%) while sheep contribute to 28% of the faunal assemblage. However, the sheep and goat distribution varied between the distinct areas, indicating different uses between classes of villagers. In general, demography points to animals being used for local meat products (Stein 1986b, 1988).

The Gritille specimens, currently housed at the Oriental Institute (Chicago) were examined for appropriateness for dietary reconstruction methods. Individual tooth contextual information was recorded along with information for dental analyses (described below). Measurements and photographs of the individual teeth were also taken to provide reference material during the latter parts of the analyses occurring at the University of Arkansas. In all, 175 specimens were analyzed, and these were ascribed to the three Neolithic phases at Gritille (Table 4.2). Specifically, Phase A provided 29 individual teeth, Phase B 131 teeth, and Phase C 15 teeth for analysis. The disparities are due to the differences in the faunal material recovered from each phase (e.g., Phase B provided the most faunal remains of all Neolithic phases). Another subset of 12 specimens was examined from the Medieval occupation as well to serve as one of the comparison samples. No specimens were sampled from the Bronze Age occupation because of the lack of identified material from this occupation available during the visit.

Cultural Phase	Lower Molar	Upper Molar	Indeterminate Tooth	*Total Teeth*
Phase C	5	9	1	**15**
Phase B	74	57	0	**131**
Phase A	12	17	0	**29**
Neolithic Total	**91**	**83**	**1**	**175**
Medieval	4	8	0	**12**
Gritille Total	**95**	**91**	**1**	**187**

Table 4.2. Distribution of Gritille teeth examined for this research broken down by tooth type and cultural phase.

Methods

Tooth Selection

Upper and lower molars were selected for dietary reconstruction analysis from the archaeological samples following methods discussed in Chapter 3. Both upper and lower can be used for microwear analysis (e.g., Merceron et al. 2004a, b; Ungar et al. 2007) while the same upper dentition is used for mesowear analysis (e.g., Franz-Odendaal and Kaiser 2003, Kaiser and Solounias 2003, Schubert 2007). All three molars were utilized to increase the sample sizes for the dietary reconstruction techniques. If jaw fragments were available from the excavated unit material, care was taken to select the second molar. However, most teeth were recovered individually from the units.

Natural differences in dietary preference between sheep and goats (discussed previously in Chapter 3 and above) may have resulted in different handling techniques. As such, dietary differences may have occurred between the sheep and goats within the sample. Although

methods for definitive separation exist, such as isotopic analysis (e.g., Balasse and Ambrose 2005) and genetic testing (e.g., Buckley et al. 2010), these each require sample destruction, which was not possible for this study. However, the failure to categorize fully the archaeological material as either sheep or goat should not be a problem in reconstructing husbandry impacts on sheep and goats. Mainland (1998a) examined goat and sheep microwear of animals handled in the same manner and found no reportable dietary difference (i.e., similar microwear patterns) between the two species. Later studies by Mainland and Halstead (2002) using microwear and Pearson et al. (2007) using isotopes found similar diets between sheep and goats. These studies indicate that during the early stages of animal husbandry, sheep and goats were eating similar diets. As such, goats and sheep can be grouped together to understand early husbandry attempts without too much concern for possible differences in dietary signals.

Mesowear Analysis Procedures

Visual inspection for mesowear data occurred after initial inspection for lack of taphonomic alterations and sufficient dental wear to allow for analyses (e.g., Rivals and Athanassiou 2008, Schubert 2007). Goat and sheep upper molars were examined and surface relief characteristics recorded (cusp shape and occlusal relief) following methods described in Fortelius and Solounias (2000). Cusp relief (high or low) indicates the distance from the cusp tip to the area between the cusps, and provides information on abrasive wear within the diet. Cusp shape (sharp, rounded, or blunt) informs on whether diet created more attritional (sharp) or abrasion (rounded or blunt) wear (Figure 4.7) (Fortelius and Solounias 2000). Mesowear scores were recorded for upper first or second molars from the archaeological samples. Both upper molars are recorded in the archaeological sample due to these teeth being difficult to distinguish

in isolation, which most of the teeth recovered were. For samples that included molars left intact with maxillae, preference was given to second molars. As Kaiser and Solounias (2003) and Franz-Odendaal and Kaiser (2003) found, mesowear can be extended beyond the molars initially used by Fortelius and Solounias (2000) and still be faithful to the methodology and results.

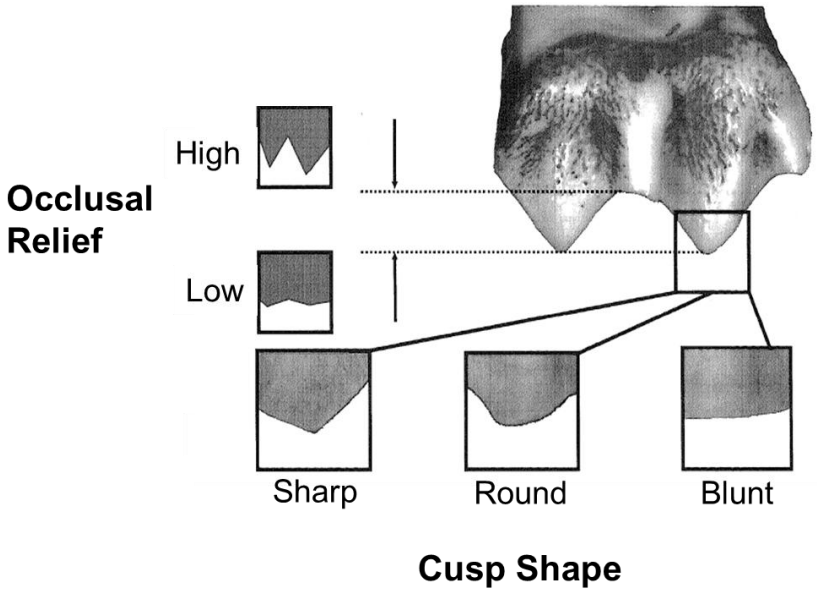

Figure 4.7. Image of an ungulate tooth's buccal surface where examination for mesowear analysis occurs. On the left side of the image, the measures of occlusal relief (high or low) are shown. On the bottom, the measures of cusp shape (sharp, round, or blunt) are illustrated (modified from Clauss et al. 2007). This measurement follows standard protocols established by Fortelius and Solounias (2000).

Molding and Casting

After examination for potential post-mortem damage (e.g., Teaford 1988), suitable molars were cleaned with alcohol and molded for microwear texture analysis. Molds were created by applying President's Jet, a high-resolution polyvinylsiloxane dental impression material (Coltène-Whaledent, Hudson, MA) to the occlusal surface of the second molar. The molding procedure was non-destructive, and created a precise, high-resolution impression of a tooth's surface (e.g., Beynon 1987, Teaford and Oyen 1989 b). President's two-part putty system (Coltène-Whaledent, Hudson, MA) shored up the molds so casts could be produced replicating the original enamel surface. Casts were created using Epotek 301 resin and hardener (Epoxy Technology Inc., Billerica, MA) following conventional procedures (e.g., Ungar 1996).

Microwear Texture Analysis Procedures

Following Merceron et al. (2004a, b, 2005), Rivals and Deniaux (2003, 2005), Scott (2012), and Ungar et al. (2007), the lingual paracone[43] of the upper molars were examined (Figure 4.8). This research uses dental microwear texture analysis (DMTA) to understand the microwear found on this facet. Instead of quantifying a tooth's surface by the number and size of pits and scratches as previous microwear studies have done, DMTA uses five variables to characterize overall surface texture (Scott et al. 2006). These variables relate to slightly different aspects of diet. Specifically, anisotropy and complexity have been shown to reflect dietary differences between species, including ruminants (Scott et al. 2005, Ungar et al. 2007). Higher anisotropy values tend to indicate a grazer diet while higher complexity is seen with a browse-based diet (Ungar et al. 2007). This methodology will provide a more nuanced approach to

[43] The facet examined occludes during the shearing of the Phase I movement of the molars across the maxillary molar (Merceron et al. 2004a, b).

understand the vagaries of domestication, beyond what SEM studies are capable of doing.

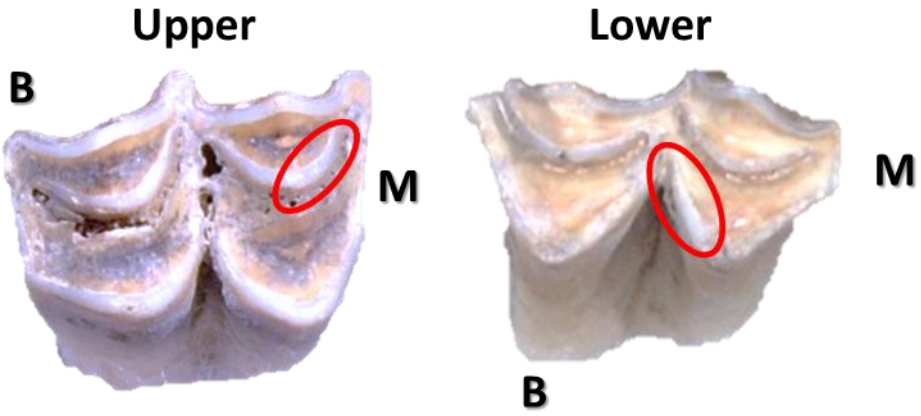

Figure 4.8. Location of Phase I shearing facets, indicated by red ovals, used for Dental Microwear Texture Analysis. Both teeth are archaeological samples from Gritille used within this analysis and are from the right side of the dentition (Mesial: M, Buccal: B). These areas were sampled following convention (references), as they have been shown again and again in the past to separate groups by diet. Photograph by M. Zolnierz.

A Sensofar Plμ white-light scanning confocal profiler (Solarius Development Inc., Sunnyvale, CA) was used to examine the microwear on the prescribed location of the casts[44] (Figure 4.8). The confocal profiler creates three-dimensional point-clouds of the tooth's surface with a lateral sampling interval of 0.18 μm and a resolution of 0.005 μm (with a 100x objective lens). Following convention, a series of four adjacent scans were used for a total scanned area of 276 X 204 μm (Scott et al. 2006). The resulting point clouds were analyzed in Solarmap Universal software (Solarius Development Inc., Sunnyvale, CA), wherein surfaces were normalized and leveled. Any defects remaining on the surface when the mold was created (e.g., dust or dirt) were erased electronically, and therefore excluded from the surface scan data. The point-cloud data were imported into Toothfrax and Sfrax software packages (www.surfract.com) for scale-sensitive fractal analyses. Scale-sensitive fractal analysis is based on the principle that apparent surface texture varies with scale of observation (Scott et al. 2006). Three algorithms are used in this study: the length-scale rotational algorithm, the area-scale tiling algorithm, and the volume filling versus scale square cuboid filling algorithm (see Scott et al., 2006 for a detailed explanation). These result in the generation of data for five texture variables used to categorize microwear surface (discussed in Chapter 3).

Research Hypotheses

The research hypotheses for this part of the research center around husbandry methods at Gritille as the animals underwent domestication.

H_0 no domestication: no change in sheep central tendencies for mesowear and microwear variables.

[44] Since casts are an exact replica of the enamel surface of the original tooth, the facet location of the cast is in the same location as the original tooth.

Mechanism of Domestication

Two possible mechanisms, penning and herding, were considered. Penning would keep animals confined to a small space close to the site forcing them to rely on limited resources, and possibly fodder, for food. Herding, on the other hand, would take the animals further from the site during the day to forage. Although the animals may have been penned at night, sheep are diurnal eaters so no new food sources would likely be exploited, although rumination still occurs (Animut and Goetsch 2008, Balch 1955, Hulet et al. 1975). If domestication first occurred by penning, increased abrasion is expected, as animals quickly reduced foliage height and ingested more soil. Less variable wear is expected, as the range of foods available was limited.

H_{B1} penning: excess grit should cause low and blunt mesowear and texture fill volume in teeth. As mesowear reflects diet over months to years, if sheep constantly consumed extra abrasives, more enamel would be worn away, resulting in a more extreme grazer signature with little to no occlusal and cusp relief left. Wild animals should have a grazer signature too but may have been able to select from parts less contaminated with soil, thus reducing grit intake and abrasion (Animut and Goetsch 2008 and references therein). Microwear, which reflects short-term diet, may not be as informative if resources exploited remained the same (although texture fill volume, which reflects feature size, may increase given rapid turnover of small features in a high wear environment).

H_{B2} restricted diet due to penning: little variation would be expected between specimens as all animals ate similar food (with higher levels of grit). If sheep were penned in an area with browse, they would be expected to rely more on less abrasive resources that result in more attrition, or tooth-tooth wear. If sheep were placed in a grazing environment, the mesowear

signature should show more abrasion resulting from high levels of grit or other abrasives (differences between attrition and abrasion, and their implications for mesowear patterns, are described below). Microwear can indicate if a browse-based diet was consumed, which would lead to higher texture complexity (e.g., pitting) and texture-fill volume.

H_{B3} foddering: mesowear and microwear signatures may suggest different diets from one another. If penning was used to control animals, foddering may have been needed during times when resources were scarce (e.g., Akeret and Rentzel 2001, Haas et al. 2008). Given Gritille's location, fodder could have come from browse resources around the Euphrates River (e.g., Hillman et al. 1997), remnants of the harvest, or plants collected and dried when resources were plentiful. Since foddering tends to be seasonal, mesowear might reflect a grazer diet, whereas microwear could show substantial variation, including some animals that had a browser signature given a browse diet in the days or weeks before death. If the fodder were graze-based, mesowear and microwear would likely present the same signatures although issues with grit contamination might remain.

If animal movements were limited by herding rather than penning, we would expect less overgrazing and less abrasion given avoidance of grit-laden swards. Preferred graze resources would have been more readily accessible including leaf blades, and young, green material (with seasonal changes, this may include more browse) (Arnold 1964). Controlled herding could lead to a narrower range of food if freedom of movement was reduced and animals could no longer travel to reach preferred resources. On the other hand, inhabitants may have herded animals in places not normally utilized such as near the Euphrates introducing browse resources, leading to wear that was more extensive.

H_{B4} narrow range of food: little variation found in mesowear and microwear between

specimens. If sheep were allowed to graze on their usual range of foods, they should show a typical grazer pattern in both mesowear and microwear, but if they lacked normal freedom of movement, the overall variation expected, especially in microwear, should be reduced. Since herding should have provided fresh food sources, the wear signatures should not show evidence of increased grit and extreme wear expected with penning.

H_{B5} wider range of food: more variable mesowear and microwear signatures found due to consumption of a wider range of food. During herding, if the sheep were moved through different environments such as woody brush, the mesowear and microwear should reflect the change in food resources. The combination of abrasion and attrition would be expected to lead to an intermediate mesowear signature. Similarly, microwear should vary, reflecting increased diet breadth.

Statistical Analysis

Mesowear

Mesowear analysis for the extant species followed calculations in Schubert (2004). Percentages for each mesowear variable were calculated (e.g., percent sharp, percent round, percent blunt, percent high, and percent low) based on the taxa and species. These percentages were imported into SYSTAT 13 (Systat Software, Inc., Chicago, IL) to allow for hierarchical cluster analysis. Cluster analysis was based on complete linkages and Euclidean distances following Schubert (2004, 2007).

Microwear

The results of scale-sensitive fractal analyses, calculated by Toothfrax and Sfrax software

packages (www.surfract.com), were exported to Excel (Microsoft 2010) to allow further calculations. As stated previously in the microwear methods section, four contiguous scans of each wear facet were taken. However, instead of basing further analyses on each of these individual scans, the median values were calculated. The median value provides a more balanced view of the individual's wear surface and follows the protocol of previous microwear texture analyses (e.g., Scott et al. 2006, Ungar et al. 2007). In addition, the microwear texture data were rank-transformed, as the assumptions for normality in parametric tests are typically not met for such datasets (Conover and Iman 1981, Scott 2012). Ranked data were analyzed using multivariate analysis of variance (MANOVA) with SYSTAT 13 (Systat Software, Inc., Chicago, IL). The dependent variables were the microwear texture variables, while the animal groups served as the independent variable. When significance was found, individual analysis of variance (ANOVA) for the significant dependent variable was carried out along with pairwise comparisons to understand where the significance occurred. Pairwise comparisons included both Tukey's Honestly Significant Difference (Tukey's HSD) and Fisher's Least Significant Difference (Fisher's LSD) to balance the risk of Type I and Type II errors (Cook and Farewell 1996). In addition to running statistical analyses on rank-transformed data, the data also were transformed by Levene's transformation following Plavcan and Cope (2001). This data transformation provides information on the degree of variation between the specimens analyzed (i.e., within-sample distribution rather than central tendency). Once transformed, a MANOVA was performed, following the same steps as the rank-transformed data.

Results

Mesowear

Hierarchical Cluster Analysis 1: Mesowear Variables by Neolithic Phase: A total of 7 cluster analyses were performed on the mesowear data based on either high or low cusp and the three shapes the tooth could have (sharp, round, blunt or sharp and blunt). Table 4.3 provides the data used for this hierarchical cluster analysis. Appendix 2 provides any other statistical charts and graphs for data analysis in Chapter 4 not given in the text, including the graphs showing the clustering pattern of the mesowear scores. Regardless of the grouping of the mesowear variable percentages, the same cluster output was seen for all seven tests. In each case, Phase B clustered separately from Phases A and C. Gritille Phase B was when animals appeared fully domesticated via traditional reconstruction methods. Phase B has the highest percentages for high and sharp cusps. This pattern reflects a more attrition-based diet. Attrition is caused when teeth contact each other during the chewing cycle, which is required to process the food ingested. Typically, the mesowear numbers associated with Phase B indicate a more browse-based subsistence. Phases A and C (the latest and earliest phases respectively) have mesowear values more aligned with abrasion and a graze-based diet.

Neolithic Phase	Number	% high	% low	% sharp	% round	% blunt
GRITILLE A	20	0.85	0.15	0.30	0.60	0.10
GRITILLE B	93	0.97	0.04	0.57	0.41	0.02
GRITILLE C	11	0.82	0.18	0.27	0.55	0.18

Table 4.3. Percentage of each mesowear variable scored for each of the three Neolithic periods studied (A, B, C). Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt.

Hierarchical Cluster Analysis 2: Mesowear Variables by Neolithic Phase Combined with Wild Taxa: For the cluster analyses based on percent high paired with cusp shape, all the cluster analyses indicated the Neolithic phases paired with gazelle (Appendix 2). Sheep and goats paired by themselves in a separate group. The Neolithic phases, along with gazelles, have more buccal cusp tip wear than the wild sheep and goats (Table 4.4). This pattern would signal more abrasive elements within the Neolithic animals' diets than what occurred in the wild. For percent low and sharp, Neolithic Phase B stands out from the other Neolithic phases again along with the wild taxa. For percent low and round, all the Neolithic phases form a distinct group from the wild taxa. Percent low and percent blunt separates Phase B, goats and sheep as one group and Phases A, C, and gazelles as another group. From the cluster analyses, the Neolithic Gritille animals overall diet were distinct from their wild sheep and goat counterparts. Specifically, the Neolithic species appear to have undergone more overall wear, especially Phases A and C. Phase B animals appear to have subsisted on a different lifetime diet leading to patterns more consistent with sheep and goats. At the very least, husbandry affected the diet of Gritille animals, including the very earliest animals (Phase C), which were not morphologically domestic.

	Number	% high	% low	% sharp	% round	% blunt
GRITILLE A	20	0.85	0.15	0.3	0.6	0.10
GRITILLE B	93	0.97	0.04	0.57	0.41	0.02
GRITILLE C	11	0.82	0.18	0.27	0.55	0.18
Goat	50	100	0	0.3	0.68	0.02
Gazelle	60	0.88	0.12	0.18	0.75	0.07
Sheep	84	100	0	0.18	0.80	0.02

Table 4.4. Percentage of each mesowear variable scored for each of the three Neolithic periods studied (A, B, C) and three animal taxa (gazelle, goat, sheep). Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt.

Hierarchical Cluster Analysis 3: Mesowear Variables by Neolithic Phase Combined with Wild Species: Since there appears to be distinct patterns between the natural wild diet and the animals recovered from the Neolithic Gritille phases, cluster analyses were performed using the individual wild species (Table 4.5). This analysis allows understanding of where the Neolithic animals group with species of known environmental origins. For percent high with all three cusp shape variables and combined sharp and blunt, all three Neolithic phases cluster with gazelles, specifically *Gazella dorcas dorcas* and *G. subgutturosa subgutturosa* (Appendix 2). As seen in the above cluster analysis, gazelles are found in desert and semi-desert environments, which provided grit to the diet. Grit then must be influencing the dietary wear of the Neolithic animals. A different pattern emerges when the percent low and cusp shape are examined. For percent low

and percent sharp, Phase A and Phase C cluster with *Capra hircus aegagrus* and *Ovis aries isphahanica.* As seen in Chapter 3, these two species often have microwear similar to the dry living gazelles. Specifically, these animals tend to wear away their cusp tip due to abrasion, not attrition. For percent low and percent round, the Neolithic phases cluster with all specimens except three species of sheep, *O. a. aries*, *O. a. urmiana*, and *O. a.* sp. This pattern is interesting, as the microwear analysis indicated these animals had different diets (see Chapter 3). For percent low and percent blunt, Phases A and C once again cluster with gazelles. Phase B clusters with the rest of the goats, sheep, and *G. gazella bennetti* except for *C. h. hircus*, which is an outlier to all the clusters. Overall, Phases A and C once again are clustering towards gazelles and away from the wild sheep and goats. These animals have greater abrasive wear leading to duller cusp tips (low and blunt) when compared to wild species. Phase B has more tendency towards sheep, exhibiting more overall wear similar to grazers. The tendency towards a more wild diet but with some girt may reflect a more natural subsistence allowance in the husbandry practices. This natural subsistence may be especially visible in the last cluster where Phase B and *O. a. gmelini* cluster near each other. In Chapter 3, *O. a. gmelini* was found to be an obligate grazer.

	Number	**% high**	**% low**	**% sharp**	**% round**	**% blunt**
GRITILLE A	20	0.85	0.15	0.30	0.60	0.10
GRITILLE B	93	0.97	0.04	0.57	0.41	0.02
GRITILLE C	11	0.82	0.18	0.27	0.55	0.18
Capra hircus aegagrus	21	100	0	0.19	0.81	0
Capra hircus hircus	3	100	0	0.67	0.00	0.33
Gazella dorcas dorcas	12	0.83	0.17	0.75	0.17	0.08
Gazella gazella bennetti	6	100	0	0.50	0.50	0
Gazella subgutturosa subgutturosa	12	0.83	0.17	0.75	0.17	0.08
Ovis aries aries	4	100	0	0	100	0
Ovis aries gmelini	10	100	0	0	0.90	0.10
Ovis aries isphahanica	3	100	0	0.33	0.67	0
Ovis aries laristanica	4	100	0	0.50	0.50	0
Ovis aries sp.	6	100	0	0	100	0
Ovis aries urmiana	1	100	0	0	100	0
Ovis vignei dolgopolovi	11	100	0	0.09	0.91	0

Table 4.5. Percentage of each mesowear variable scored for each of the three Neolithic periods studied (A, B, C) and individual animal species. Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt.

Microwear

MANOVA 1: Comparison of Gritille Neolithic Periods: The MANOVA based on the Gritille Neolithic periods examined (C, B, A) as the independent factors and the microwear texture variables as the dependent factors (Table 4.6) indicated that heterogeneity was significant (*HAsfc*$_9$ p= 0.012, *HAsfc*$_{81}$ p= 0.044) (Table 4.7). All other variables provided no significant difference and therefore, no further testing occurred with these variables.

PHASE		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	**3x3*HAsfc* Median**	**9x9*HAsfc* Median**
A	Mean	1.957	.004	.248	9409.344	.492	.902
	N	26	26	26	26	26	26
	Std. Deviation	1.144	.001	.136	4992.238	.1293	.259
	Median	1.686	.004	.208	10342.939	.494	.858
	Skewness	1.073	.374	1.854	-.356	.819	.792
B	Mean	1.831	.004	.539	8227.177	.414	.790
	N	82	82	82	82	82	82
	Std. Deviation	.772	.001	2.577	4694.084	.125	.211
	Median	1.721	.004	.153	8512.543	.392	.727
	Skewness	1.376	.204	8.898	.102	1.209	.912
C	Mean	1.688	.004	1.539	10434.783	.430	.718
	N	15	15	15	15	15	15
	Std. Deviation	.768	.001	3.412	5194.801	.184	.238
	Median	1.535	.004	.208	12023.322	.416	.684
	Skewness	1.842	.285	2.457	-.611	.887	.467

Table 4.6. Table of general statistics for each microwear variable for each of the three Gritille Neolithic periods (A, B, C) analyzed during MANOVA 1.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	683.105	2	341.553	0.265	0.767
Error	154,378.895	120	1,286.491		
EPLSAR_MEDIAN	523.131	2	261.566	0.203	0.816
Error	154,537.869	120	1,287.816		
SMC_MEDIAN	1,742.638	2	871.319	0.682	0.508
Error	153,319.362	120	1,277.661		
TFV_MEDIAN	4,469.126	2	2,234.563	1.781	0.173
Error	150,592.874	120	1,254.941		
_3X3HASFC_MEDIAN	10,949.116	2	5,474.558	4.559	0.012*
Error	144,112.884	120	1,200.941		
_9X9HASFC_MEDIAN	7,854.556	2	3,927.278	3.201	0.044*
Error	147,207.444	120	1,226.729		

Table 4.7. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was p < 0.05. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

Tukey's HSD for $HAsfc_9$ found the two later phases of Neolithic Gritille, A and B, significantly differed from each other (p= 0.011). Fisher's LSD found Phase A significantly different from B (p= 0.004) and the early occupation of C (p =0.031). The latter is taken as suggestive, or of marginal significance as the result was not significant in the Tukey's test comparison. Still, these differences are as expected given reported dietary differences between

the three periods. For 9X9-heterogeneity, Phase A was significantly different from C under both Tukey's HSD and Fisher's LSD ($p= 0.047$, $p= 0.018$ respectively. Scott (2012) found in examining known-diet ungulates, browsers tend to have higher heterogeneity values than grazers for both heterogeneity calculations (Table 4.8). Gritille's heterogeneity is slightly complicated as the pattern is slightly different in heterogeneity variables. However, the highest heterogeneity occurred at the end of the Gritille occupation (Phase A). This difference in heterogeneity (the pattern of wear across the occlusal surface) may relate to a subtle shift in dietary properties. One hypothesis for the demise of Gritille's occupation is environmental degradation (i.e., the land around the site could no longer support the occupants). Possibly the shifting heterogeneity may reflect changing conditions that influenced the dietary resources available to the animals. This change could be due to several factors such as increasing amount of grit or dry soil at the site or a change of the types of plants that could grow in the degraded soil.

	Asfc	***EpLsar***	***Smc***	***Tfv***	**3X3 *HAsfc***	**9X9 *HAsfc***
Obligate Grazer	0.985	0.0065	1.343	2306.9	0.387	0.698
Browser-Grazer Intermediate	2.063	0.0037	0.417	6248.3	0.497	0.866
Browser	3.611	0.0022	0.767	10975.1	0.622	0.951

Table 4.8. Median dental microwear texture values from Extant African bovids used to show dietary distinctions. Animals have been placed into general dietary categories of grazers, intermediate feeders, and browsers based on observation of modern diets (modified from Scott 2012).

The MANOVA using the Neolithic Gritille phases data that were transformed using Levene's transformation (following Plavcan and Cope 2001) found complexity to be significant ($p= 0.027$) (Table 4.9). Both pairwise comparisons (Tukey's HSD and Fisher's LSD) following the individual ANOVA indicated Phases A and B variation were significantly different ($p= 0.022, 0.008$ respectively). Complexity was more variable in Phase A than Phase B. The complexity variable was also higher in Phase A. This finding may support the idea developed with the heterogeneity variable and a shift in diet due to environmental changes. Of course, to understand fully this hypothesis a microwear comparison is needed to compare the Gritille animals to known diet animals (see below). Nevertheless, of note is the fact that the significant microwear differences found most likely are not due to seasonal change in diet. As explored in Chapter 3 with known diet, extant animals, heterogeneity and complexity were not found to be significantly different between seasons (texture fill volume and anisotropy were significant).

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	0.503	2	0.251	3.707	0.027*
Error	8.139	120	0.068		
LEVEPLSAR	0.145	2	0.073	0.993	0.374
Error	8.776	120	0.073		
LEVSMC	3.029	2	1.515	2.475	0.088
Error	73.429	120	0.612		
LEVTFV	70.443	2	35.221	2.840	0.062
Error	1,488.315	120	12.403		
LEVHASFC9	0.137	2	0.069	2.236	0.111
Error	3.677	120	0.031		
LEVHASFC81	0.128	2	0.064	2.051	0.133
Error	3.744	120	0.031		

Table 4.9. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

MANOVA 2: Comparison of Neolithic Gritille with Wild Taxa: The Neolithic periods were compared to the wild taxa groups in a MANOVA with the periods and taxa as the independent variables and the dental microwear textures as the dependent variables (Table 4.10). Both texture fill volume and 3x3-heterogeneity showed significance (Table 4.11). All other variables provided no significant difference and therefore, no further testing occurred with these variables.

Specimen Group		***Asfc*** **Median**	***epLsar*** **Median**	***Smc*** **Median**	***Tfv*** **Median**	**3x3*HAsfc*** **Median**	**9x9*HAsfc*** **Median**
A	Mean	1.957	.004	.248	9409.344	.492	.902
	N	26	26	26	26	26	26
	Std. Deviation	1.144	.001	.136	4992.238	.129	.259
	Median	1.686	.004	.208	10342.939	.494	.858
	Skewness	1.073	.374	1.854	-.356	.819	.792
B	Mean	1.831	.004	.539	8227.177	.414	.790
	N	82	82	82	82	82	82
	Std. Deviation	.772	.001	2.577	4694.084	.125	.211
	Median	1.721	.004	.153	8512.543	.392	.727
	Skewness	1.376	.204	8.898	.102	1.209	.912
C	Mean	1.688	.004	1.539	10434.783	.430	.718
	N	15	15	15	15	15	15
	Std. Deviation	.768	.001	3.412	5194.801	.184	.238
	Median	1.535	.004	.208	12023.322	.416	.684
	Skewness	1.842	.285	2.457	-.611	.887	.467

Table 4.10. Table of general statistics for each microwear variable for each of the three Gritille Neolithic periods (A, B, C) and three animal taxa (gazelle, goat, sheep) analyzed during MANOVA 2. Continued on following page.

Specimen Group		***Asfc*** **Median**	***epLsar*** **Median**	***Smc*** **Median**	***Tfv*** **Median**	**3x3*HAsfc*** **Median**	**9x9*HA sfc*** **Median**
gazelle	Mean	2.233	.004	.887	12240.252	.419	.867
	N	29	29	29	29	29	29
	Std. Deviation	1.085	.001	3.300	3811.257	.095	.282
	Median	1.947	.004	.154	11731.732	.398	.777
	Skewness	.837	.204	5.307	-.374	.706	1.917
goat	Mean	1.772	.004	.254	6600.180	.390	.812
	N	36	36	36	36	36	36
	Std. Deviation	1.068	.001	.192	4843.095	.116	.237
	Median	1.551	.004	.180	6517.121	.364	.762
	Skewness	1.284	.355	3.080	.064	1.051	2.080
sheep	Mean	1.664	.004	5.804	7733.003	.419	.847
	N	70	70	70	70	70	70
	Std. Deviation	.902	.001	37.470	4907.395	.141	.340
	Median	1.490	.004	.209	7966.933	.380	.765
	Skewness	1.123	.370	8.251	-.029	1.539	1.833

Table 4.10 (Cont.). Table of general statistics for each microwear variable for each of the three Gritille Neolithic periods (A, B, C) and three animal taxa (gazelle, goat, sheep) analyzed during MANOVA 2.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	50,519.091	5	10,103.818	1.841	0.105
Error	1,377,266.295	251	5,487.117		
EPLSAR_MEDIAN	30,267.932	5	6,053.586	1.090	0.367
Error	1,394,569.784	251	5,556.055		
SMC_MEDIAN	15,663.343	5	3,132.669	0.556	0.734
Error	1,414,566.521	251	5,635.723		
TFV_MEDIAN	150,279.742	5	30,055.948	5.967	0.000*
Error	1,264,248.258	251	5,036.846		
_3X3HASFC_MEDIAN	72,077.035	5	14,415.407	2.688	0.022*
Error	1,346,321.969	251	5,363.833		
_9X9HASFC_MEDIAN	48,520.916	5	9,704.183	1.769	0.120
Error	1,376,861.154	251	5,485.503		

Table 4.11. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) and animal taxa (gazelle, goat, sheep) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

Tukey's HSD pairwise comparison following the ANOVA based on *Tfv* indicated that Gritille's Phase B was different from gazelles (p= 0.002) and Gritille's Phase C was significant from goats (p= 0.024). The finding of Phase B separating from gazelles follows the pattern seen in the mesowear analyses. Phase B has lower texture fill values compared to gazelles, which is consistent with a grazer. Phase C was the earliest occupation for Gritille and, although not significant in the Neolithic only MANOVA, does possess the highest *Tfv* values. According to

Scott (2012), the values lie within the browser range. This is interesting as the mesowear analyses indicated more abrasion during the periods, a characteristic of a grazer. For Phase B, Fisher's LSD finds significance in comparison for gazelles ($p < 0.001$). Fisher's LSD indicates significance for Phase A comparison with gazelles ($p= 0.029$) and goats ($p= 0.031$). Using Fisher's LSD, not only are goats different ($p= 0.002$) but so are sheep ($p= 0.013$) for Phase C. Since these results are based on Fisher's LSD, the differences should be considered suggestive, or of marginal significance at best. What stands out in these comparisons is that although all the Neolithic phases have higher *Tfv* than sheep or goats, Phase C texture fill volume is almost as great as the gazelles. Phase A and Phase B *Tfv* values are in-line with sheep. Phase B has the lowest level as expected for a grazer, although when compared to Scott (2012) the values place the Phase B animals in intermediate feeders. This pattern may reflect initial husbandry impacts on Neolithic animals' diets.

The 3x3-heterogeneity variable proves significant in Tukey's HSD pairwise comparison in two cases. Phase A is different from both goats ($p= 0.009$) and sheep ($p= 0.044$). This significant comparison is reflected in Fisher's LSD as well. Like MANOVA 1, the heterogeneity value for Phase A is larger than its comparisons (sheep and goats), and may be indicative of outside factors influencing dietary properties not seen in the other Neolithic phases or in the natural variation of the wild diets.

The MANOVA on the Levene's transformed data revealed both complexity and 9x9-heterogeneity to be significantly different ($p= 0.018$, 0.042 respectively) (Table 4.12). In examining the pairwise comparisons for complexity, Fisher's LSD found Phase B variation was significantly different from both goats and sheep. Tukey's HSD also indicated Phase B was significantly different from sheep ($p= 0.018$). This significance is interesting given previous

analyses placing Phase B within the ranges of wild sheep and goats. However, as seen with the mesowear analyses, increased grit could have increased the range of variation seen in the complexity variable during Phase B. Tukey's HSD found no significant pairings for the Levene's transformed 9x9-heterogeneity data. Fisher's LSD once again identified Phase B's variation significantly different from sheep ($p= 0.007$). The significant variation may provide credence towards human husbandry during Phase B, which although reflecting a natural diet in the wild, contained elements that increased the grit.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	1.342	5	0.268	2.801	0.018*
Error	24.154	252	0.096		
LEVEP	0.535	5	0.107	1.400	0.225
Error	19.247	252	0.076		
LEVSMC	9.766	5	1.953	2.117	0.064
Error	232.543	252	0.923		
LEVTFV	83.822	5	16.764	1.828	0.108
Error	2,311.093	252	9.171		
LEV9HASFC	0.241	5	0.048	1.541	0.178
Error	7.899	252	0.031		
LEV81HASFC	0.416	5	0.083	2.344	0.042*
Error	8.955	252	0.036		

Table 4.12. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) and animal taxa (gazelle, goat, sheep) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

MANOVA 3: Neolithic Phases Compared to Individual Wild Animal Species: In running a MANOVA with either the Neolithic Gritille phases or individual wild species as the independent factor and the microwear texture variables as the dependent variable (Appendix 2), all variables were found to be significant (Table 4.13).

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	259,307.855	14	18,521.990	3.836	0.000
Error	1,168,477.531	242	4,828.420		
EPLSAR_MEDIAN	186,064.014	14	13,290.287	2.596	0.002
Error	1,238,773.702	242	5,118.900		
SMC_MEDIAN	218,349.568	14	15,596.398	3.114	0.000
Error	1,211,880.295	242	5,007.770		
TFV_MEDIAN	211,087.488	14	15,077.678	3.032	0.000
Error	1,203,440.512	242	4,972.895		
_3X3HASFC_MEDIAN	139,725.028	14	9,980.359	1.889	0.028
Error	1,278,673.976	242	5,283.777		
_9X9HASFC_MEDIAN	155,075.575	14	11,076.827	2.110	0.012
Error	1,270,306.495	242	5,249.200		

Table 4.13. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) and animal taxa (gazelle, goat, sheep) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

When complexity is examined, *Ovis aries gmelini* is found to be significantly different from Phase A and Phase B by Tukey's HSD. In examining the values for complexity, both Neolithic Gritille phases are higher than the *Asfc* values for *O. a. gmelini.* The previous MANOVA analysis in Chapter 3 indicates this species of sheep separates out from the other wild species as a grazer. Although Phases A and B values fall into the grazing paradigm according to Scott (2012), their diet may contain browse or, as suggested by mesowear, more grit. Fisher's

LSD found *Gazella dorcas dorcas, O. a. gmelini,* and *O. vignei dolgopolovi* significant in all three periods. Several other species were also significant but were limited to only one period (see Appendix 2). As previously discussed dorcas gazelles and the urial lived in drier areas and have microwear variables associated with browsing. This significant pairing would indicate the Gritille Neolithic does not have a similar diet to those species living in dry, desert areas either.

For anisotropy, no significant comparisons were found using Tukey's HSD. Fisher's LSD again found significant pairings between the Neolithic phases and those species inhabiting desert or dry locations like *Capra hircus* sp., *G. d. dorcas, O. a. urmiana,* and *O. a. dolgopolovi*. Since anisotropy is a variable relied upon to separate browsers from grazers (e.g., Scott 2012, Ungar et al. 2007), this finding appears to place the Neolithic within the grazer paradigm.

The ANOVA with *Smc* as the dependent variable found significance between both Phases A and B with *O. a. gmelini* following Tukey's HSD comparison. The mean scale of maximum value is high for *O. a. gmelini*, even higher than mean values reported by Scott (2012). The inflated values may be providing an incorrect comparison with the other species, or could indicate *O. a. gmelini* ate only a graze-based diet. This significant comparison then, like complexity would indicate Phases A and B had other dietary sources besides graze in the diet. Fisher's LSD also identified *C. h. hircus* significant between these two Neolithic periods as well. This significant comparison provides evidence that the diet was not predominately dry browse either. In addition, for Phase C Fisher's LSD identified *O. vignei dolgopolovi* and *O. a. gmelini* significant as well. This significant pairing follows the trends seen with *SMC* for the two later phases. However, of note is the fact that both of these significant pairings with Phase C are both sheep species. Phase C may not reflect a natural sheep diet, as opposed to the later domesticate animals at Gritille. This result suggests the idea that initial husbandry practices may

have been different from later practices in order to focus on the process of domesticating animals.

Tukey's HSD finds one significant coupling for texture fill volume. Specifically Phase B is different from *G. d. dorcas* (p= 0.003). The dorcas gazelles have much higher volume of occlusal surface removed from microwear texture than animals from Phase B. The diet during this period was not as destructive as one of an animal's living in desert conditions. Fisher's LSD found similar significant pairings between the Gritille Neolithic phases and goats and gazelles. Phase C also is significantly different for *Tfv* from *O. a. aries* (p= 0.008) and *O. a.* sp. (p= 0.015). This significance is interesting as Phase C animals have higher *Tfv* than the wild species. As other dental microwear textures direct us towards a graze-based diet for Phase C animals, the higher *Tfv* may indicate a human interference with diet by increasing grit.

Tukey's HSD finds a difference in 3x3-heterogeneity involving Phase A with *C. h. aegagrus*. Phase A has values larger than for these goats. This result may provide support to environmental degradation at Gritille as the other microwear variables still are indicating a graze based diet. When Fisher's LSD is examined, not only is *C. h. aegagrus* significant but so too are *O. a. isphahanica*, *O. a.* sp., and *O. v. dolgopolovi*. In all four cases, Phase A has larger 3x3-heterogeneity values than these other animals. These animals inhabited different environments indicating whatever Phase A ovicaprids were consuming, it provided a new, non-sheep wear pattern across the occlusal surface. Fisher's LSD also indicated that both Phases B and C were significantly different from *O. a. gmelini*. The significance in these pairings is not surprising given previous interpretations based on *O. a. gmelini.*

For the 9X9-heterogeneity, Tukey's HSD found no significant comparisons. Fisher's LSD identified significant comparisons between Phases B and C with *O. a. gmelini* (p= 0.002,

p= 0.001 respectively). This significant pairing continues from the 3x3-heterogeneity. Phase A has a significant pairing with *O. a.* sp. (p= 0.005). This last comparison is interesting as *O. a.* sp. was collected in a wet environment, which may reflect an environment similar to Gritille's location on the Euphrates River. However, if animals had to be herded further away due to degradation at the site, this significant comparison may be understood.

For the MANOVA based on the Levene's transformed data, both complexity and scale of maximum complexity were significant (p= 0.007, p< 0.001 respectively) (Table 4.14). Fisher's LSD identified all three phases' complexity variation distinct from *O. a. gmelini*. In addition, Phase B has significant variation differences from *C. h. aegagrus, G. d. dorcas, O. a. aries* and *O. a. laristanica*. Tukey's HSD only recognizes Phase B complexity variation being significantly different from *O. a. gmelini*. Phase B complexity variation encompasses more than what a solely graze based diet would indicate. For scale of maximum complexity, Fisher's LSD identifies *O. a. gmelini* significantly different for all periods. In addition, Phases A and B are significantly different from goats. Tukey's HSD identifies only Phases A and B variations significantly different from *O. a. gmelini*. This significance follows the variation in complexity. The *Smc* is related to complexity, the variable relied upon to separate browsers from grazers. The results indicated by this MANOVA suggest the conditions during the Neolithic increased the variation of what is expected in grazers due to modified diets.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	2.931	14	0.209	2.254	0.007*
Error	22.566	243	0.093		
LEVEPLSAR	1.634	14	0.117	1.563	0.090
Error	18.147	243	0.075		
LEVSMC	76.903	14	5.493	8.070	0.000*
Error	165.406	243	0.681		
LEVTFV	199.926	14	14.280	1.581	0.085
Error	2,194.989	243	9.033		
LEV9HASFC	0.578	14	0.041	1.326	0.193
Error	7.563	243	0.031		
LEV81HASFC	0.654	14	0.047	1.302	0.206
Error	8.717	243	0.036		

Table 4.14. Results of the MANOVA run using the Gritille Neolithic periods (A, B, C) and animal taxa (gazelle, goat, sheep) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 2).

Conclusion

The null hypotheses (H_0 no domestication: no change in sheep central tendencies for mesowear and microwear variables) can be rejected based on the statistical analyses of dietary reconstruction data. In addition, since Phase C, the earliest Neolithic period at Gritille, indicated significantly different diets from wild animals, domestication or animal husbandry must have

been occurring. This evidence provides more evidence towards the ideas that animal control started prior to morphological indications of domestication.

H_{B1} penning: excess grit should cause low and blunt mesowear and texture fill volume in teeth. For mesowear, Phase A and Phase C exhibit more specimens with low and blunt mesowear. In fact, for these periods, the Neolithic animals align closer with gazelle species than the wild goats and sheep. When texture fill volume is examined, Phase C is once again pulled out as being different from sheep (Fisher's LSD) and goats (Tukey's HSD). Further, Phase C exhibits the highest *Tfv* numbers for all three Neolithic phases. Phase C is the earliest Neolithic period examined at Gritille. During this period, traditional archaeological reconstruction methods suggested animals were not fully domesticated. Penning during this period would be an important part of animal keeping, allowing stocks to reproduce and build up animal supplies. Therefore, it appears the dietary reconstructions indicate penning during Phase C. Phase A, the end of the Gritille occupation, does not present significantly different *Tfv* levels from the wild animals, and falls within the range of wild sheep. The mesowear signature then may be reflecting a different handling practice during this period, beyond just penning and could support the idea the environment was becoming degraded due to poor agricultural sustainability practices.

H_{B2} restricted diet due to penning: little variation would be expected between specimens as all animals ate similar food (with higher levels of grit). For both mesowear and microwear analyses, all the Neolithic phases at Gritille do not have a consistent dietary reconstruction signature. In examining the mesowear, which provides a lifelong dietary signal, Phase B stands

out from the other two periods. Therefore, diet was not restricted during the Neolithic. Instead, diet appears to have changed during each Gritille phase. Most likely, this change corresponds to changes in the overall culture at the site. New husbandry strategies were most likely adopted to meet the changing needs at the site, and as such, animal diet was also modified.

H_{B3} foddering: mesowear and microwear signatures may suggest different diets from one another. Once again, if we examine Phase B, differences are seen that may suggest foddering. The mesowear analyses indicate Phase B often aligns itself with the wild animals, including sheep. If the Levene's transformed data were examined, Phase B variation in complexity and scale of maximum complexity (more complex surfaces are associated with browse) are different from sheep species. Possibly animals during Phase B had incidences of foddering. The dietary signature suggests the animals were allowed to graze but offered fodder with properties different from the normal diet, perhaps browse or food contaminated with grit. This idea would give credence to the idea animals were fed on the stubble of fields after the harvest. These crop remains would be close to the ground and contaminated by dirt and other debris. Unfortunately, since the archaeological material cannot be investigated by season of death, full understanding of the foddering hypothesis cannot occur.

H_{B4} narrow range of food: little variation found in mesowear and microwear between specimens. If sheep were allowed to graze on their usual range of foods, they should show a typical grazer pattern in both mesowear and microwear, but if they lacked normal freedom of movement, the overall variation expected, especially in microwear, should be reduced. Based on the dietary signatures and the differences seen between the Neolithic and the wild specimens, the

Gritille animals were not being fed a natural, wild diet. Specifically, the mesowear analyses indicate excessive grit within the diet. Therefore, this hypothesis is not supported. Human husbandry methods influenced diet and included a wide amount of variation, which is reflected by Levene's transformed data. Specifically, the Neolithic animals tend to align closer to browsers than grazers. Animals were probably not allowed to roam the landscape, eating their preferred food sources like wild animals or what occurs in the Near East today.

H_{B5} wider range of food: more variable mesowear and microwear signatures found due to consumption of a wider range of food. During herding, if the sheep were moved through different environments such as woody brush, the mesowear and microwear should reflect the change in food resources. The combination of abrasion and attrition would be expected to lead to an intermediate mesowear signature. This hypothesis appears to be supported based on the dietary reconstruction. However, this hypothesis needs further analyses, such as isotopes, to understand fully herding movements. Most likely, Phase A had the most open range of movements of all the Gritille phases. This pattern, reflected through the significant variables, could reflect either the understanding the Neolithic people had of domesticated animals at this point or that more range was needed in order to feed the animals due to a decrease in overall resources.

Chapter Five: Archaeological Comparison

In this chapter, ruminant dental wear results for Gritille will be compared to those from other archaeological sites around the Euphrates River to examine how Neolithic husbandry practices compare to those in later periods. Comparisons between Gritille and later sites should provide more insight into domesticate handling during the initial period of animal husbandry. One possible drawback on relying on archaeological remains is the damage archaeological specimens undergo while in the ground and the biases that may come from deposition (discussed in Chapter 4). Although archaeological samples have undergone deposition and other taphonomic processes, as King et al. (1999) found, dietary microwear was not altered[45] (e.g., browser wear was not damaged to look like grazer wear). Furthermore, inspection of teeth for damage was done prior to collecting dental mesowear and microwear information. Therefore, comparisons among archaeological samples should provide insight in similar, reliable ways as the wild, extant specimens.

Materials

Gritille Höyük (Turkey)[46]

As discussed previously in Chapter 4, the 1.5-hectare site of Gritille was located on a bluff on the right bank of the Euphrates River. This Karababa Basin site is currently covered by water due to the Ataturk Dam construction (Figure 5.1) (Ellis and Voigt 1982, Monahan 2000,

[45] If taphonomic processes occurred, such as abrasion, the alteration would be in a recognizable pattern, which can be ignored when the tooth is examined (King et al. 1999).

[46] The majority of information on Gritille presented here is repeated from Chapter 4. Like similar information that is continuous throughout the research (e.g., methods section), this information is provided again to allow the chapters to stand alone should the reader be interested in only specific attributes of the dissertation research.

Stein 1988, 1989). Excavations were limited to several field seasons in the early 1980s under the direction of Richard S. Ellis from Bryn Mawr College as part of the Lower Euphrates Salvage Project (Monahan 2000, Stein 1989). The site has discontinuous occupations dating to the Neolithic (around 10,000 BP), Bronze (around 4,200 BP), and Byzantine-Seljuk (around 1,000 BP) cultural phases (Ellis and Voigt 1982). This Medieval period was the largest and best preserved (Voigt 1988). Gritille's location on the Euphrates floodplain provided farmable land to its occupants over its settlement history (Ellis and Voight 1982). The modern climate consists of hot summers and mild, moist winters (Ellis and Voigt 1982, Monahan 2000). Enough rain fell during the winter to support dry farming, with mean yearly rainfall between 400-600mm (Stein 1986a, 1988, 1989). Furthermore, three habitat types surround the site, providing a range of resources. The Mediterranean woodlands are comprised of deciduous trees and pines at higher elevations, the Irano-Turanian steppe-desert consists of shrubs and wild cereals, and the Kurdo-Zagrosian vegetation located in the uplands consists of oak-pistachio forests. Animals in these zones include gazelles, hyenas, foxes, deer, and brown bears (Monahan 2007, Stein 1988). Specifically, sheep and goats are found within the Kurdo-Zagrosian environs. Sheep live in the foothills while the goats prefer the mountains (Monahan 2000). Further, its location between the Euphrates and Mediterranean puts Gritille in a natural crossroads for trade (Ellis and Voigt 1982).

Figure 5.1. Map of Near East archaeological sites used within this research imposed on a current topographical map. The main archaeological site of Gritille is marked in red balloon while the comparison sites (Hacınebi and Tell Qarqur) are indicated by blue (map created in Google Scribble Maps).

Great care was taken in material recovery from Gritille (e.g., wet and dry screening) in order to be able to understand the site's economy. Most of the archaeological materials were filtered through .5cm meshed screen. The material not dry screened went through a wet screening process (Stein 1988). The majority of flora and faunal material recovered came from fire or storage pits and secondary trash deposits. This consistency in recovery location allows

the material between phases to be compared without having to deal with contextual issues (Monahan 2000, 2007). Gritille's Neolithic botanical remains indicated a shift in agricultural resources over the period associated with domestication. A decrease in pulses (i.e., legumes) occurred over time (65% pulses to only 20% in the late PPNB). Concurrently, an increase in cereals (two-row barley, einkorn, emmer, and wheat) took place, with barley contributing the highest portion of cereals (Miller 2001). Fuel sources also shifted at Gritille, from wood to dung. This switch in fuel resource indicates possible changes in the environment around the site, especially towards the end of the Pre-Pottery Neolithic occupation (Miller 1996). This change may have been due to farming or herding practices (e.g., Rollefson and Köhler-Rollefson 1989) or some other environmental or climatic change (Monahan 2000).

The lowest stratigraphic layer recovered from Gritille dates to Pre-Pottery Neolithic B, based on radiocarbon dating. Over 80,000 animal remain fragments were recovered within the 4 meter Neolithic layer (Stein 1986a, 1988). The Neolithic occupations occurred in four distinct stratigraphic layers. Layers A and B were from the upper Neolithic (i.e., later) and C and D represented the earlier occupations (Monahan 2000). The widest variety of animals were recovered from the basal layer, but even at this time, initial steps towards sheep and goat domestication could have occurred (Monahan 2000). The majority of identifiable bones throughout the Neolithic occupation came from caprines (Stein 1986a, 1988). Although bone ratios indicated sheep and goats were represented equally in faunal remains, over time, sheep became the preferred stock animal (Monahan 2000). This preference changed during Phase A when an increase in cattle and pig use occurred (Monahan 2007). Later, during the Medieval occupation, goats outnumbered sheep (Monahan 2000). Other animals recovered from the Neolithic occupation included pigs, cattle, gazelles, deer, and dogs. Although located near

water, aquatic resources did not appear to contribute greatly to the subsistence base (Stein 1986a). Further, due to the amount of meat provided, cattle may have had a greater dietary impact than sheep and goats (Monahan 2000).

The Neolithic fauna used in this research arise from three of the four sub-phases (C-A). The earliest Phase (D) was not used due to lack of identified material from this phase (Monahan 2007, Voigt 1988). Sheep and goats appeared throughout the sequence as discussed above, but only the later phases (e.g., Phase B) show evidence of domestication through traditional indicators, such as morphology (see Chapter 4 for discussion). Caprine sizes began to decrease during Phase C but did not reach a consistent size change until Phase B. This signal suggests initial husbandry began during Phase C, but either interbreeding still occurred or hunting of wild animals continued throughout this occupational level (Monahan 2000). Demographic reconstruction indicated evidence for juvenile cull prior to Phase B, but again it was not until Phase B that male cull was observed (Monahan 2000, 2007). Stein (1986a) reported the cull pattern followed the meat model as discussed in Chapter 4. Domesticated animals were most likely relied upon during the spring and autumn months. Wild animals were used during the winter, when their migrations brought them close to the site, and provided an abundant subsistence resource (Stein 1986a).

Much later during the Medieval period, Gritille evolved into a fortified site, with three distinct occupational areas containing more than 12,000 animal fragments. The majority of these fragments were pig (49%) while sheep contributed to 28% of the faunal assemblage. However, the sheep and goat distributions varied between the distinct areas, indicating different uses in different classes of villagers. In general, demography pointed to animals being used for local meat products (Stein 1986b, 1988).

The Gritille specimens, currently housed at the Oriental Institute (Chicago), were examined for appropriateness for dietary reconstruction methods. Individual tooth contextual information was recorded along with information for dental analyses (described below). Measurements and photographs of the individual teeth were also taken to provide reference material during the latter parts of the analyses occurring at the University of Arkansas. In all, 175 specimens were collected from the three Neolithic phases at Gritille (Table 5.1). Specifically, Phase A provided 29 teeth, Phase B 131 teeth, and Phase C 15 teeth for analysis. The disparities are due to the differences in the faunal material recovered from each phase (e.g., Phase B provided the most faunal remains of all Neolithic phases). Another subset of 12 specimens was examined from the Medieval occupation as well to serve as one of the comparison samples. No specimens were sampled from the Bronze Age occupation because of the lack of identified material from this occupation available during the visit.

Cultural Phase	**Lower Molar**	**Upper Molar**	**Indeterminate Tooth**	***Total Teeth***
Phase C	5	9	1	**15**
Phase B	74	57	0	**131**
Phase A	12	17	0	**29**
Neolithic Total	**91**	**83**	**1**	**175**
Medieval	4	8	0	**12**
Gritille Total	**95**	**91**	**1**	**187**

Table 5.1. Distribution of Gritille teeth examined for this research broken down by tooth type and cultural phase.

Hacınebi Tepe (Turkey)

The Late Chalcolithic (ca. 4,100- 3,300 BC[47]) site of Hacınebi is located in the Euphrates River Valley (Figure 5.1) (Bigelow 1999, 2011). Hacınebi is, like Gritille, located on limestone bluffs along the Euphrates River. Hacınebi is a 3.3-hectare mound on the east side of the river in an ideal location for trade routes. The site encompasses the local Anatolian cultural traditions, which followed the Neolithic, as well the later Uruk tradition. The Uruk expansion began in southern Mesopotamia in which the first urban, state-level societies developed. Their economy and expansion were aided by extensive trade settlements throughout the Near East (Bigelow 1999, 2011). The area surrounding Hacınebi consists of alluvial terraces and hills, supporting the growth of open oak-pistachio forests during the Holocene, which transitioned into steppe flora, such as barley, lentils, and wheat (Bigelow 2011). The Hacınebi samples make for excellent comparisons with the Gritille specimens.

The site of Hacınebi was discovered during the Tigris-Euphrates survey led by Dr. Guillermo Algaze. The original phases identified were Hellenistic and Chalcolithic (Bigelow 2011). Excavated over six field seasons (directed by Dr. Gil Stein) from 1992-1997, three main late Chalcolithic phases are recognized A (4,100-3,800BC), B1 (3,800-3,600BC), and B2 (3,600-3,300BC). Phase A is the earliest settlement phase and is continuous with B1, although changes in the material occur including changes in ceramics and building patterns (e.g., building of large infrastructure possibly for administrative purposes). Phase B2 deposits contain archeological remains associated with traditional Anatolian and Uruk cultures (e.g., presence of both local and Uruk pottery, increased use of bitumen). The presence of Uruk cultural remains indicates the possible connection of Hacınebi with the rest of the Uruk network originating in southern

[47] Dating at the site and stratigraphy was done through both absolute and relative methods (Bigelow 1999).

Mesopotamia (Bigelow 1999, 2011).

Bone material from the site was collected during the excavation by dry sieving through 0.5cm screen. The inhabitants of Hacınebi relied predominantly on domestic animals for their meat supply (Bigelow 2011) (Figure 5.2). The main animals found at the site throughout the sequence are goats and sheep, followed by pigs and cattle. During Phase A, the bone elements recovered at the site suggest domesticated animals (e.g., sheep, goats) were killed and butchered elsewhere, with only the usable meat parts of the carcasses brought back. This butchery method showed a pastoral-based economy, as the animals were kept far from the site (see Chapter 4 for pastoralism discussion). Further, demographic models for Phase A indicate that ovicaprids were used for wool production. During Phase B1, a shift transpired in meat preference with an increase in pigs, which could indicate a more sedentary community or a change in environment. A change in butchering also occurred with ovicaprines being slaughtered at the site, with whole carcass remnants recovered as opposed to the previous period when only the meaty parts were found. Bigelow suggested that this may indicate a shift in subsistence patterns, with the inhabitants moving towards a more sedentary/ meat based society due to subsistence stress. The Phase B2 fauna indicate a shift back towards a more pastoral society possibly becoming more involved in Uruk trade (Bigelow 2011). Use and distribution of sheep and goat material may have been based on social hierarchy at the site (Bigelow 1999).

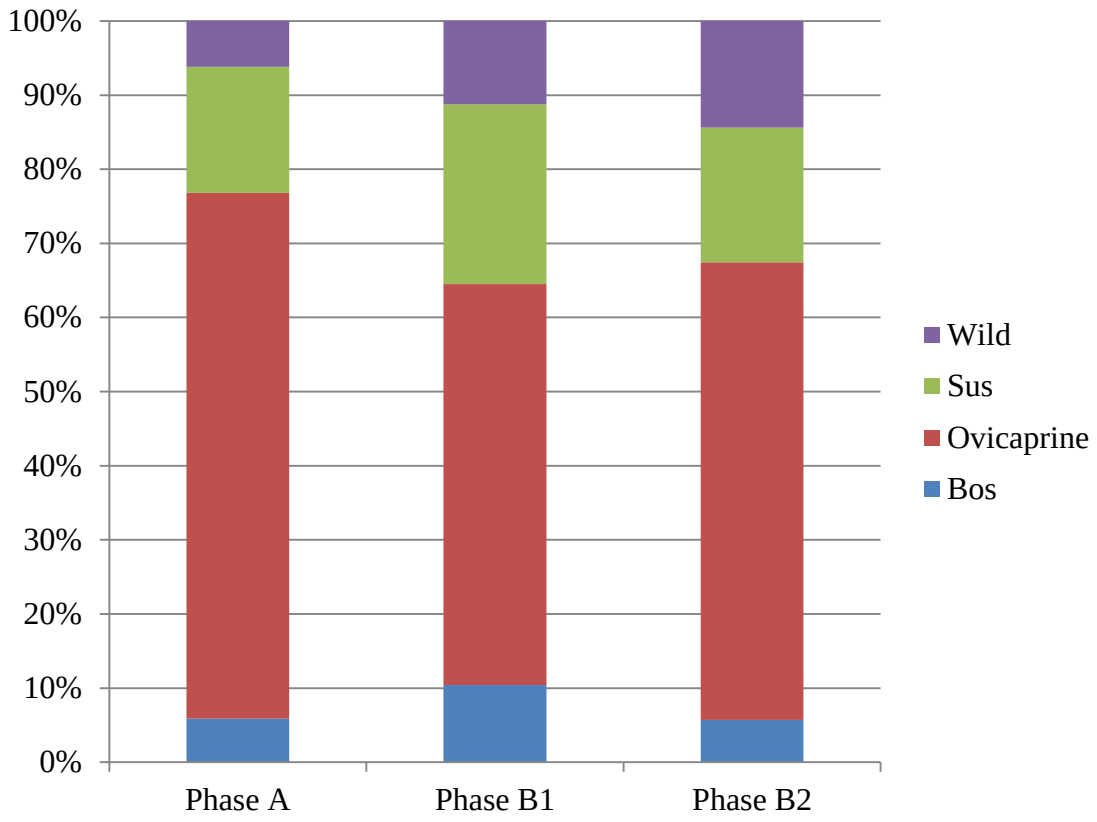

Figure 5.2. Distribution of faunal remains from Hacınebi separated by Late Chalcolithic phase (columns) and faunal type (wild: purple, pig: green, cattle: blue, sheep and goats: red) (modified from Bigelow 2011).

The Hacınebi faunal remains are also housed at the Oriental Institute in Chicago. Analysis of this sample followed the same procedures as the Gritille specimens (e.g., contextual information, photographs, measurements, dental analyses). In all, 122 specimens from Hacınebi were included in analysis (Table 5.2). A total of 10 specimens in the sample date to the Early Bronze age occupation of Hacınebi, which followed the Chalcolithic occupation. The remainder of the samples came from the Late Chalcolithic occupation phases, including material from local and Uruk influences.

Cultural Phase	Lower Molar	Upper Molar	*Total Teeth*
LC A	2	0	**2**
LCB1	19	13	**32**
LCB2 Anatolian Context	18	15	**33**
LCB2 Uruk Context	29	16	**45**
Chalcolithic Tooth Total	**68**	**44**	**112**
EB	9	1	**10**
Hacınebi Tooth Total	**77**	**45**	**122**

Table 5.2. Distribution of Hacınebi teeth examined for this research broken down by tooth type and cultural phase: Late Chalcolithic (LC) and Early Bronze Age (EB).

Tell Qarqur (Syria)

Tell Qarqur comprises two mounds, a small one in the north connected to a larger one to the south. The site spans 12 hectares and rises 30 meters above the Orontes River Valley, in western Syria (Figure 5.1) (Casana et al. 2008). Excavations at Tell Qarqur began in the 1980s with focused, continuous expeditions beginning in 1993. Interest in the site stems from the possibility that this site is Karaka/ Qarqara, discussed in Assyrian documents (Dornemann 2003). The site represents occupations spanning 10,000 years, from the Pre-Pottery Neolithic to the Mamluk period (AD 1350). Material examined came from later periods in Tell Qarqur's history when Tell Qarqur was a major city in the region based on archaeological evidence (Dornemann 2003).

Animal remains underwent a two-step analysis after recovery. The first step took place in the field, whereas the second involved a more thorough follow-up examination of

archaeological context, indications of burning, and butchering. The composition of animals used during different periods changed from period to period, presumably reflecting differences in animal preferences (Figure 5.3). Unequal distribution of animal remains occurred during the Bronze Age indicating differential access to meat within the population. The Iron Age remains, however, indicated a more even distribution and therefore access to the whole population. Domesticated sheep and goats played a large dietary role throughout the excavation periods (Arter 2003).

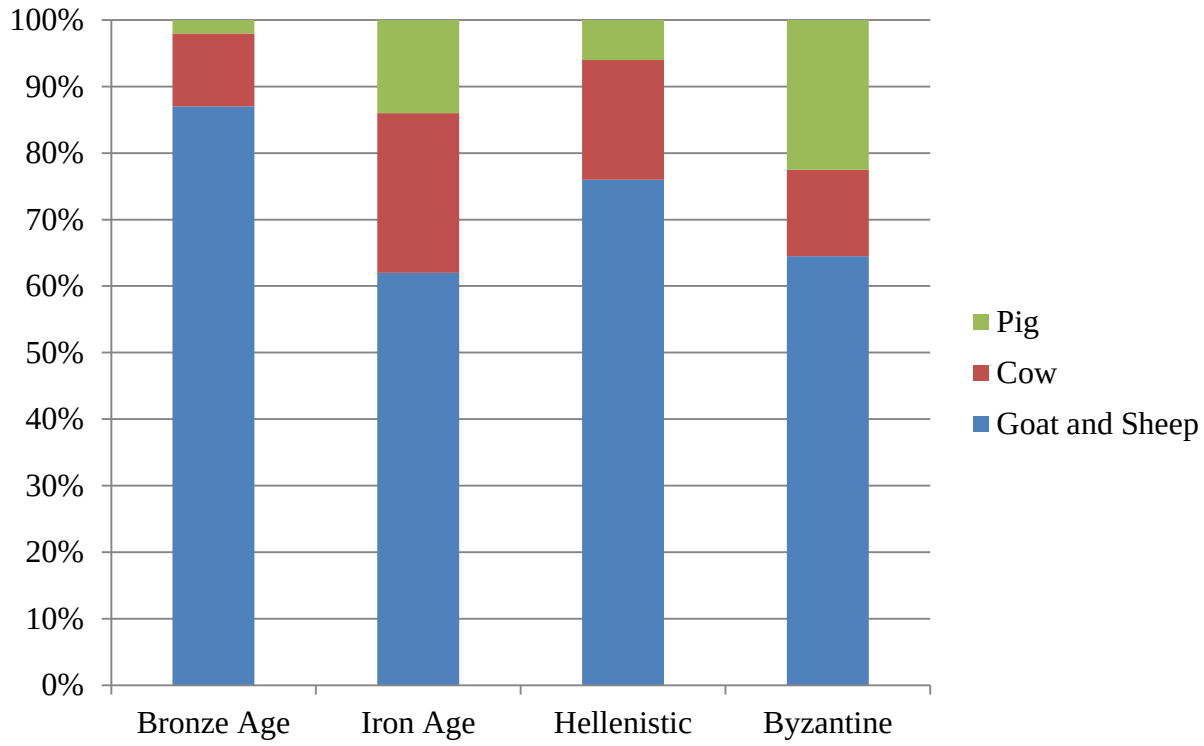

Figure 5.3. The use of domesticated animals throughout different cultural periods (columns) at the site of Tell Qarqur. Although use preference changed for pig (green) and cow (red), caprines (blue) played a leading role throughout Tell Qarqur's occupations (modified from Arter 2003).

The teeth examined were a subsample of those selected for use in isotopic analyses. Dr. Kate Grossman selected the sheep teeth using traditional methods of separation to create the subsample. A total of 26 mandibular molars were examined for microwear analysis. Since no maxillary molars were included in the subsample, mesowear was not performed on this sample.

Methods

Tooth Selection

Upper and lower molars were selected for dietary reconstruction analysis. Both upper and lower teeth can be used for microwear analysis (e.g., Merceron et al. 2004a, b; Ungar et al. 2007), while only upper dentitions are used for mesowear analysis (e.g., Franz-Odendaal and Kaiser 2003, Kaiser and Solounias 2003, Schubert 2007). To increase the sample size of the archaeological specimens, all three molars were utilized in the dietary reconstruction. If jaw fragments were available from the excavated unit material, care was taken to select the second molar. However, most teeth were recovered individually from the units.

Due to the nature of mesowear and microwear analysis, teeth that had no wear to very slight or very high wear were left out of the study (e.g., Schubert 2004, 2007). Payne's (1973, 1987) scoring method was followed to characterize wear. Although this selection method omits early cull animals, it should not prove a problem, as we do not know how animals were treated during early husbandry. Examination of older individuals provides information on how the overall herd was handled to maintain life.

Natural differences in dietary preference between sheep and goats occur today (discussed previously in Chapter 3). As such, the same might have been true for the archaeological sample.

Although methods for definitive separation of these taxa exist (see Chapter 3), such as isotopic analysis (e.g., Balasse and Ambrose 2005) and genetic testing (e.g., Buckley et al. 2010), these each require sample destruction, which was not possible for this study. However, the failure to categorize the archaeological material into sheep and goats should not be a problem in reconstructing husbandry. Mainland (1998a) examined goat and sheep microwear of animals handled in the same manner and found no reportable dietary difference (similar microwear patterns) between the two species. Later studies by Mainland and Halstead (2002) using microwear and Pearson et al. (2007) using isotopes also found similar diets between sheep and goats. These studies indicate that during the early stages of animal husbandry, sheep and goats had similar food preferences. As such, goats and sheep can be grouped together to understand early husbandry attempts without too much concern for possible differences in dietary signals.

Mesowear Analysis Procedures

Visual inspection for mesowear data occurred after initial inspection for lack of taphonomic alterations and sufficient dental wear to allow for analyses (e.g., Rivals and Athanassiou 2008, Schubert 2007). Goat and sheep upper molars were examined and surface relief characteristics recorded (cusp shape and occlusal relief) following methods described in Fortelius and Solounias (2000). Cusp relief (high or low) indicates the distance from the cusp tip to the area between the cusps, and provides information on abrasive wear within the diet. Cusp shape (sharp, rounded, or blunt) informs on whether diet created more attritional (sharp) or abrasion (rounded or blunt) wear (Figure 5.4) (Fortelius and Solounias 2000). Mesowear scores were recorded for upper first or second molars from the archaeological samples. Both molars were used since these teeth are difficult to distinguish in isolation (without a maxilla or other

teeth from the same animal to compare to). As Kaiser and Solounias (2003) and Franz-Odendaal and Kaiser (2003) suggested, mesowear can be extended beyond the second molars initially used by Fortelius and Solounias (2000) and still be faithful to the methodology and results.

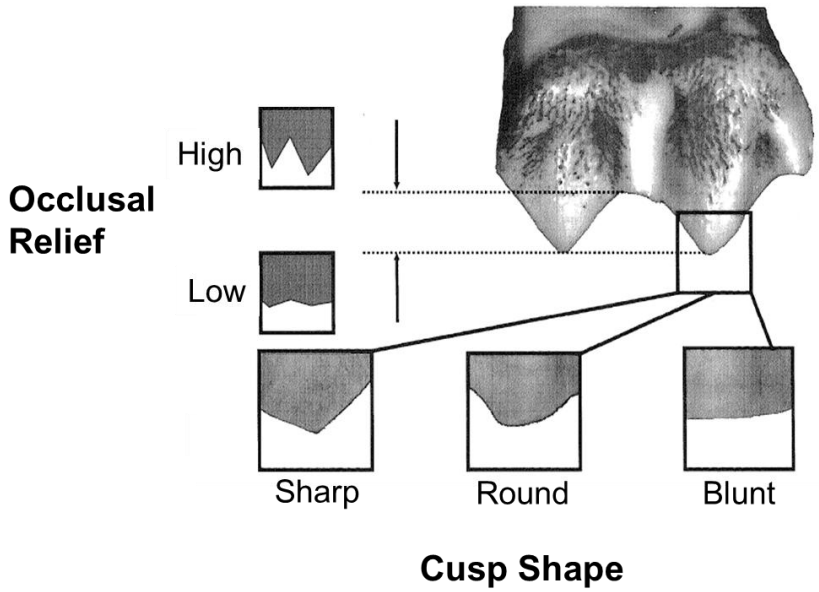

Figure 5.4. Image of an ungulate tooth's buccal surface where examination for mesowear analysis occurs. On the left side of the image, the measures of occlusal relief (high or low) are shown. On the bottom, the measures of cusp shape (sharp, round, or blunt) are illustrated (modified from Clauss et al. 2007). This measurement follows standard protocols established by Fortelius and Solounias (2000).

Measurements: The hypsodonty index (third molar crown height divided by the third molar crown width) (Janis 1988) was also measured in accordance with the procedure laid out by Fortelius and Solounias (2000). The hypsodonty index has been shown to categorize animals into different dietary types based on their environment (open vs. closed). For instance, Janis (1988) suggested that grazers tended to have high hypsodonty indices, although grazers near water sources had lower values than grazers in more open habitats due to the grit encountered. As Janis (1995) discussed, browsers tend to have a low hypsodonty index while grazers have higher ones. Unfortunately, mixed feeders cannot be parsed out using a simple hypsodonty index (Janis 1995).

Molding and Casting

After examination for potential post-mortem damage (e.g., Teaford 1988), suitable molars were cleaned with alcohol and molded for microwear texture analysis. Molds were created by applying President's Jet, a high-resolution polyvinylsiloxane dental impression material (Coltène-Whaledent, Hudson, MA) to the occlusal surface of the second molar. The molding procedure was non-destructive, and created a precise, high-resolution impression of a tooth's surface (e.g., Beynon 1987, Teaford and Oyen 1989 b). President's two-part putty system (Coltène-Whaledent, Hudson, MA) shored up the molds so casts could be produced replicating the original enamel surface. Casts were created using Epotek 301 resin and hardener (Epoxy Technology Inc., Billerica, MA) following conventional procedures (e.g., Ungar 1996).

Microwear Texture Analysis Procedures

The current study followed Merceron et al. (2004a, b, 2005), Rivals and Deniaux (2003,

2005), Scott (2012), and Ungar et al. (2007), by examining the lingual paracone[48] of the upper molars (Figure 5.5). A Sensofar Plμ white-light scanning confocal profiler (Solarius Development Inc., Sunnyvale, CA) was used to examine the microwear on the prescribed location of the casts[49] (Figure 5.5). The confocal profiler created three-dimensional point-clouds of the tooth's surface with a lateral sampling interval of 0.18 μm and a resolution of 0.005 μm (with a 100x objective lens). Following convention, a series of four adjacent scans were used for a total scanned area of 276 X 204 μm (Scott et al. 2006). The resulting point clouds were analyzed in Solarmap Universal software (Solarius Development Inc., Sunnyvale, CA), wherein surfaces were normalized and leveled. Any defects remaining on the surface when the mold was created (e.g., dust or dirt) were erased electronically, and therefore excluded from the surface scan data. The point-cloud data were imported into Toothfrax and Sfrax software packages (www.surfract.com) for scale-sensitive fractal analyses. Scale-sensitive fractal analysis is based on the principle that apparent surface texture varies with scale of observation (Scott et al. 2006). Three algorithms were used in this study: the length-scale rotational algorithm, the area-scale tiling algorithm, and the volume filling versus scale square cuboid filling algorithm (see Scott et al., 2006 for a detailed explanation). These result in the generation of data for five texture variables used to categorize microwear surface (discussed in Chapter 3).

[48] The facet examined occludes during the shearing of the Phase I movement of the molars across the maxillary molar (Merceron et al. 2004a, b).

[49] Since casts are an exact replica of the enamel surface of the original tooth, the facet location of the cast is in the same location as the original tooth.

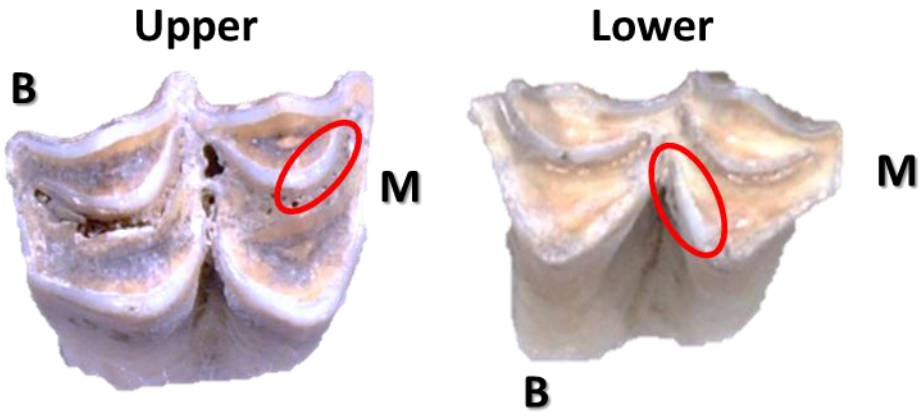

Figure 5.5. Location of Phase I shearing facets, indicated by red ovals, used for Dental Microwear Texture Analysis. Both teeth are archaeological samples from Gritille used within this analysis and are from the right side of the dentition (Mesial: M, Buccal: B). These areas were sampled following convention (references), as they have been shown again and again in the past to separate groups by diet. Photograph by M. Zolnierz.

Research Hypotheses

The research hypotheses for this part of the study center around husbandry methods at Gritille as the animals underwent domestication compared to fully domesticated animals in the later period.

H_0 no difference in animal husbandry practices: no change in sheep central tendencies for mesowear and microwear variables.

H_{c1} differences in animal husbandry practices relating to Neolithic establishment of domesticated animals: the mesowear and microwear patterns for the Gritille Neolithic animals will display a wider range of mesowear and microwear variables than what is seen for later cultural periods. This variation would be due to establishing husbandry practices. Later periods should have more consistent wear given the use of already domesticated animals and the knowledge required to ensure animals survived.

Statistical Analysis

Mesowear

Mesowear analysis for the extant species followed calculations in Schubert (2004). Percentages for each mesowear variable were calculated (e.g., percent sharp, percent round, percent blunt, percent high, and percent low) based on the taxa and species. These percentages were imported into SYSTAT 13 (Systat Software, Inc., Chicago, IL) to allow for hierarchical cluster analysis. Cluster analysis was based on complete linkages and Euclidean distances following Schubert (2004, 2007).

Microwear

The results of scale-sensitive fractal analyses, calculated by Toothfrax and Sfrax software packages (www.surfract.com), were exported to Excel (Microsoft 2010) to allow further calculations. As stated previously in the microwear methods section, four contiguous scans of each wear facet were taken. However, instead of basing further analyses on each of these individual scans, the median values were calculated. The median value provides a more balanced view of the individual's wear surface and follows the protocol of previous microwear texture analyses (e.g., Scott et al. 2006, Ungar et al. 2007). In addition, the microwear texture data were rank-transformed, as the assumptions for normality in parametric tests may not be met (Conover and Iman 1981, Scott 2012). Ranked data were analyzed using multivariate analysis of variance (MANOVA) with SYSTAT 13 (Systat Software, Inc., Chicago, IL). The dependent variables were the microwear texture variables, while the animal groups served as the independent variable. If significance was found, individual analyses of variance were carried

out, along with pairwise comparisons, to determine the sources of that significance. Pairwise comparisons included both Tukey's Honestly Significant Difference (Tukey's HSD) and Fisher's Least Significant Difference (Fisher's LSD) to balance the risk of Type I and Type II errors (Cook and Farewell 1996). In addition to running statistical analyses on the rank-transformed data, the data also were transformed by Levene's transformation following Plavcan and Cope (2001). This data transformation provides information on sample distributions (e.g., the degree of variation between the specimens within a sample). A MANOVA and follow-up tests were performed on the Levene's transformed data too, following the same steps as the rank-transformed data.

Results

Mesowear

Hierarchical Cluster Analysis 1: Mesowear Variables by Archaeological Site: A series of cluster analyses were performed to examine how the archaeological sites varied from each other. Table 5.3 provides the data used for this hierarchical cluster analysis. Appendix 3 provides any other statistical charts and graphs for data analysis in Chapter 5 not given in the text, including the graphs showing the clustering pattern of the mesowear scores. Cluster analyses based on percent high with all three cusp shapes and hypsodonty index found that the Hacınebi Late Chalcolithic B1 and B2 Uruk influence clustered away from the other archaeological sites and phases. This separation also included the Late Chalcolithic B2 found in local Anatolian context. These two periods indicated more abrasive wear on the buccal surface leading to lower percentages of high mesowear scores. The cluster analyses based on percentage low revealed slightly different patterns. For percentage low and percentage sharp Hacınebi Late

Chalcolithic B1 and B2 Uruk influence along with LC A clustered by themselves. For percentage low and percentage round, Gritille Medieval specimens and Hacınebi Early Bronze formed a grouping. This grouping also occurred when the hypsodonty index was included within the cluster analyses. Overall, differences in lifetime wear occurred between the archaeological samples. This difference suggests that handling or diet was not consistent even at the same site between periods, or that mesowear does not accurately portray differences in handling and diet. For instance, the Late Chalcolithic B2 with Uruk influence separated out, which could reflect different husbandry practices from southern Mesopotamia. Late Chalcolithic B1, which was within this cluster, should follow a more traditional husbandry method. However, based on demographic reconstruction, a shift on animal reliance occurred that might have indicated a shifting environment. This environmental change then may be what was reflected in the increased abrasive wear.

	Number	% high	% low	% sharp	% round	% blunt	Hypsodonty Average
Gritille Medieval	10	100	0	0.10	0.90	0	1.29
HN EB	5	100	0	0.20	0.80	0	1.47
HN LC A	2	100	0	0.50	0.50	0	1.63
HN LC B1	16	0.94	0.06	0.38	0.63	0	1.11
HN LC B2 Local	23	100	0	0.26	0.70	0.04	1.52
HN LC B2 Uruk	28	0.93	0.07	0.29	0.68	0.04	1.56

Table 5.3. Percentage of each mesowear variable scored for each of the archaeological sites and periods studied. Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt. The average hypsodonty, a method that can distinguish dietary types, is provided in the right column (see mesowear analysis procedures for full description).

Hierarchical Cluster Analysis 2: Mesowear Variables by All Archaeological Phases Including Gritille Neolithic: As with the previous set of analyses, the hierarchical cluster analyses for all archaeological periods including the Neolithic Gritille for percentage sharp and any cusp shape (Table 5.4) provided the same cluster pattern. In addition, when the hypsodonty index was included as well, the pattern continued. All three Neolithic Gritille Phases clustered with the Late Chalcolithic B1 and Late Chalcolithic B2 with Uruk influence from Hacınebi. In the percentage low, Phases A and C from Gritille formed their own cluster for each cusp shape. Phase B clustered with the Late Chalcolithic A from Hacınebi in all percent low cases. Based on

the groupings of Phase A and C from Gritille with the archaeological periods that also have unique dietary patterns, it appeared that Phases A and C were affected by excessive grit in the diet. This grit could have entered the diet by environmental degradation, as suggested by the clustering with LC B1. Alternatively, though, increasing livestock beyond what the land could handle may have resulted from Hacınebi increasing livestock supplies to enter into the Uruk trade network. Phase B clustering with the LC A at Hacınebi is interesting, as this period is thought to have followed traditional Anatolian traditions. However, since there were so few specimens included in the LC A sample, not too much certainty can be drawn from this clustering. Still, it appears that the Neolithic Phases at Gritille were following different handling strategies as evidenced by the dietary properties given to the animals.

	Number	% high	% low	% sharp	% round	% blunt	Hypsodonty Average
Gritille Medieval	10	100	0	0.10	0.90	0	1.29
HN EB	5	100	0	0.20	0.80	0	1.47
HN LC A	2	100	0	0.50	0.50	0	1.63
HN LC B1	16	0.94	0.06	0.38	0.63	0	1.11
HN LC B2 Local	23	100	0	0.26	0.70	0.04	1.52
HN LC B2 Uruk	28	0.93	0.07	0.29	0.68	0.04	1.56
Qarqur	17	100	0	0.24	0.65	0.12	1.7
GRITILLE A	20	0.85	0.15	0.3	0.6	0.10	N/A
GRITILLE B	93	0.97	0.04	0.57	0.41	0.02	1.29
GRITILLE C	11	0.82	0.18	0.27	0.55	0.18	1.68

Table 5.4. Percentage of each mesowear variable scored for each of the archaeological sites and periods studied. Cusp relief is indicated by % high and % low, which totals 100% reflecting all teeth examined for that taxa's mesowear analysis (listed in the number column). Cusp shape is indicated by % sharp, % round, and % blunt. The average hypsodonty, a method that can distinguish dietary types, is provided in the right column (see mesowear analysis procedures for full description).

Microwear

MANOVA 1: Comparison of Archaeological Sites Excluding the Neolithic: In examining the archaeological sites as the independent variable and the microwear texture variables as the dependent variables (Table 5.5), no significance was found with just the rank-

transformed data (Table 5.6). Therefore, no further ANOVAs and pairwise comparisons were warranted.

Site		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	**Tfv Median**	**3x3*HAsfc* Median**	**9x9*HAsfc* Median**
Gritille	Mean	2.225	.003	.286	8691.525	.413	.738
	N	12	12	12	12	12	12
	Std. Deviation	1.389	.001	.344	5124.952	.130	.181
	Median	1.935	.003	.152	10784.577	.409	.776
	Skewness	.489	.756	3.330	-1.108	.214	-.078
Hacınebi	Mean	1.902	.004	2.779	8257.355	.499	1.003
	N	106	106	106	106	106	106
	Std. Deviation	.805	.001	23.527	4945.515	.210	.585
	Median	1.895	.004	.153	8585.927	.452	.921
	Skewness	.683	.338	10.063	-.126	2.395	5.920
Qarqur	Mean	1.606	.003	.273	8408.692	.440	.876
	N	16	16	16	16	16	16
	Std. Deviation	.653	.001	.165	3837.843	.096	.260
	Median	1.471	.003	.267	9209.603	.426	.836
	Skewness	.906	.839	2.813	-.062	.843	.355

Table 5.5. Table of general statistics for each microwear variable for each of the three comparison archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur).

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	3,348.692	2	1,674.346	1.113	0.332
Error	197,148.808	131	1,504.953		
EPLSAR_MEDIAN	7,004.066	2	3,502.033	2.371	0.097
Error	193,493.434	131	1,477.049		
SMC_MEDIAN	7,290.206	2	3,645.103	2.471	0.088
Error	193,207.294	131	1,474.865		
TFV_MEDIAN	70.048	2	35.024	0.023	0.977
Error	200,426.952	131	1,529.977		
_3X3HASFC MED	3,839.910	2	1,919.955	1.279	0.282
Error	196,657.590	131	1,501.203		
_9X9HASFC MED	8,013.240	2	4,006.620	2.727	0.069
Error	192,484.260	131	1,469.345		

Table 5.6. Results of the MANOVA run using the three archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. No variables met this criterion.

Significance in the variation of complexity was found, however, with the Levene's transformed data ($p= 0.015$) (Table 5.7). Appendix 3 provides any other statistical charts and graphs for the MANOVA and follow-up ANOVA analyses not given in the text. All other variables provided no significant differences and therefore, no further testing occurred with these variables. Tukey's HSD pairwise comparison found significance in the pairings between the Gritille Medieval period and Hacınebi ($p= 0.009$) and with Tell Qarqur ($p= 0.048$). This

significance was also noted by Fisher's LSD comparison as well. Gritille's Medieval period had more variation than the other two periods. Being that this was a much later occupation than the others, different handling strategies and even environment may be influencing this texture variable.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	0.781	2	0.391	4.371	0.015*
Error	11.710	131	0.089		
LEVEPLSAR	0.166	2	0.083	0.815	0.445
Error	13.346	131	0.102		
LEVSMC	0.124	2	0.062	0.083	0.921
Error	97.800	131	0.747		
LEVTFV	38.790	2	19.395	2.027	0.136
Error	1,253.657	131	9.570		
LEV9HASFC	0.149	2	0.075	1.582	0.210
Error	6.175	131	0.047		
LEV81HASFC	0.051	2	0.025	0.436	0.648
Error	7.662	131	0.058		

Table 5.7. Results of the MANOVA run using the three archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 3).

MANOVA 2: Comparison of Archaeological Site Phases Excluding the Neolithic: Once again, the MANOVA did not find any significant difference between the central tendencies of the different archaeological periods using rank-transformed data (Table 5.8, 5.9). The MANOVA based on Levene's transformed data also indicated no significance differences in dispersion between these phases (Table 5.10). This finding is interesting given the distinctions found within the mesowear differences. The microwear of these archaeological animals does appear to vary enough to indicate significance through analyses. The mesowear indicates the opposite, especially samples from Hacınebi. Why this pattern has developed is not certain, and may warrant further testing using other reconstruction techniques to parse out.

PHASE		*Asfc* Median	*epLsar* Median	*Smc* Median	*Tfv* Median	3x3*HAsfc* Median	9x9*HAsfc* Median
EB	Mean	1.622	.005	.169	7781.612	.478	.873
	N	10	10	10	10	10	10
	Std. Deviation	.578	.0016	.028	4933.562	.1982	.2295
	Median	1.565	.004	.153	9221.575	.422	.804
	Skewness	.752	.379	1.033	-.603	2.181	1.305
LC A	Mean	1.673	.003	.375	14125.857	.637	1.090
	N	2	2	2	2	2	2
	Std. Deviation	1.010	.000	.318	3478.503	.078	.267
	Median	1.673	.003	.375	14125.857	.637	1.090
	Skewness	.	.	.	.	.	.
LC B1 (LOCAL) PHASE	Mean	2.004	.004	.191	6841.471	.481	.881
	N	30	30	30	30	30	30
	Std. Deviation	.780	.001	.080	4758.377	.248	.220
	Median	2.106	.003	.152	6801.454	.443	.814
	Skewness	.272	.228	2.095	.068	4.074	.651

Table 5.8. Table of general statistics for each microwear variable for each of the three comparison archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by archaeological phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence (LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur). Continued on next page.

PHASE		*Asfc* Median	*epLsar* Median	*Smc* Median	*Tfv* Median	3x3*HAsfc* Median	9x9*HAsfc* Median
LC B2 (NON-URUK)	Mean	1.742	.003	9.581	8094.784	.501	1.209
	N	29	29	29	29	29	29
	Std. Deviation	.704	.001	44.830	4733.412	.173	.984
	Median	1.656	.003	.208	8042.042	.472	1.002
	Skewness	.020	.642	5.256	-.109	.718	4.207
LC B2 URUK	Mean	2.041	.004	.244	9406.255	.509	.969
	N	35	35	35	35	35	35
	Std. Deviation	.938	.001	.137	5072.201	.217	.383
	Median	1.969	.004	.208	9454.544	.446	.934
	Skewness	.920	.469	1.680	-.273	1.329	.940
Gritille Medieval	Mean	2.225	.003	.286	8691.525	.413	.738
	N	12	12	12	12	12	12
	Std. Deviation	1.389	.001	.344	5124.952	.130	.181
	Median	1.935	.003	.152	10784.577	.409	.776
	Skewness	.489	.756	3.330	-1.108	.214	-.078

Table 5.8 (Cont.). Table of general statistics for each microwear variable for each of the three comparison archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by archaeological phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence (LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur). Continued on next page.

PHASE		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	**3x3*HAsfc* Median**	**9x9*HAsfc* Median**
Qarqur	Mean	1.606	.003	.273	8408.692	.440	.876
PHASE		***Asfc* Median**	***epLsar* Median**	***Smc* Median**	***Tfv* Median**	**3x3*HAsfc* Median**	**9x9*HAsfc* Median**
Qarqur continued	N	16	16	16	16	16	16
	Std. Deviation	.653	.001	.165	3837.843	.096	.260
	Median	1.471	.003	.267	9209.603	.426	.836
	Skewness	.906	.839	2.813	-.062	.843	.355

Table 5.8 (Cont.). Table of general statistics for each microwear variable for each of the three comparison archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by archaeological phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence (LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur).

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	8,120.918	6	1,353.486	0.894	0.502
Error	192,376.582	127	1,514.776		
EPLSAR_MEDIAN	16,362.804	6	2,727.134	1.881	0.089
Error	184,134.696	127	1,449.879		
SMC_MEDIAN	9,972.705	6	1,662.118	1.108	0.361
Error	190,524.795	127	1,500.195		
TFV_MEDIAN	12,054.740	6	2,009.123	1.354	0.238
Error	188,442.260	127	1,483.797		
_3X3HASFC_MEDIAN	9,414.088	6	1,569.015	1.043	0.401
Error	191,083.412	127	1,504.594		
_9X9HASFC_MEDIAN	13,715.871	6	2,285.978	1.554	0.166
Error	186,781.629	127	1,470.721		

Table 5.9. Table 5.6. Results of the MANOVA run using all the archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) by individual period as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. No variables met this criterion.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	0.843	6	0.140	1.531	0.173
Error	11.648	127	0.092		
LEVEPLSAR	0.979	6	0.163	1.653	0.138
Error	12.534	127	0.099		
LEVSMC	5.362	6	0.894	1.226	0.297
Error	92.561	127	0.729		
LEVTFV	50.191	6	8.365	0.855	0.530
Error	1,242.256	127	9.782		
LEV9HASFC	0.294	6	0.049	1.033	0.407
Error	6.030	127	0.047		
LEV81HASFC	0.608	6	0.101	1.813	0.102
Error	7.104	127	0.056		

Table 5.10. Results of the MANOVA run using all archaeological sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) by individual period as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. No variables met this criterion

MANOVA 3: Comparison of Archaeological Site Phases: When the Gritille Neolithic phases and the other archaeological phases are used as the independent variable in a MANOVA with the microwear texture variables as dependent variables (Appendix 3), significant variables are found (anisotropy p= 0.027, 3x3-heterogeneity p= 0.021, and 9x9-heterogeneity p= 0.002) (Table 5.11). All other variables provided no significant difference and therefore, no further testing occurred with these variables.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
ASFC_MEDIAN	36,332.257	9	4,036.917	0.723	0.688
Error	1,373,822.728	246	5,584.645		
EPLSAR_MEDIAN	102,209.434	9	11,356.604	2.137	0.027*
Error	1,307,327.401	246	5,314.339		
SMC_MEDIAN	41,543.399	9	4,615.933	0.828	0.591
Error	1,371,533.960	246	5,575.341		
TFV_MEDIAN	74,980.250	9	8,331.139	1.549	0.131
Error	1,323,099.250	246	5,378.452		
_3X3HASFC_MEDIAN	105,503.175	9	11,722.575	2.221	0.021*
Error	1,298,166.575	246	5,277.100		
_9X9HASFC_MEDIAN	142,446.024	9	15,827.336	3.068	0.002*
Error	1,269,154.585	246	5,159.165		

Table 5.11. Results of the MANOVA run using the three archaeological sites' periods (Gritille, Hacınebi, Tell Qarqur) as the independent variables and the microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 3).

Tukey's HSD does not identify the source of significant variation between anisotropy, but Fisher's LSD found Phase B significantly different from the Late Chalcolithic B2 non-Uruk influence ($p= 0.020$) and Medieval Gritille ($p= 0.015$). We should consider these results suggestive, or of marginal significance, since Tukey's failed to resolve the differences. In any case, Phase B values suggest more of a grazer-like diet than these later periods, including the later Medieval period at Gritille.

For 3x3-heterogeneity, Tukey's HSD once again did not resolve the source of variation, but Fisher's LSD suggested Phase B was different from LC A, LC B2 local, and LC B2 Uruk (values found in Appendix 3). Phase A was significantly different from Gritille Medieval. Phase C was significantly different from LC A as well. In the significant comparisons of Phases B and C, the Neolithic phases had lower heterogeneity values than the other archaeological phases. Having lower values is a condition often associated with grazing (Scott 2012), although it is not the common indicator to separate out browsing from grazing diets (Table 5.12). Therefore, for this variable, the Neolithic have overall wear patterning across the occlusal surface more aligned with grazing than later sequences. As the mesowear analyses indicated the Late Chalcolithic periods, especially LC B2 Uruk had excessive grit within the diet. Previous analyses in Chapter 4 indicated Phase B had grit possibly due to foddering. These periods may have had different husbandry strategies, which increased the level of grit, or the environment may again be factoring into the microwear signature.

	Asfc	***EpLsar***	***Smc***	***Tfv***	**3X3 *HAsfc***	**9X9 *HAsfc***
Obligate Grazer	0.985	0.0065	1.343	2306.9	0.387	0.698
Browser-Grazer Intermediate	2.063	0.0037	0.417	6248.3	0.497	0.866
Browser	3.611	0.0022	0.767	10975.1	0.622	0.951

Table 5.12. Median dental microwear texture values from Extant African bovids used to show dietary distinctions. Animals have been placed into general dietary categories of grazers, intermediate feeders, and browsers based on observation of modern diets (modified from Scott 2012).

The 9x9-heterogeneity variable had several significant pairings. Fisher's LSD suggested Phase C was significantly different from all Hacınebi phases examined. Tukey's LSD indicated that both Phases B and C were significantly different from the LC B2 Local condition from Hacınebi. Given that the examination of Hacınebi included a wide variation of cultural practices and environmental conditions, demonstrating that Phase C was different from the others was especially noteworthy. The dietary practices undergone during Phase C, the earliest Neolithic phase at Gritille, must have included practices that affected the finest scale of microwear.

For the MANOVA using the Levene's transformed microwear texture variables, both anisotropy ($p= 0.017$) and 9x9-heterogeneity ($p= 0.003$) were found to be significant (Table 5.13). All other variables were not significant. Fisher's LSD pairwise comparison on the anisotropy variable suggested that the Medieval period at Gritille was significantly different from Phases C and B. Tukey's HSD found only Phase B to have significantly different variation from the Medieval period. It is curious the Medieval period and Phase B are significantly different, given that complexity distinguishes different dietary types. Phase B dietary reconstruction often aligned these animals with wild sheep and goats (see Chapter 4). The complexity values when compared to the Medieval period were smaller, as expected for an animal consuming graze and having a much narrower range. This may indicate the changing availability of resources around the site due to environmental changes.

Univariate F-Tests					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
LEVASFC	1.588	9	0.176	2.308	0.017*
Error	18.884	247	0.076		
LEVEPLSAR	1.316	9	0.146	1.673	0.096
Error	21.580	247	0.087		
LEVSMC	8.575	9	0.953	1.411	0.184
Error	166.843	247	0.675		
LEVTFV	121.149	9	13.461	1.217	0.285
Error	2,731.391	247	11.058		
LEVHASFC9	0.514	9	0.057	1.395	0.191
Error	10.112	247	0.041		
LEVHASFC81	0.954	9	0.106	2.409	0.012*
Error	10.867	247	0.044		

Table 5.13. Results of the MANOVA run using the three archaeological sites' periods (Gritille, Hacınebi, Tell Qarqur) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors. The significance for the MANOVA was $p < 0.05$. Any variable meeting this level (indicated by the star) was examined further with an ANOVA and pairwise comparison tests (results of these tests are listed in Appendix 3).

Fisher's LSD suggested variation in 9x9-heterogeneity between Phase B and both Late Chalcolithic B2 occupations at Hacınebi . Phase A variation was also different from LC B2 Local. Tukey's HSD only identified the variation between Phase B and the LC B2 Local as significant. For 9x9 heterogeneity, not only were the means different when Phase B and LC B2 were compared but so too were their variations. These periods had differences in microwear

patterning across the occlusal surface.

Conclusion

H_0 no difference in animal husbandry practices: no change in sheep central tendencies for mesowear and microwear variables. The null hypothesis can be rejected based on the patterns seen in the mesowear hierarchical cluster analyses and the significant results found when examining the microwear texture data.

H_{c1} differences in animal husbandry practices relating to Neolithic establishment of domesticated animals: the mesowear and microwear patterns for the Gritille Neolithic animals display a wider range of mesowear and microwear variation than what is seen for later cultural periods. When the mesowear variables are examined, the Neolithic Gritille Phases A and C are different enough from the other archaeological sites to cluster separately from them, especially when percentage low is examined. Phase B often clusters with LC A in the same analyses. For the microwear-based examination, three of the six texture variables differed significantly in their central tendencies between the Neolithic and other archaeological material. Using Levene-transformed data to examine distribution dispersion, an additional variable appears to vary significantly. Different diets based on husbandry methods, environments, or some combination of the two allows separation of the Neolithic material from the other archaeological periods, a feat not evidenced when only the later archaeological periods were examined separately.

Chapter Six: Conclusion

Why Study Domestication?

The domestication of animals during the Neolithic is one of the most important milestones in human history. Yet, despite many decades of exhaustive research, the motive forces behind animal domestication and the processes by which it first occurred are not fully understood. Theories regarding domestication abound. Archeologists use several approaches to infer domestication of animals recovered at archeological sites. Osteological evidence for reduction in overall body-size has been considered an important indicator of domestication (Clutton-Brock 1999). More specifically, reduced facial length and tooth size have been considered key indicators (Flannery 1983). In addition, domesticates typically retain juvenile characteristics, such as horn shape (for those animals possessing horns), coat color, and fat distribution (Clutton-Brock 1999).

However, there are complicating issues when it comes to diagnosing domestication from skeletal morphology. For instance, there are not established measurement standards, and this hinders comparisons between studies (Legge 1996). Further, the causes of observed size reduction in early domesticates are not fully understood (e.g., experimental studies suggest that selection for docility creates changes in behavior and cranial morphology, but should not affect body size) (Arbuckle 2005), which lessens our confidence in this proxy as an indicator of domestication. Factors proposed to explain reduction of body size include temperature fluctuation and decreased food availability related to environmental change (Davis 1981), human selection for smaller animals for ease of control and keeping (Isaac 1962), and malnutrition from overcrowded conditions resulting in lower growth rate and stunted (undersized) adult size (Zeder

2006a).

Researchers have also looked to species composition at archeological sites to assess degree of domestication. The percentage of sheep, for instance, is expected to increase, while the proportion of wild species, such as gazelles, should have decreased during the adoption of domestication given shifts in reliance from wild to domestic animals. In addition, the sudden appearance of non-endemic species in an area could also reflect introduction of domesticates. Another factor considered in assessment of domestication is demographic patterns, which can reflect culling practices. Because relatively few males are needed to propagate a herd, most are killed early in life, whereas females tend to be slaughtered after fertility ends (Legge 1996). This is a different pattern than expected if animals were hunted in the wild.

However, there are inherent limitations to these approaches for inferring domestication. Because current criteria only place animals into two discrete categories (domesticated or not), species undergoing the process of domestication are more difficult to identify, as no or few marked morphological changes may have yet occurred. The overall process and timing leading to changes is not well understood. Horwitz (1989) suggested as little as 30 years would be needed for domestication and associated morphological changes to occur. Arbuckle (2005) found changes could occur quickly in smaller laboratory animals, though the size and variance of cattle, goats, pigs, and sheep, along with the conditions in which the Neolithic humans placed these animals, could have extended the process from decades to centuries. Because anatomical changes took time, it may be difficult to identify the onset of domestication at a site given the continuation of hunting wild animals (Hongo et al. 2002). In addition, Neolithic hunting patterns are not fully understood. Many ruminant species do not normally associate in mixed sex groups except during the breeding season (Grigson 1989), and this influences demographic profiles of

game collected and brought back to a site. Zeder and Hesse (2000) and Zeder (2006a) have shown that if sex is not controlled for in studies, or only limited bone elements are included in analyses, demographic profiles may be skewed, and may suggest domestication where none has occurred. This calls into question claims of domestication based solely on demographic profiles.

Dietary Reconstruction

While the studies of demographic profiles and morphological features have contributed much to our understanding of domestication of animals, these approaches often lead to a simple dichotomous classification—domesticated or not, which provides only limited detail on the timing and processes by which domestication occurred. Furthermore, traditional archaeological indicators for domestication examine various aspects of the archaeofauna recovered from sites (e.g., DNA, demography, morphology). Unfortunately, it appears that for every article supporting a reconstruction method, there is another published criticizing that method. From this, one begins to understand that domestication was not a simple process that Neolithic humans began to do one day. The process of domestication likely began before the Neolithic (as indicated by genetics and demographics), and grew during the Neolithic due to factors that may not be recoverable in the archaeological record. Mesowear- and microwear-based dietary reconstructions provide a different view from traditional methods, allowing understanding of how humans handled animals through diet.

Dental Mesowear Analysis

Dental mesowear analysis reflects the diet of an animal over months to years. The wear caused by abrasion from food leaves a different gross wear pattern than attrition due to tooth-on-

tooth contact. Grazers tend to have low relief on their molar surface because wear caused by their abrasive diets blunts shearing crests, whereas browsers have more crest relief and sharper surfaces because tooth-tooth wear, or attrition, tends to sharpen crests. Mixed feeders usually have an intermediate level of molar relief. For the most part, this method has been applied to paleospecies to compare extant taxa with their fossil ancestors and assess changes over time (e.g., Merceron et al. 2007, Croft and Weinstein 2008). Kaiser et al. (2009), however, used dental microwear analysis to compare modern zoo giraffes with their wild counterparts to assess the effect of foddering. These authors found that captive giraffes that would have eaten a browse diet in the wild had marked abrasive wear and lower relief, a pattern expected of grazers. The fodder provided by the zoo caused increased rates of wear because it contained more abrasives than would its natural diet. This study shows that mesowear analysis can also prove useful in distinguishing wild from captive ruminants.

Dental Microwear Analysis

Microwear analysis distinguishes dietary types based on the patterns abrasives leave behind on the surface of enamel during mastication. These patterns are related to the properties of the ingested material and the movements of the jaw during mastication (Janis 1990; Mainland 2003; Merceron et al. 2004a, b, 2005; Scott 2012; Solounias and Hayek 1993; Solounias et al. 1988; Ungar et al. 2007). Grazers' microwear is composed predominantly of long, narrow scratches (Daegling and Grine 1999, Mainland 2003, Rensberger 1978). Browsers that eat harder foods have wear surfaces dominated by pits. In general, these features will be larger than those left behind by a folivorous diet (Daegling and Grine 1999). This microscopic wear lasts a few days to a few weeks. Each meal slowly replaces the previous meal's affect on the enamel

surface. The rates vary depending on the properties of the food ingested (Covert and Kay 1981, Teaford and Oyen 1989a, see Mainland 1998a for opposing view).

The earliest published dental microwear analysis involved the study of sheep (e.g., Baker et al. 1959). In the late 1990s and early 2000s, Mainland began to reinvestigate sheep microwear by scanning electron microscopy (SEM) in an attempt to determine whether this method could be used for reconstructing diets of zooarcheological samples. For instance, Mainland (1998a) compared microwear found on deciduous premolars of modern sheep and goats allowed to graze naturally to those foddered with hay. The analysis of wear features indicated distinctions between the two diets, with the foddered animals having more pits and wider scratches than the grazing animals (although the causes for the differences were not articulated in the paper). Mainland (2003) also examined microwear differences between sheep living in different environments; those in pastureland had striated surfaces, perhaps due to soil ingestion, whereas those in more wooded environments had mostly pitted surfaces with only a few scratches, consistent with a diet including more tree and shrub parts (see Lucas et al. 2013 for alternative view). Further, Mainland and Halstead (2005) found short-term feeding differences in caprines recovered from ceremonial contexts compared with those from daily refuse pits; the former had small microwear features indicative of soft diets, whereas high striation levels in the latter suggested a more abrasive diet.

Researchers have now begun to use texture analysis (DMTA) for studies of mammalian dental microwear. Microwear texture analysis involves a white-light confocal profiler and scale-sensitive fractal analysis for a 3D whole-surface characterization of microwear textures. DMTA has proven to be a faster method than SEM feature-based studies, and observer error in measurements eliminated because surface characterization is automated. Instead of quantifying a

tooth's surface by the number and size of pits and scratches, DMTA uses five variables to characterize overall surface texture (Scott et al. 2006). These variables relate to slightly different aspects of diet and have been shown to reflect dietary differences between species, including ruminants (Scott et al. 2005, Ungar et al. 2007). Two of the five microwear variables — anisotropy (*epLsar*) and complexity (*Asfc*) — are particularly useful for distinguishing grazers from browsers. Higher anisotropy values tend to indicate a grazer diet while higher complexity is seen with a browse-based diet (Ungar et al. 2007).

Combined Mesowear and Microwear Analyses

Several studies have combined dental microwear and mesowear analysis for insights into the diets of fossil species (e.g., Merceron et al. 2007; Rivals and Athanassiou 2008; Schubert 2004; Valli and Palombo 2008). In most cases, mesowear and microwear point to the same type of diet. Further, Valli and Palombo (2008) found that microwear allows subtle differences to be discerned where mesowear does not (given the time averaging nature of mesowear). Similarly, Rivals and Athanassiou (2008) noted that gazelles with seasonal or regional differences have slightly different microwear signatures but similar mesowear (indicative of mixed feeding). As Schubert (2004) concluded, combining mesowear and microwear offers a more robust reconstruction of diet.

Rivals et al. (2011) performed low-magnification light microscopy microwear analysis in combination with a modified mesowear analysis on wild and domesticated animals including wild and domestic cattle, wild and domestic goats, and wild and domestic pigs from the Neolithic site of Kouphovouno (Sparta), Greece. Both mesowear and microwear distinguished wild from domestic animals although, as one would predict given the later date of the site, most

of the animals (up to 95%) were interpreted to be domesticated (the method used to separate wild from domestic not detailed in the paper). Domesticated goats had intermediate tooth relief (mixed feeder). The microwear of wild goats were heavily pitted, consistent with browsing (high complexity values using DMTA) while the domesticated caprines had large numbers of parallel scratches and variable pit percentages (which might correspond to high anisotropy values in DMTA). This signature was interpreted as reflecting a grazer diet brought about by either keeping goats and sheep together in overstocked conditions leading to increased soil ingestion or seasonal resource differences (Rivals et al. 2011).

In this research, dental mesowear and microwear analyses were used to understand diet during the Neolithic. Both these methods utilized the amount of enamel wear present on the teeth to reconstruct dietary patterns, as dental wear provides important insight into an animal's life. During life, dental wear guides dietary choices and limits the amount of food eaten. In extreme cases of dental senescence, it can even lead to starvation and death (Jurado et al. 2008). Dental mesowear and microwear analyses provide a way to understand diet through different aspects of wear, gross and microscopic respectively. When comparing archaeological animals from the Neolithic to wild animals, understanding of how human control modified wild dietary types can be understood.

Dietary Reconstruction of Wild Animals

Specimens from the Field Museum of Natural History (FMNH) (Chicago) were included as comparison samples in this study. These specimens were wild animals shot in their natural habitats during expeditions to the Near East, specifically Iran. Specimens used in this dissertation had known provenances (location and collection dates). This information provides

some insight into the animals' environment prior to death.

In all, the wild species provided insight into the dietary differences that occurred between various species of gazelles, goats, and sheep living in Iran. The statistical analyses indicate dietary distinctions between the species could be determined based on dietary reconstruction methods of dental mesowear and microwear. These distinctions included differences in diet eaten between the taxa as well as dietary differences that occurred between species living in differing environments. Dietary reconstruction methods reflect the diet eaten during the period prior to death and over their lifetime, and serve as a proxy for the environment in which a species lived. As such, comparing Neolithic individuals to wild ones should provide insight into what types of husbandry environments these animals were placed by seeing which groups/ environments the Neolithic specimens align with or differ from.

Dietary Reconstruction of Neolithic Animals from Gritille

The Neolithic Gritille fauna used in this research arose from three of the four sub-phases (C-A) recovered during the site's excavations. Sheep and goats appeared throughout the sequence, but only the later phases (Phase B) suggested domestication through traditional indicators, such as morphology. Caprine sizes began to decrease during Phase C but did not reach a consistent size change until Phase B. This signal suggests that initial husbandry began during phase C, but either interbreeding still occurred with wild individuals or hunting of wild animals continued throughout this occupational level (Monahan 2000). Demographic reconstruction indicates juvenile cull occurred prior to Phase B, but it was not until Phase B that male cull was observed (Monahan 2000, 2007).

Neolithic Phase C ovicaprines at Gritille appear to have dietary signals supporting

penning. The penning indicated through the dietary reconstruction methods from the early Neolithic occupations of Gritille is supported by Stiner et al. (2014). Fecal analysis provided information on penning and led the authors to conclude penning was a necessary beginning for domestication (Stiner et. al 2014). Penning animals could provide a source a ready source for fertilizer or fuel for fires, especially if wood resources were scarce as humans cleared the landscape for agriculture (Harris 1977, Hesse 1984, Miller 1996). Animals from Phase B appeared to have been closest to the wild diet, but still different from it. Humans could have foddered the animals, such as allowing them to graze off the stubble of crop fields. During the last Phase (A), the mesowear suggests a rising gross wear rate, approaching levels of gazelles. This pattern is consistent with changes in microwear variables such as the variation in complexity and heterogeneity. These signatures are consistent with the idea that the environment started to degrade around Gritille, resulting in increased grit within the diet.

Dietary Reconstruction of Gritille Neolithic Compared to Later Archaeological Sites

Gritille was compared to other archaeological sites around the Euphrates River to assess how Neolithic husbandry practices compared to later periods. This baseline provides more insight into the handling during the initial period of animal husbandry. The sites included specimens from Hacınebi and Tell Qarqur. Hacınebi teeth represented three Chalcolithic phases, Phase A (4,100-3,800BC), B1 (3,800-3,600BC), and B2 (3,600- 3,300BC). Phase A is the earliest settlement phase and is continuous to B1, although changes in the archeological record occur, such as alteration in ceramics and building patterns (e.g., building of large infrastructure possibly for administrative purposes). Phase B2 is characterized by the traditional Anatolian cultures and the presence of Uruk material (e.g., presence of both local and Uruk pottery,

increased use of bitumen). The presence of Uruk indicates the possible connection of Hacınebi with the rest of the Uruk network originating in southern Mesopotamia (Bigelow 1999, 2011). Specimens from Tell Qarqur came from later periods in its history when the site was a major city in the region based on archaeological evidence (Dornemann 2003).

The mesowear and microwear patterns for the Gritille Neolithic animals display a wider range of mesowear and microwear patterns than what is seen for later cultural periods. When the mesowear variables are examined, the Neolithic Gritille Phases A and C are different enough from the other archaeological sites to cluster separately from them. Phase B often clusters with LC A from Hacınebi, which is thought to reflect a pastoral-based lifestyle. For the microwear-based examination, different diets reflecting different husbandry methods, environments, or some combination of the two allows separation of the Neolithic material from the other archaeological periods, a feat not done when only the later archaeological periods were examined separately.

Interestingly, the comparative archaeological materials indicated no significant differences in microwear variables despite varying times and environments. However, when the Neolithic samples are included, differences emerge. One may hypothesize changes in environment are being reflected by the differences in microwear variables, but the comparative archaeological sites are from different environments and indicate similar dietary wear. The other major impact on animal diet is human husbandry. Therefore, the Neolithic Gritille dietary reconstruction results indicate different husbandry strategies were utilized over the phases examined (e.g., during the incipient period of domestication). Gritille inhabitants were adapting and adjusting their husbandry techniques as they developed domesticated animals. Neolithic people may not have had a standard strategy, especially if animals were being domesticated for

varying reasons (e.g., dung for fuel or fertilizer, religion, feasting, secondary products, or meat stores).

These difference between Neolithic husbandry and later periods beg the question of whether ethnographic examples, often used as the basis for traditional domestication indicators, are appropriate for Neolithic, and earlier, animal investigations. For instance, as discussed previously, during Phase C, the Gritille animals appear to be penned. However, modern uses of pens are often limited to protection and not for feeding. If animals are eating in pens today, it is from fodder sources, which would not lead to the microwear variables seen and brings up the question of agricultural resources available for fodder. Other issues with ethnographic examples include sizes of the initial domestic stock, the behavior, and requirements of control needed for animals undergoing domestication. Therefore, it appears that a reevaluation for using ethnographic examples to understand the practices during the Neolithic may be warranted. Modern examples may not provide true understanding of how animals were treated in the Neolithic, which then influences our understanding of the process of domestication. Domestication was a unique development in human history and requires a unique approach to understand.

Conclusion

In the end, researchers may never really understand the reasons why domestication or pastoralism occurred, especially if the transition period left no marked traditional archaeological indicators. By continuing to follow old methods, ideas, and definitions of domestication and pastoralism researchers today may fail to understand how technology grew and changed (Smith 2001). As discussed in this dissertation, even the definitions of domestication and pastoralism

vary depending on the sources. Varied backgrounds of different researchers provide different viewpoints in defining these economic strategies. Furthermore, archaeological evidence can be used to support competing ideas. For example, broad-spectrum use of animals could indicate population pressure, climatic change, environmental degradation due to sedentism, technological changes, or even the evolution of relationships between humans and the animals around them. Therefore, archaeological evidence can be interpreted in many ways, depending on the preconceived notions of the researcher speculating on the motive forces behind domestication. This poses a serious challenge to hypothesis testing.

This divide warrants new methodology to tease out differences in such a manner that semantics will not prove problematic. As Binford (1968) suggested, setting forth a new hypothesis free from traditional methods (ethnographic and archaeology-based) was warranted, as traditional ideas were not providing insight with new evidence. Why domestication occurred is still an unanswered question, and begs for new methods and techniques to be used to test specific hypotheses related to domestication. This is especially true when the Neolithic results presented in this dissertation are examined. Dietary reconstructions indicate that not only are the Neolithic phases different from each other, but they are different from later phases as well, including those from the same site. The finding of so many differences between all the archaeological periods indicates there was no one mode of animal husbandry or diet in the course of early domestication. Because people adapted to the specific environments in which they were living, they developed varying husbandry strategies as well. As such, one may begin to wonder whether, if there is so much variation in raising animals, then could there not be variation in adopting domestication in the first place? There was not one cut-and-paste method for raising animals in this area of the Near East, and so there was not likely one reason for adoption of these

animals. Domestication may have started for various reasons and at various points prior to the Neolithic. We can speculate that word of mouth may have spread the idea of domestication, but each culture modified their practices to allow each to have successful practices. If more examinations of sites in the Near East are carried out, including earlier periods, a better understanding can be ascertained as to the how and possibly why domestication occurred. As seen with this research and that of Stiner et al. (2014), finding indicators of penning is a logical place to begin. Dietary reconstruction provides a method that allows sites that have already been dug to be examined, and does not require anything more than the faunal remains themselves. Furthermore, this methodology allows the tracing of handling changes as domestic animals became integrated into the agricultural lifeways of a society. By using mesowear and microwear analyses at other Near Eastern sites, comparisons can be made to better understand and interpret the dental wear for domestication. This methodology can be used for Pre-Neolithic and Neolithic sites to trace how animal diets changed, providing information on animal husbandry, and how domestication developed not only over time but also over space.

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Appendix 1: Extant Species Statistical Output

Mesowear

Cluster Analysis 1: by Taxa

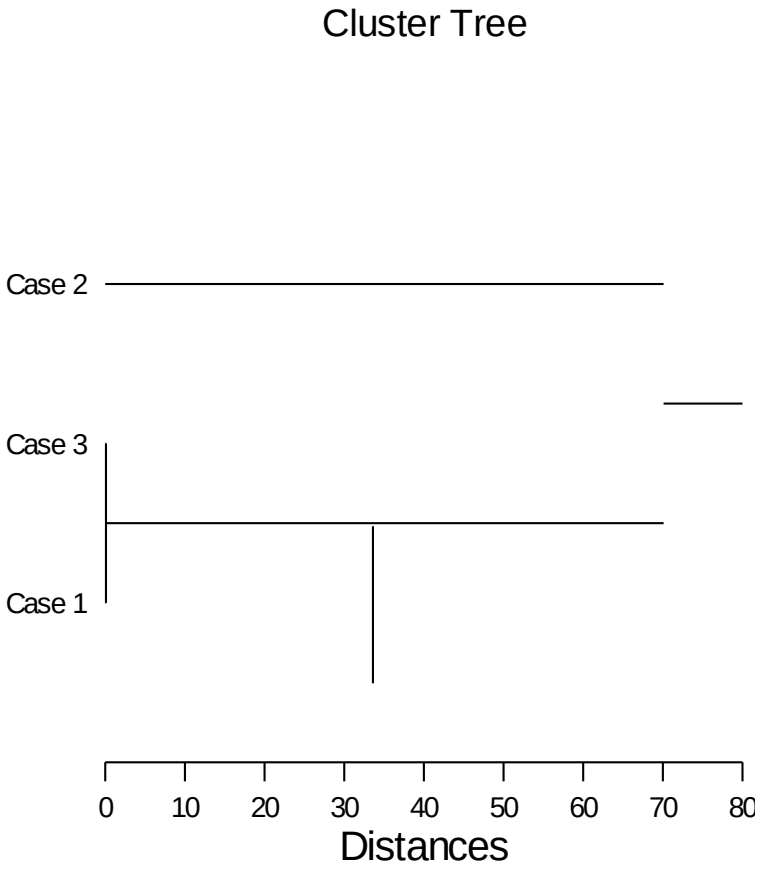

Figure Appendix 1.1. Hierarchical cluster analysis by percentage high and percentage sharp. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

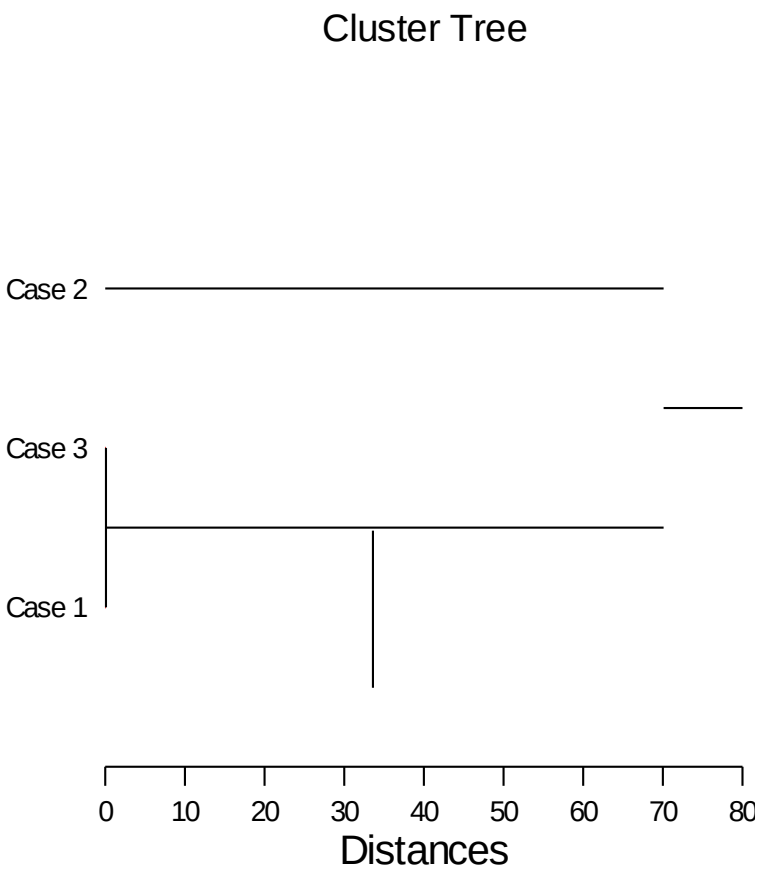

Figure Appendix 1.2. Hierarchical cluster analysis percentage high and percentage round. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

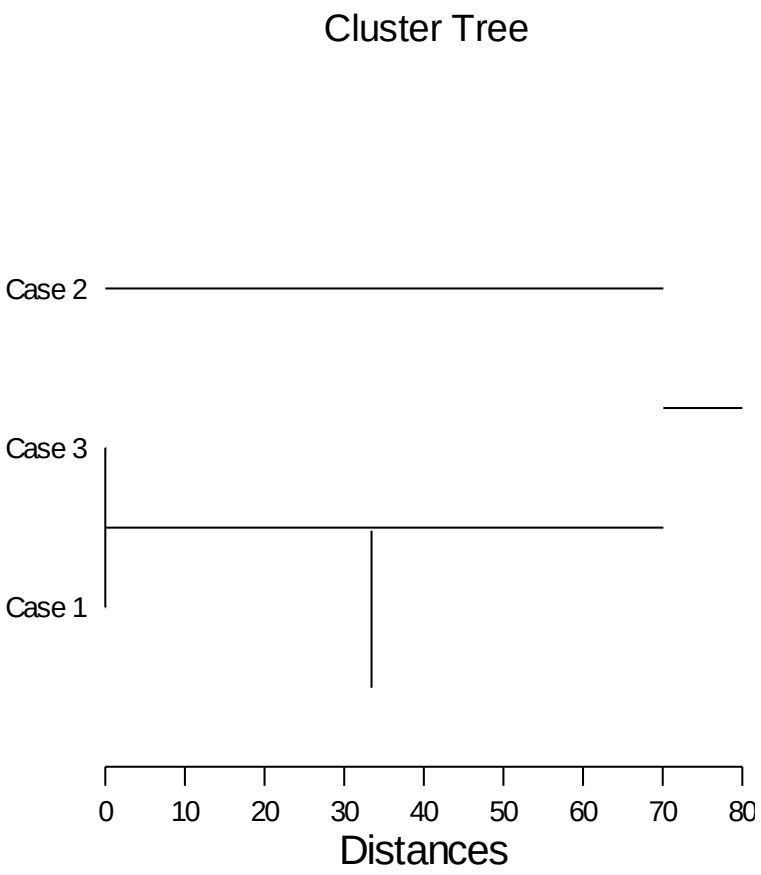

Figure Appendix 1.3. Hierarchical analysis percentage high and percentage blunt. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

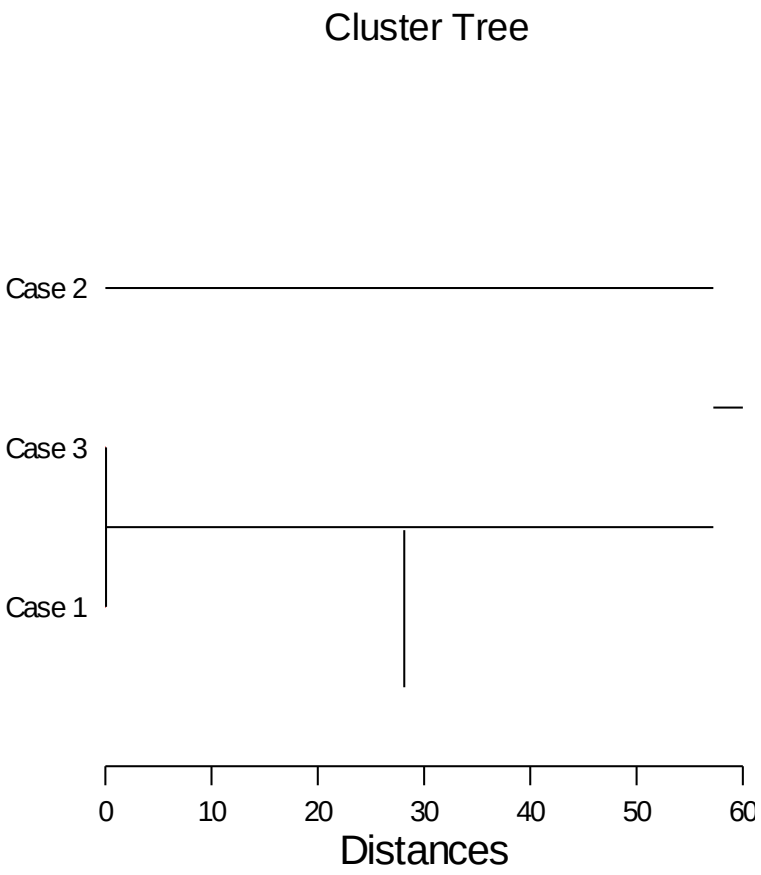

Figure Appendix 1.4. Hierarchical cluster analysis by percentage high and percentage sharp and blunt. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

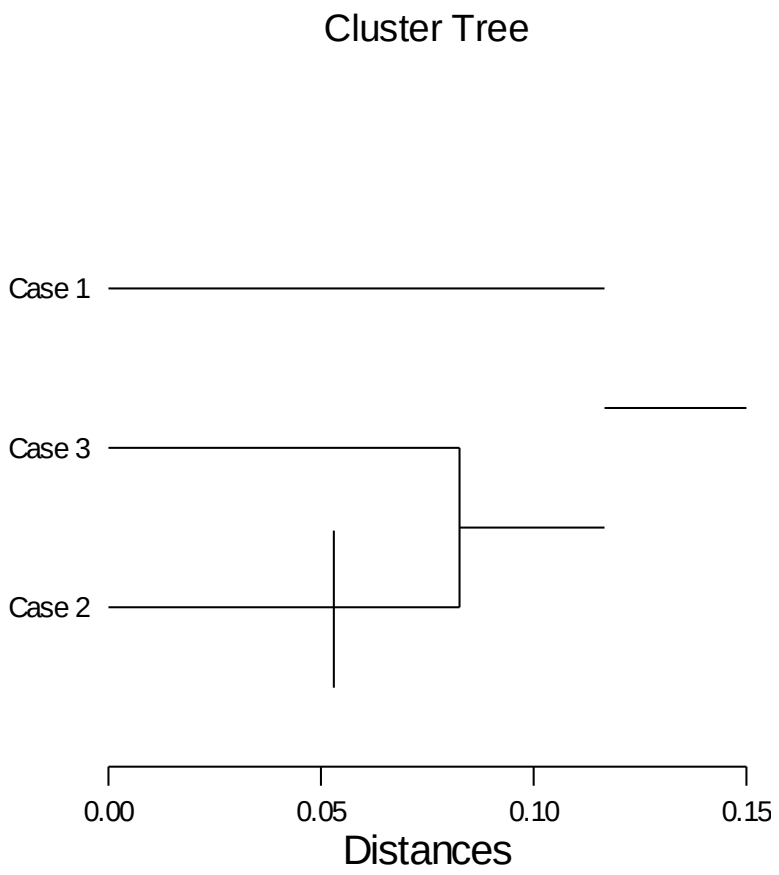

Figure Appendix 1.5. Hierarchical cluster analysis by percentage low and percentage sharp. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

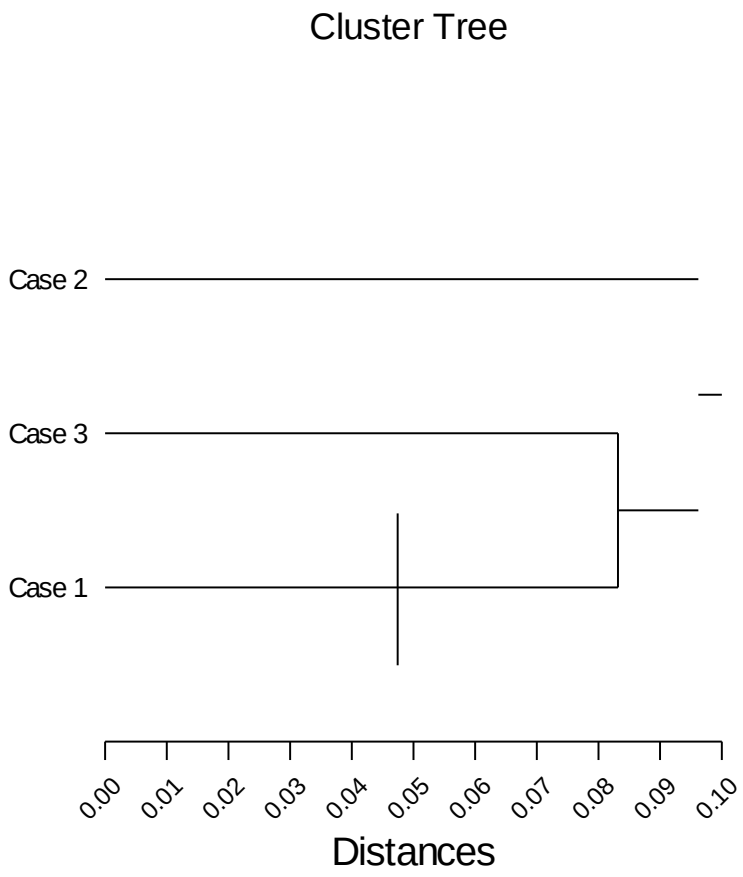

Figure Appendix 1.6. Hierarchical cluster analysis by percentage low and percentage round. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

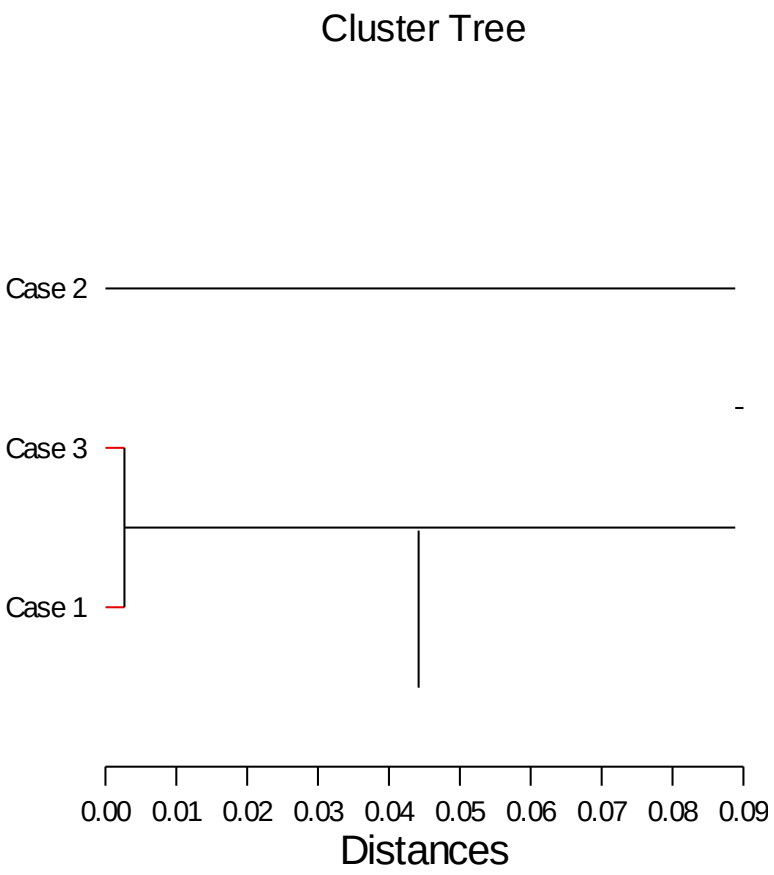

Figure Appendix 1.7. Hierarchical cluster analysis by percentage low and percentage blunt. Group 1 is goats, group 2 is gazelle, and group 3 is sheep.

Cluster Analysis 2: by Species

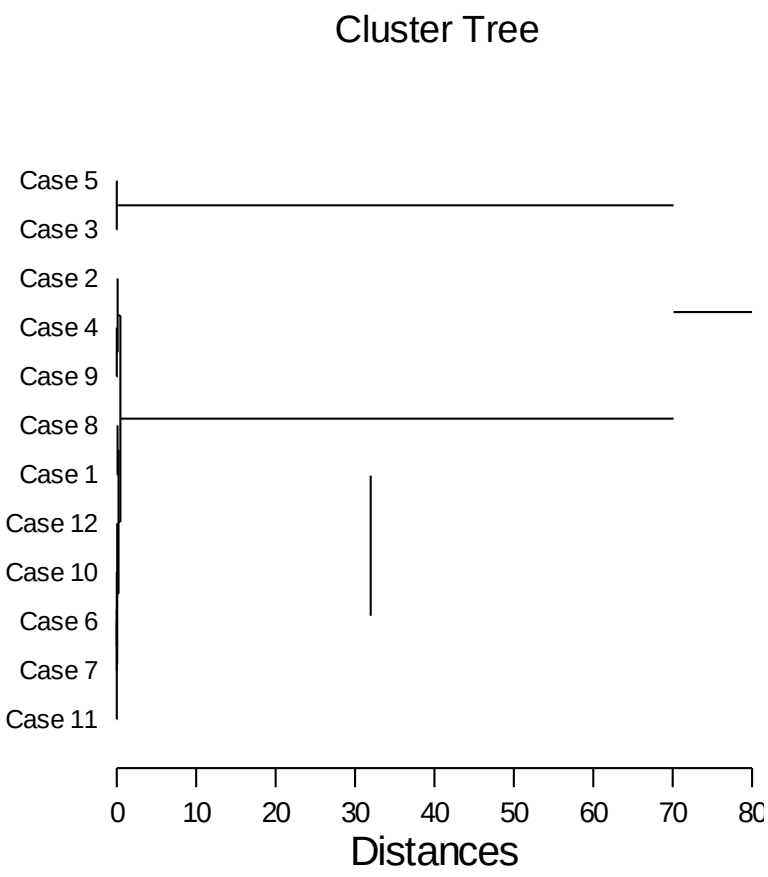

Figure Appendix 1. 8. Hierarchical cluster analysis based on percentage high and percentage sharp. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus,* 3= *Gazella dorcas dorcas,* 4= *Gazella gazella bennetti,* 5= *Gazella subgutturosa subgutturosa,* 6= *Ovis aries aries,* 7= *Ovis aries gmelini,* 8= *Ovis aries isphagnaica,* 9= *Ovis aries laristanica,* 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

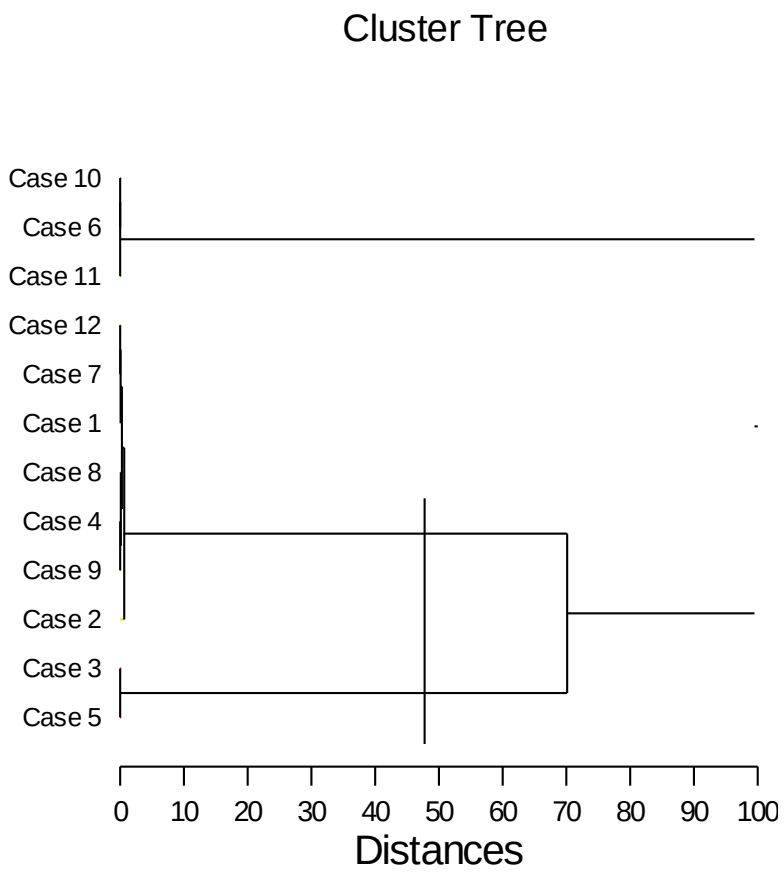

Figure Appendix 1.9. Hierarchical cluster analysis based on percentage high and percentage round. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

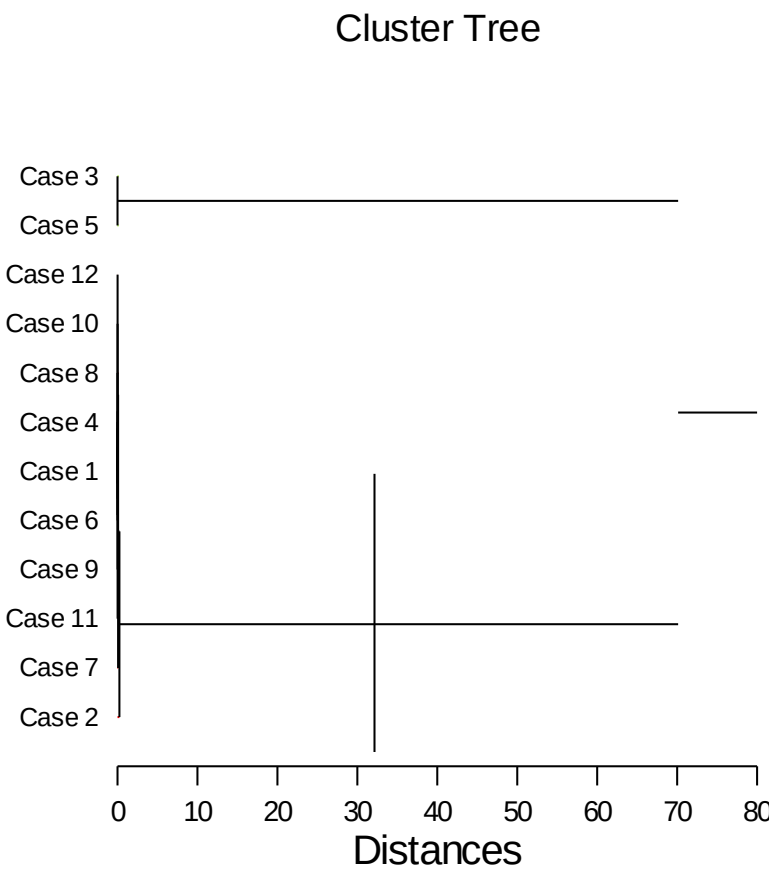

Figure Appendix 1.10. Hierarchical cluster analysis based on percentage high and percentage blunt. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

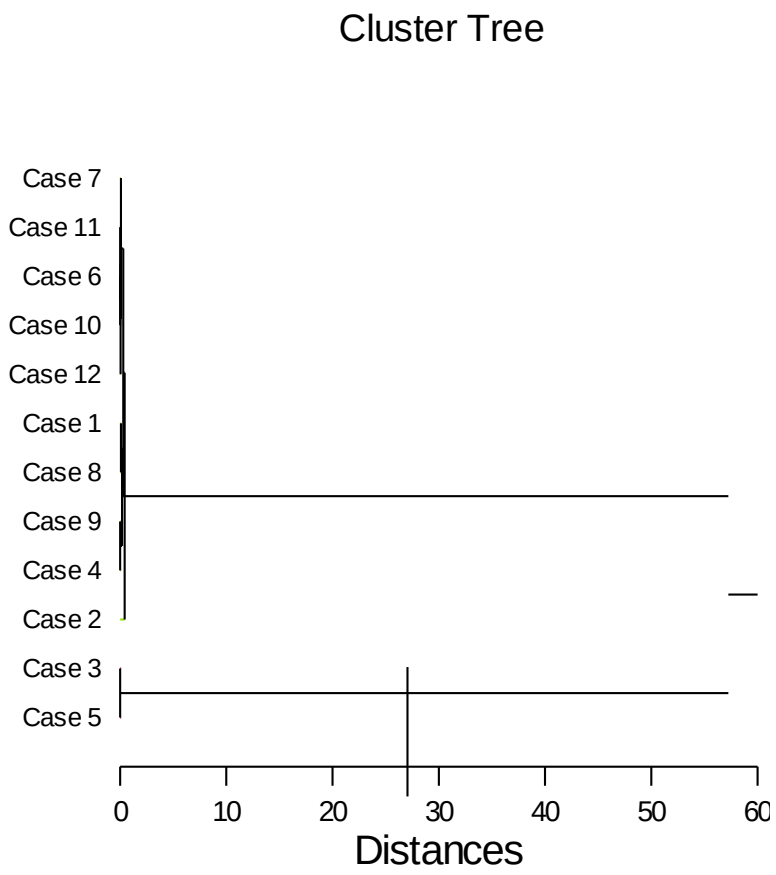

Figure Appendix 1.11. Hierarchical cluster analysis by percentage high and percentage sharp and blunt. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

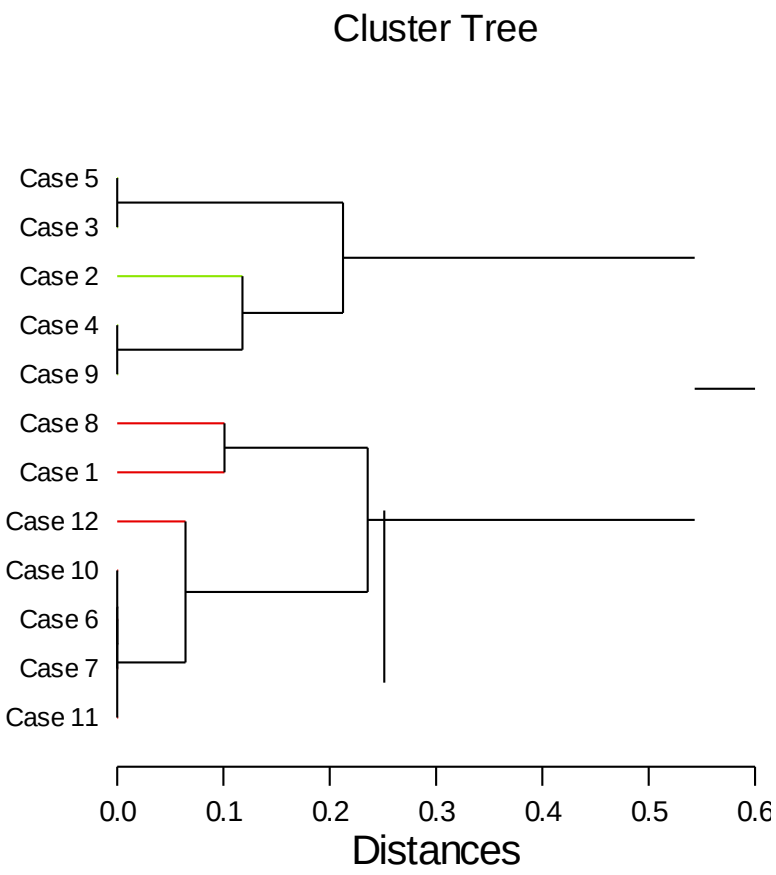

Figure Appendix 1.12. Hierarchical cluster analysis based on percentage low and percentage sharp. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

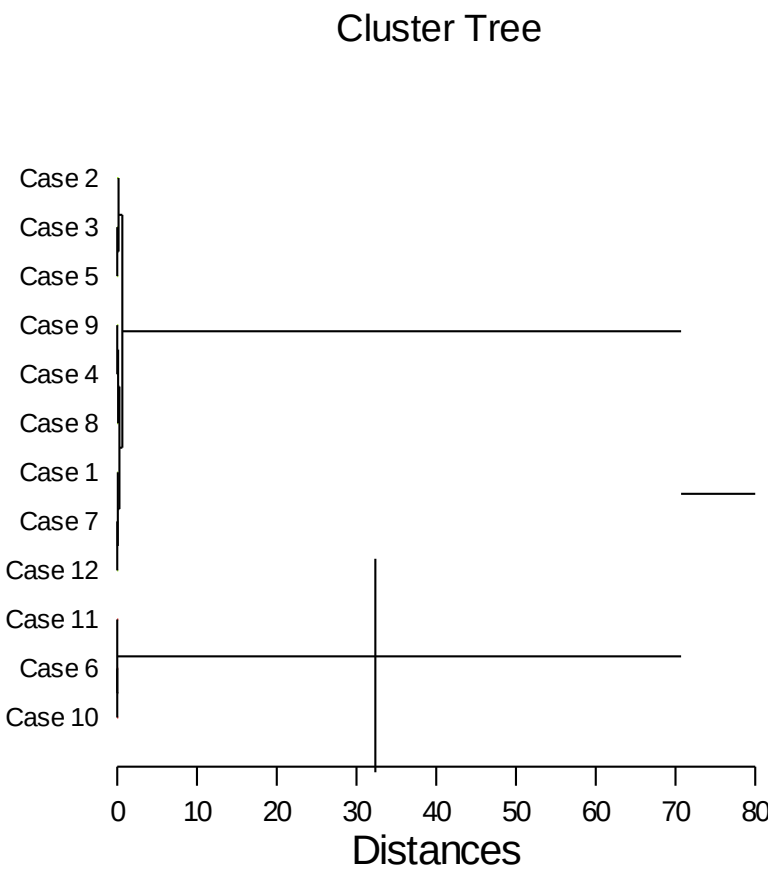

Figure Appendix 1.13. Hierarchical cluster analysis based on percentage low and percentage round. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

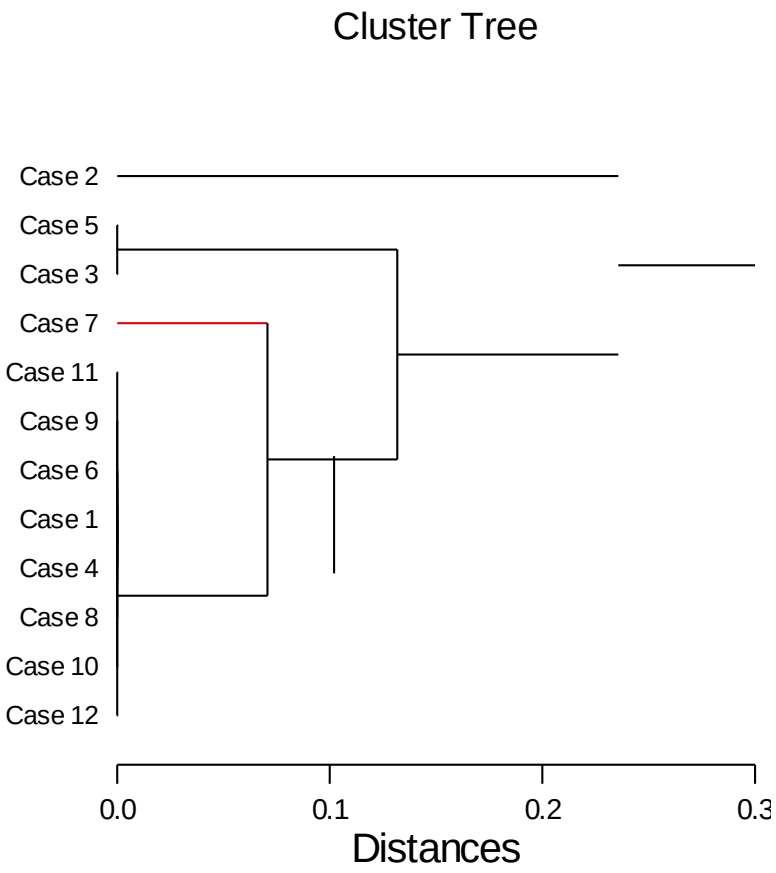

Figure Appendix 1.14. Hierarchical cluster analysis based on percentage low and percentage blunt. 1= *Capra hircus aegagrus*, 2= *Capra hircus hircus*, 3= *Gazella dorcas dorcas*, 4= *Gazella gazella bennetti*, 5= *Gazella subgutturosa subgutturosa*, 6= *Ovis aries aries*, 7= *Ovis aries gmelini*, 8= *Ovis aries isphagnaica*, 9= *Ovis aries laristanica*, 10= *Ovis aries* sp., 11= *Ovis aries urmiana*, 12= *Ovis vignei dolgopolovi*

Microwear

MANOVA 1

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.736	3.507	12, 254	0.000
Pillai Trace	0.279	3.459	12, 256	0.000
Hotelling-Lawley Trace	0.339	3.555	12, 252	0.000

Table Appendix 1.1. Results of the MANOVA run using the taxa (gazelle, goat, sheep) as the independent variables and the microwear texture variables as the dependent factors.

Pairwise Comparison of *Asfc*

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	20.362	0.085	-2.083	42.808
gazelle	sheep	22.048	0.025*	2.183	41.913
goat	sheep	1.686	0.975	-16.763	20.135

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	20.362	0.035*	1.418	39.306
gazelle	sheep	22.048	0.010*	5.282	38.814
goat	sheep	1.686	0.831	-13.885	17.257

Table Appendix 1.2. Results of the pairwise comparison for complexity. Tukey's HSD on the top and Fisher's LSD on the bottom. Stars indicate significance.

Pairwise Comparison of *Tfv*

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	42.046	0.000*	20.852	63.240
gazelle	sheep	33.108	0.000*	14.350	51.866
goat	sheep	-8.938	0.452	-26.359	8.482

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	42.046	0.000*	24.158	59.934
gazelle	sheep	33.108	0.000*	17.276	48.939
goat	sheep	-8.938	0.231	-23.641	5.765

Table Appendix 1.3. Results of the pairwise comparison for texture fill volume. Tukey's HSD on the top and Fisher's LSD on the bottom. Stars indicate significance.

Levene's Transformed Values for MANOVA 1

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.858	1.682	12, 254	0.071
Pillai Trace	0.145	1.661	12, 256	0.076
Hotelling-Lawley Trace	0.162	1.703	12, 252	0.066

Table Appendix 1.4. Results of the MANOVA run using the taxa (gazelle, goat, sheep) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors.

Pairwise Comparison for Levene's Transformed 9X9-Heterogeneity

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Gazelle	Goat	-0.002	0.999	-0.119	0.114
Gazelle	Sheep	-0.091	0.097	-0.194	0.012
Goat	Sheep	-0.088	0.077	-0.184	0.007

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Gazelle	Goat	-0.002	0.962	-0.100	0.096
gazelle	Sheep	-0.091	0.041	-0.177	-0.004
goat	Sheep	-0.088	0.032	-0.169	-0.008

Table Appendix 1.5. Results of the pairwise comparison for 9X9 Heterogeneity. Tukey's HSD on the top and Fisher's LSD on the bottom. Stars indicate significance.

MANOVA 2

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.288	2.530	66, 636	0.000
Pillai Trace	1.058	2.394	66, 738	0.000
Hotelling-Lawley Trace	1.490	2.626	66, 698	0.000

Table Appendix 1.6. Results of the MANOVA run using the individual gazelle, goat, sheep species as the independent variables and the microwear texture variables as the dependent factors.

Pairwise Comparison of Individual Species for *Asfc*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Ovis aries gmelini*	35.675	0.038	0.931	70.418
Gazella dorcas dorcas	*Ovis aries aries*	61.758	0.020	4.870	118.645
Gazella dorcas dorcas	*Ovis aries gmelini*	66.824	0.000	22.330	111.319
Gazella subgutturosa subg	*Ovis aries gmelini*	48.733	0.018	4.239	93.228
Ovis aries aries	*Ovis vignei dolgopolovi*	-53.625	0.030	-104.786	-2.464
Ovis aries gmelini	*Ovis aries urmiana*	-59.933	0.035	-117.816	-2.051
Ovis aries gmelini	*Ovis vignei dolgopolovi*	-58.692	0.000	-95.585	-21.799

Table Appendix 1.7. Results of the Tukey's HSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Gazella dorcas dorcas*	-31.150	0.010	-54.700	-7.600
Capra hircus aegagrus	*Ovis aries aries*	30.608	0.046	0.545	60.671
Capra hircus aegagrus	*Ovis aries gmelini*	35.675	0.001	14.630	56.719
Capra hircus aegagrus	*Ovis vignei dolgopolovi*	-23.017	0.013	-41.118	-4.917
Capra hircus hircus	*Gazella dorcas dorcas*	-75.091	0.005	-127.280	-22.902
Capra hircus hircus	*Gazella subgutturosa subg*	-57.000	0.033	-109.189	-4.811
Capra hircus hircus	*Ovis aries urmiana*	-68.200	0.019	-125.003	-11.397
Capra hircus hircus	*Ovis vignei dolgopolovi*	-66.958	0.009	-116.926	-16.991
Gazella dorcas dorcas	*Ovis aries aries*	61.758	0.001	27.301	96.214
Gazella dorcas dorcas	*Ovis aries gmelini*	66.824	0.000	39.874	93.775

Table Appendix 1.8. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella dorcas dorcas	*Ovis aries isphahanica*	41.091	0.042	1.450	80.732
Gazella dorcas dorcas	*Ovis aries laristanica*	52.491	0.005	15.872	89.109
Gazella dorcas dorcas	*Ovis aries sp.*	40.000	0.007	11.051	68.949
Gazella gazella bennetti	*Ovis aries gmelini*	40.448	0.011	9.371	71.525
Gazella subgutturosa subg	*Ovis aries aries*	43.667	0.013	9.210	78.123
Gazella subgutturosa subg	*Ovis aries gmelini*	48.733	0.000	21.783	75.684
Ovis aries gmelini	*Ovis aries urmiana*	-59.933	0.001	-94.993	-24.874
Ovis aries gmelini	*Ovis vignei dolgopolovi*	-58.692	0.000	-81.038	-36.346
Ovis aries laristanica	*Ovis aries urmiana*	-45.600	0.038	-88.539	-2.661
Ovis aries laristanica	*Ovis vignei dolgopolovi*	-44.358	0.010	-77.734	-10.983
Ovis aries sp.	*Ovis vignei dolgopolovi*	-31.867	0.012	-56.588	-7.147

Table Appendix 1.8 (Cont.). Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for Anisotropy

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Ovis aries sp.	*Ovis vignei dolgopolovi*	42.140	0.047	0.217	84.064

Table Appendix 1.9. Results of the Tukey's HSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Capra hircus hircus*	-52.441	0.043	-103.185	-1.698
Capra hircus aegagrus	*Gazella dorcas dorcas*	32.150	0.010	7.959	56.341
Capra hircus aegagrus	*Ovis aries gmelini*	23.592	0.033	1.975	45.209
Capra hircus aegagrus	*Ovis aries urmiana*	40.059	0.019	6.655	73.462
Capra hircus aegagrus	*Ovis vignei dolgopolovi*	28.017	0.003	9.424	46.610
Capra hircus hircus	*Gazella dorcas dorcas*	84.591	0.002	30.981	138.201
Capra hircus hircus	*Gazella subgutturosa subg*	59.227	0.031	5.618	112.837
Capra hircus hircus	*Ovis aries gmelini*	76.033	0.005	23.535	128.532
Capra hircus hircus	*Ovis aries urmiana*	92.500	0.002	34.151	150.849
Capra hircus hircus	*Ovis vignei dolgopolovi*	80.458	0.002	29.131	131.786
Gazella dorcas dorcas	*Gazella gazella bennetti*	-52.519	0.003	-86.238	-18.801

Table Appendix 1.10. Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella dorcas dorcas	*Ovis aries aries*	-52.424	0.004	-87.819	-17.030
Gazella dorcas dorcas	*Ovis aries isphahanica*	-47.091	0.024	-87.810	-6.371
Gazella dorcas dorcas	*Ovis aries sp.*	-46.273	0.003	-76.010	-16.535
Gazella gazella bennetti	*Ovis aries gmelini*	43.962	0.007	12.039	75.885
Gazella gazella bennetti	*Ovis aries urmiana*	60.429	0.004	19.593	101.264
Gazella gazella bennetti	*Ovis vignei dolgopolovi*	48.387	0.002	18.429	78.345
Ovis aries aries	*Ovis aries gmelini*	43.867	0.011	10.179	77.554
Ovis aries aries	*Ovis aries urmiana*	60.333	0.005	18.104	102.563
Ovis aries aries	*Ovis vignei dolgopolovi*	48.292	0.003	16.460	80.124
Ovis aries gmelini	*Ovis aries sp.*	-37.715	0.008	-65.399	-10.031
Ovis aries isphahanica	*Ovis aries urmiana*	55.000	0.022	8.217	101.783
Ovis aries isphahanica	*Ovis vignei dolgopolovi*	42.958	0.026	5.294	80.622

Table Appendix 1.10 (Cont.). Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Ovis aries sp.	*Ovis aries urmiana*	54.182	0.005	16.567	91.797
Ovis aries sp.	*Ovis vignei dolgopolovi*	42.140	0.001	16.747	67.533

Table Appendix 1.10 (Cont.). Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for the Scale of Maximum Complexity

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus aegagrus	*Ovis aries gmelini*	-54.649	0.000	-89.790	-19.509
Gazella dorcas dorcas	*Ovis aries gmelini*	-56.994	0.002	-101.997	-11.991
Ovis aries gmelini	*Ovis aries sp.*	53.994	0.005	8.991	98.997
Ovis aries gmelini	*Ovis aries urmiana*	65.667	0.013	7.123	124.210
Ovis aries gmelini	*Ovis vignei dolgopolovi*	65.267	0.000	27.952	102.581

Table Appendix 1.11. Results of the Tukey's HSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Capra hircus hircus*	-61.882	0.016	-111.846	-11.919
Capra hircus aegagrus	*Ovis aries aries*	-31.049	0.045	-61.456	-0.642
Capra hircus aegagrus	*Ovis aries gmelini*	-54.649	0.000	-75.934	-33.364
Capra hircus hircus	*Gazella dorcas dorcas*	64.227	0.018	11.442	117.013
Capra hircus hircus	*Gazella gazella bennetti*	55.786	0.047	0.729	110.843
Capra hircus hircus	*Ovis aries sp.*	61.227	0.023	8.442	114.013
Capra hircus hircus	*Ovis aries urmiana*	72.900	0.013	15.448	130.352
Capra hircus hircus	*Ovis vignei dolgopolovi*	72.500	0.005	21.962	123.038
Gazella dorcas dorcas	*Ovis aries gmelini*	-56.994	0.000	-84.252	-29.736
Gazella gazella bennetti	*Ovis aries gmelini*	-48.552	0.003	-79.984	-17.120
Gazella subgutturosa subg	*Ovis aries gmelini*	-36.448	0.009	-63.707	-9.190

Table Appendix 1.12. Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella subgutturosa subg	*Ovis vignei dolgopolovi*	28.818	0.024	3.816	53.821
Ovis aries aries	*Ovis aries urmiana*	42.067	0.047	0.486	83.647
Ovis aries aries	*Ovis vignei dolgopolovi*	41.667	0.010	10.324	73.009
Ovis aries gmelini	*Ovis aries isphahanica*	41.017	0.038	2.375	79.658
Ovis aries gmelini	*Ovis aries laristanica*	48.067	0.008	12.607	83.527
Ovis aries gmelini	*Ovis aries sp.*	53.994	0.000	26.736	81.252
Ovis aries gmelini	*Ovis aries urmiana*	65.667	0.000	30.207	101.127
Ovis aries gmelini	*Ovis vignei dolgopolovi*	65.267	0.000	42.665	87.868

Table Appendix 1.12 (Cont.). Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for the *Tfv*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Gazella dorcas dorcas*	-60.235	0.000	-100.776	-19.694
Gazella dorcas dorcas	*Ovis aries aries*	71.000	0.005	11.683	130.317
Gazella dorcas dorcas	*Ovis aries sp.*	59.091	0.006	9.255	108.927
Gazella dorcas dorcas	*Ovis vignei dolgopolovi*	52.542	0.003	9.986	95.097

Table Appendix 1.13. Results of the Tukey's HSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Gazella dorcas dorcas*	-60.235	0.000	-84.791	-35.679
Capra hircus aegagrus	*Gazella subgutturosa subg*	-39.326	0.002	-63.882	-14.770
Capra hircus aegagrus	*Ovis aries gmelini*	-22.769	0.042	-44.712	-0.826
Gazella dorcas dorcas	*Gazella gazella bennetti*	40.143	0.022	5.915	74.370
Gazella dorcas dorcas	*Ovis aries aries*	71.000	0.000	35.072	106.928
Gazella dorcas dorcas	*Ovis aries gmelini*	37.467	0.009	9.365	65.568
Gazella dorcas dorcas	*Ovis aries laristanica*	58.000	0.003	19.818	96.182
Gazella dorcas dorcas	*Ovis aries sp.*	59.091	0.000	28.905	89.277
Gazella dorcas dorcas	*Ovis aries urmiana*	52.000	0.008	13.818	90.182
Gazella dorcas dorcas	*Ovis vignei dolgopolovi*	52.542	0.000	26.766	78.318
Gazella subgutturosa subg	*Ovis aries aries*	50.091	0.007	14.163	86.019

Table Appendix 1.14. Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella subgutturosa subg	*Ovis aries sp.*	38.182	0.014	7.996	68.368
Gazella subgutturosa subg	*Ovis vignei dolgopolovi*	31.633	0.017	5.857	57.409

Table Appendix 1.14 (Cont.). Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for 9X9 Heterogeneity

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus aegagrus	*Ovis aries gmelini*	-0.126	0.045	-0.250	-0.003
Capra hircus aegagrus	*Ovis aries sp.*	-0.140	0.047	-0.278	-0.002
Gazella subgutturosa subg	*Ovis aries gmelini*	-0.194	0.017	-0.352	-0.036
Gazella subgutturosa subg	*Ovis aries sp.*	-0.208	0.017	-0.378	-0.038

Table Appendix 1.15. Results of the Fisher's LSD pairwise comparison for 9X9 Heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Tukey's HSD did not report any significant pairwise comparisons.

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.285	2.548	66, 636	0.000
Pillai Trace	1.011	2.265	66, 738	0.000
Hotelling-Lawley Trace	1.613	2.843	66, 698	0.000

Table Appendix 1.16. Results of the MANOVA run using all species (gazelle, goat, sheep) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors.

Pairwise comparison for Levene's transformed *SMC*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Ovis aries gmelini*	-2.310	0.000	-3.186	-1.434
Gazella dorcas dorcas	*Ovis aries gmelini*	-1.982	0.000	-3.104	-0.861
Gazella gazella bennetti	*Ovis aries gmelini*	-2.204	0.000	-3.498	-0.911
Gazella subgutturosa subg	*Ovis aries gmelini*	-2.131	0.000	-3.253	-1.009
Ovis aries aries	*Ovis aries gmelini*	-1.880	0.000	-3.245	-0.515
Ovis aries gmelini	*Ovis aries isphahanica*	2.344	0.000	0.754	3.934
Ovis aries gmelini	*Ovis aries laristanica*	2.322	0.000	0.863	3.782
Ovis aries gmelini	*Ovis aries sp.*	2.426	0.000	1.304	3.548
Ovis aries gmelini	*Ovis aries urmiana*	2.370	0.000	0.910	3.829
Ovis aries gmelini	*Ovis vignei dolgopolovi*	2.343	0.000	1.413	3.273

Table Appendix 1.17. Results of the Tukey's HSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Ovis aries gmelini*	-2.310	0.000	-2.841	-1.780
Capra hircus hircus	*Ovis aries sp.*	1.313	0.050	-0.003	2.629
Gazella dorcas dorcas	*Ovis aries gmelini*	-1.982	0.000	-2.662	-1.303
Gazella gazella bennetti	*Ovis aries gmelini*	-2.204	0.000	-2.988	-1.421
Gazella subgutturosa subg	*Ovis aries gmelini*	-2.131	0.000	-2.811	-1.452
Ovis aries aries	*Ovis aries gmelini*	-1.880	0.000	-2.707	-1.053
Ovis aries gmelini	*Ovis aries isphahanica*	2.344	0.000	1.381	3.307
Ovis aries gmelini	*Ovis aries laristanica*	2.322	0.000	1.439	3.206
Ovis aries gmelini	*Ovis aries sp.*	2.426	0.000	1.747	3.106
Ovis aries gmelini	*Ovis aries urmiana*	2.370	0.000	1.486	3.254
Ovis aries gmelini	*Ovis vignei dolgopolovi*	2.343	0.000	1.780	2.907

Table Appendix 1.18. Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparisons for Levene's Transformed *Tfv*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Ovis aries urmiana*	-4.514	0.005	-8.266	-0.762
Gazella dorcas dorcas	*Ovis aries urmiana*	-5.202	0.003	-9.427	-0.977
Gazella gazella bennetti	*Ovis aries urmiana*	-5.288	0.009	-9.874	-0.701
Gazella subgutturosa subg	*Ovis aries urmiana*	-5.317	0.002	-9.541	-1.092
Ovis aries gmelini	*Ovis aries urmiana*	-5.109	0.002	-9.154	-1.064
Ovis aries isphahanica	*Ovis aries urmiana*	-5.328	0.043	-10.583	-0.073
Ovis aries sp.	*Ovis aries urmiana*	-4.962	0.007	-9.187	-0.738
Ovis aries urmiana	*Ovis vignei dolgopolovi*	4.790	0.003	0.939	8.641

Table Appendix 1.19. Results of the Tukey's HSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Capra hircus aegagrus	*Ovis aries urmiana*	-4.514	0.000	-6.787	-2.242
Capra hircus hircus	*Ovis aries urmiana*	-4.537	0.025	-8.507	-0.568
Gazella dorcas dorcas	*Ovis aries urmiana*	-5.202	0.000	-7.761	-2.643
Gazella gazella bennetti	*Ovis aries urmiana*	-5.288	0.000	-8.066	-2.510
Gazella subgutturosa subg	*Ovis aries urmiana*	-5.317	0.000	-7.876	-2.757
Ovis aries aries	*Ovis aries urmiana*	-3.930	0.008	-6.803	-1.057
Ovis aries gmelini	*Ovis aries urmiana*	-5.109	0.000	-7.559	-2.659
Ovis aries isphahanica	*Ovis aries urmiana*	-5.328	0.001	-8.511	-2.145
Ovis aries laristanica	*Ovis aries urmiana*	-4.674	0.003	-7.675	-1.673
Ovis aries sp.	*Ovis aries urmiana*	-4.962	0.000	-7.522	-2.403
Ovis aries urmiana	*Ovis vignei dolgopolovi*	4.790	0.000	2.458	7.123

Table Appendix 1.20. Results of the Fisher's LSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

MANOVA 3: Wild Animal Taxa by Season

		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
fall gazelle	Mean	2.295	.003	.176	12216.9183	.422	.886
	N	9	9	9	9	9	9
	Std. Deviation	1.005	.001	.041	3610.499	.091	.196
	Median	2.050	.003	.151	11513.8421	.407	.816
	Skewness	2.098	-.856	1.513	.150	-.014	.646
fall goat	Mean	1.205	.004	.297	2741.529	.374	.782
	N	9	9	9	9	9	9
	Std. Deviation	.515	.001	.118	3958.655	.097	.179
	Median	.991	.004	.267	1065.995	.365	.762
	Skewness	.633	.332	1.265	2.171	.170	.765
fall sheep	Mean	1.831	.003	1.862	7954.405	.427	.925
	N	44	44	44	44	44	44
	Std. Deviation	.935	.001	4.402	4933.246	.150	.382
	Median	1.859	.002	.208	7966.932	.392	.847
	Skewness	1.102	.645	3.368	-.027	1.398	1.581

Table Appendix 1.21. Table of general statistics for each microwear variable for each of the taxa (gazelle, goat, and sheep) grouped by season (fall, winter, spring, summer). Continued on next page.

		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
spring gazelle	Mean	2.345	.003	3.421	14644.0711	.480	.995
	N	6	6	6	6	6	6
	Std. Deviation	.699	.001	7.155	2760.927	.123	.354
	Median	2.302	.003	.209	15062.068	.461	.938
	Skewness	.115	.889	2.404	-.129	.960	1.200
spring goat	Mean	1.363	.005	.415	7455.247	.374	.682
	N	6	6	6	6	6	6
	Std. Deviation	.494	.002	.415	5593.288	.140	.075
	Median	1.335	.005	.152	7328.641	.331	.688
	Skewness	.054	-.013	1.119	.106	1.993	.045
spring sheep	Mean	1.071	.005	1.162	4901.077	.447	.729
	N	6	6	6	6	6	6
	Std. Deviation	.513	.001	2.277	5940.193	.197	.184
	Median	.970	.005	.267	2154.133	.371	.695
	Skewness	.355	-.830	2.447	1.191	2.027	.000

Table Appendix 1.21 (Cont.). Table of general statistics for each microwear variable for each of the taxa (gazelle, goat, and sheep) grouped by season (fall, winter, spring, summer). Continued on next page.

		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
summer gazelle	Mean	2.937	.002	.189	13549.3881	.346	.723
	N	3	3	3	3	3	3
	Std. Deviation	1.743	.001	.066	1621.746	.082	.103
	Median	3.568	.002	.151	12975.298	.375	.775
	Skewness	-1.415	1.732	1.731	1.393	-1.370	-1.685
summer goat	Mean	2.718	.003	.150	9560.470	.372	.805
	N	3	3	3	3	3	3
	Std. Deviation	1.415	.000	.000	8285.838	.084	.163
	Median	3.386	.003	.150	13616.784	.412	.858
	Skewness	-1.65	1.46	-.123	-1.675	-1.65	-1.316
summer sheep	Mean	1.561	.004	.196	6018.229	.411	.772
	N	8	8	8	8	8	8
	Std. Deviation	.884	.001	.065	3760.680	.105	.294
	Median	1.345	.005	.179	5179.089	.378	.658
	Skewness	1.422	-.394	1.829	.696	2.176	.963

Table Appendix 1.21 (Cont.). Table of general statistics for each microwear variable for each of the taxa (gazelle, goat, and sheep) grouped by season (fall, winter, spring, summer). Continued on next page.

		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
winter gazelle	Mean	1.928	.004	.276	10591.1311	.402	.819
	N	11	11	11	11	11	11
	Std. Deviation	1.172	.001	.165	4351.182	.076	.328
	Median	1.684	.004	.209	10518.306	.393	.735
	Skewness	1.223	-.166	1.211	.044	.406	2.800
winter goat	Mean	2.034	.004	.196	7751.101	.406	.871
	N	18	18	18	18	18	18
	Std. Deviation	1.207	.001	.055	3542.349	.128	.293
	Median	1.661	.004	.152	8086.475	.374	.802
	Skewness	1.044	-.327	.503	-.778	1.009	1.788
winter sheep	Mean	1.450	.004	.217	8587.756	.370	.673
	N	9	9	9	9	9	9
	Std. Deviation	.855	.001	.071	4996.043	.093	.138
	Median	1.406	.004	.209	8955.218	.345	.655
	Skewness	1.014	.188	.517	-.552	.518	-.220

Table Appendix 1.21 (Cont.). Table of general statistics for each microwear variable for each of the taxa (gazelle, goat, and sheep) grouped by season (fall, winter, spring, summer)

MANOVA Results for Wild Animal Taxa by Season

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.422	1.630	66, 615	0.002
Pillai Trace	0.762	1.574	66, 714	0.003
Hotelling-Lawley Trace	0.985	1.677	66, 674	0.001

Table Appendix 1.22. Results of the MANOVA run using the taxa (gazelle, goat, sheep) and season (spring, summer, fall, winter) as the independent variables and the microwear texture variables as the dependent factors.

ANOVA for Complexity

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TAXON$	14,413.212	2	7,206.606	5.454	0.005*
SEASON$	3,970.213	3	1,323.404	1.001	0.395
TAXON$*SEASON$	18,759.654	6	3,126.609	2.366	0.034*
Error	157,250.571	119	1,321.433		

Table Appendix 1.23. Results of the ANOVA using the taxa (gazelle, goat, sheep) and season (spring, summer, fall, winter) as the independent variables and complexity as the dependent factors. Stars indicate significance.

Pairwise Comparison for Complexity Based on Taxon

Tukey's Honestly-Significant-Difference Test					
TAXON$(i)	**TAXON$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	20.032	0.150	-1.708	41.772
gazelle	sheep	31.998	0.004*	12.583	51.414
goat	sheep	11.966	0.421	-5.863	29.796

Fisher's Least-Significant-Difference Test					
TAXON$(i)	**TAXON$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	goat	20.032	0.063	1.895	38.169
gazelle	sheep	31.998	0.001*	15.801	48.196
goat	sheep	11.966	0.210	-2.908	26.841

Table Appendix 1.24. Results of the pairwise comparison for complexity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results ($p < 0.05$) are marked by a star.

Pairwise Comparison for Complexity Based on Interaction between Taxon and Season

Fisher's Least-Significant-Difference Test					
TAXON$(i)*SEASO-N$(i)	**TAXON$(j)*SEASO-N$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle*fall	goat*fall	46.167	0.008	12.235	80.098
gazelle*fall	sheep*spring	53.000	0.007	15.063	90.937
gazelle*fall	sheep*winter	38.778	0.025	4.846	72.709
gazelle*spring	goat*fall	51.250	0.009	13.313	89.187
gazelle*spring	goat*spring	42.917	0.043	1.359	84.474
gazelle*spring	sheep*spring	58.083	0.007	16.526	99.641
gazelle*spring	sheep*winter	43.861	0.024	5.925	81.798
gazelle*summer	goat*fall	51.167	0.037	3.180	99.153
gazelle*summer	sheep*spring	58.000	0.026	7.103	108.897
goat*fall	goat*summer	-52.000	0.034	-99.986	-4.014
goat*fall	goat*winter	-30.306	0.043	-59.691	-0.920
goat*fall	sheep*fall	-27.072	0.044	-53.405	-0.739
goat*summer	sheep*spring	58.833	0.024	7.936	109.731
goat*winter	sheep*spring	37.139	0.032	3.207	71.070
sheep*fall	sheep*spring	33.905	0.034	2.580	65.230

Table Appendix 1.25. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Tukey's HSD did not report any significant pairwise comparisons.

ANOVA for Anisotropy

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TAXON$	4,725.967	2	2,362.984	1.843	0.163
SEASON$	8,477.692	3	2,825.897	2.204	0.091
TAXON$*SEASON$	14,409.637	6	2,401.606	1.873	0.091
Error	152,584.168	119	1,282.220		

Table Appendix 1.26. Results of the ANOVA using the taxa (gazelle, goat, sheep) and season (spring, summer, fall, winter) as the independent variables and anisotropy as the dependent factors.

ANOVA for Texture Fill Volume

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TAXON$	28,820.188	2	14,410.094	12.243	0.000*
SEASON$	3,300.874	3	1,100.291	0.935	0.426
TAXON$*SEASON$	18,473.229	6	3,078.872	2.616	0.020*
Error	140,067.572	119	1,177.038		

Table Appendix 1.27. Results of the ANOVA using the taxa (gazelle, goat, sheep) and season (spring, summer, fall, winter) as the independent variables and texture fill volume as the dependent factors. Stars indicate significance.

Pairwise Comparison for TFV and Taxon

Tukey's Honestly-Significant-Difference Test					
TAXON$(i)	**TAXON$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	Goat	41.664	0.000*	21.146	62.182
gazelle	sheep	41.915	0.000*	23.591	60.239
goat	sheep	0.251	1.000	-16.576	17.078

Fisher's Least-Significant-Difference Test					
TAXON$(i)	**TAXON$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle	Goat	41.664	0.000*	24.546	58.781
gazelle	sheep	41.915	0.000*	26.628	57.202
goat	sheep	0.251	0.978	-13.787	14.289

Table Appendix 1.28. Results of the pairwise comparison for complexity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results ($p < 0.05$) are marked by a star.

Pairwise Comparison for TFV and Season and Taxon Interaction

Tukey's Honestly-Significant-Difference Test					
TAXON$(i)*SEASO-N$(i)	**TAXON$(j)*SEASO-N$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle*fall	goat*fall	66.889	0.004	12.966	120.812
gazelle*spring	goat*fall	85.167	0.000	24.879	145.454
gazelle*spring	sheep*spring	69.667	0.029	3.625	135.709
gazelle*spring	sheep*summer	62.167	0.047	0.390	123.943
gazelle*summer	goat*fall	83.333	0.020	7.075	159.592

Table Appendix 1.29. Results of the Tukey's HSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
TAXON$(i)*SEASO-N$(i)	**TAXON$(j)*SEASO-N$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
gazelle*fall	goat*fall	66.889	0.000	34.865	98.913
gazelle*fall	goat*winter	33.222	0.019	5.489	60.956
gazelle*fall	sheep*fall	30.116	0.018	5.264	54.969
gazelle*fall	sheep*spring	51.389	0.005	15.585	87.193
gazelle*fall	sheep*summer	43.889	0.010	10.879	76.899
gazelle*spring	goat*fall	85.167	0.000	49.363	120.971
gazelle*spring	goat*spring	50.000	0.013	10.779	89.221
gazelle*spring	goat*winter	51.500	0.002	19.476	83.524
gazelle*spring	sheep*fall	48.394	0.002	18.830	77.958
gazelle*spring	sheep*spring	69.667	0.001	30.445	108.888
gazelle*spring	sheep*summer	62.167	0.001	25.479	98.855
gazelle*spring	sheep*winter	42.611	0.020	6.807	78.415
gazelle*summer	goat*fall	83.333	0.000	38.044	128.622
gazelle*summer	goat*spring	48.167	0.049	0.131	96.203
gazelle*summer	goat*winter	49.667	0.022	7.303	92.030
gazelle*summer	sheep*fall	46.561	0.025	6.024	87.097
gazelle*summer	sheep*spring	67.833	0.006	19.797	115.869
gazelle*summer	sheep*summer	60.333	0.011	14.342	106.324

Table Appendix 1.30. Results of the Fisher's LSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

TAXON$(i)*SEASO-N$(i)	TAXON$(j)*SEASO-N$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
gazelle*winter	goat*fall	50.100	0.002	18.887	81.313
goat*fall	goat*summer	-50.000	0.031	-95.289	-4.711
goat*fall	goat*winter	-33.667	0.018	-61.400	-5.933
goat*fall	sheep*fall	-36.773	0.004	-61.625	-11.920
goat*fall	sheep*winter	-42.556	0.010	-74.580	-10.532

Table Appendix 1.30 (Cont.). Results of the Fisher's LSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Levene's Transformed MANOVA 3

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.592	0.960	66, 615	0.569
Pillai Trace	0.476	0.933	66, 714	0.629
Hotelling-Lawley Trace	0.582	0.990	66, 674	0.502

Table Appendix 1.31. Results of the MANOVA run using the taxa (gazelle, goat, sheep) and season (spring, summer, fall, winter) as the independent variables and the Levene's transformed microwear texture variables as the dependent factors.

Appendix 2: Neolithic Statistical Output

Mesowear

Cluster Analysis 1: by Neolithic Phase

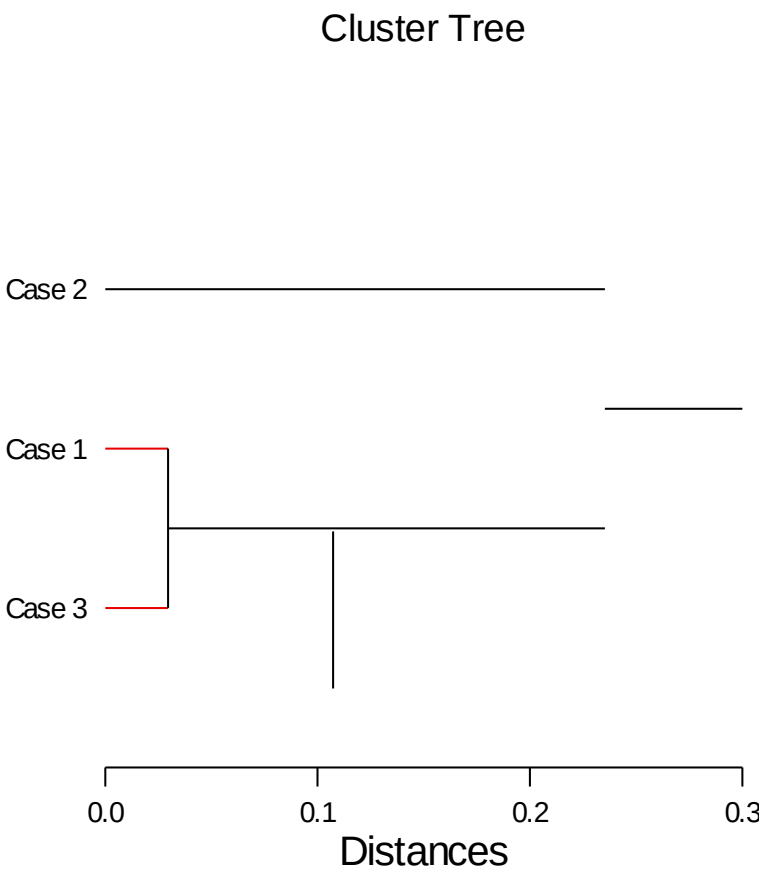

Figure Appendix 2.1. Hierarchical cluster analysis by percentage high and percentage sharp. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

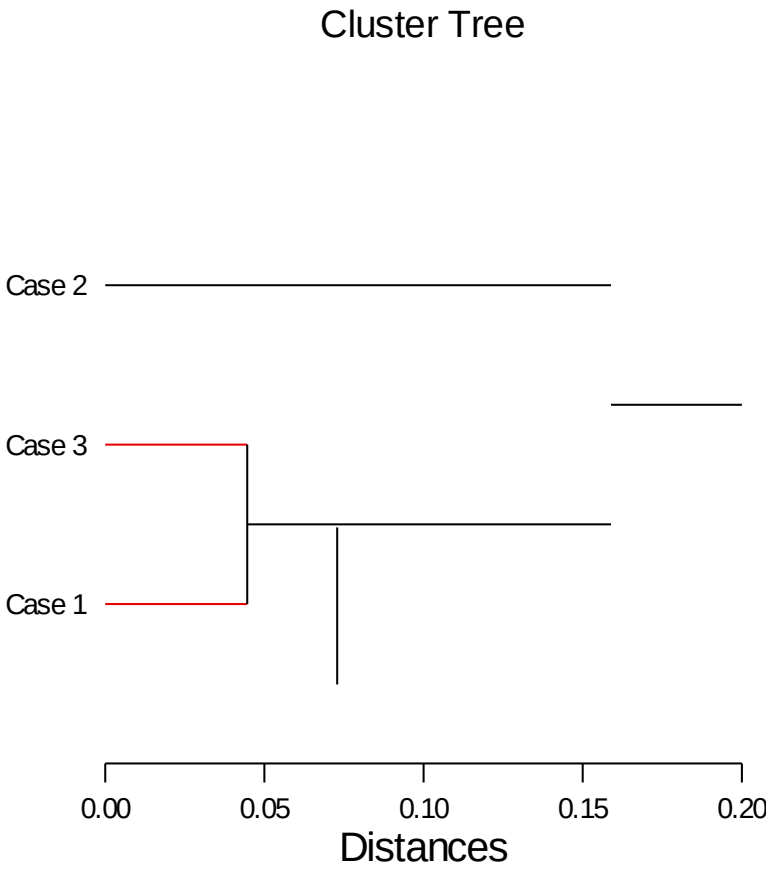

Figure Appendix 2.2. Hierarchical cluster analysis by percentage high and percentage round. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

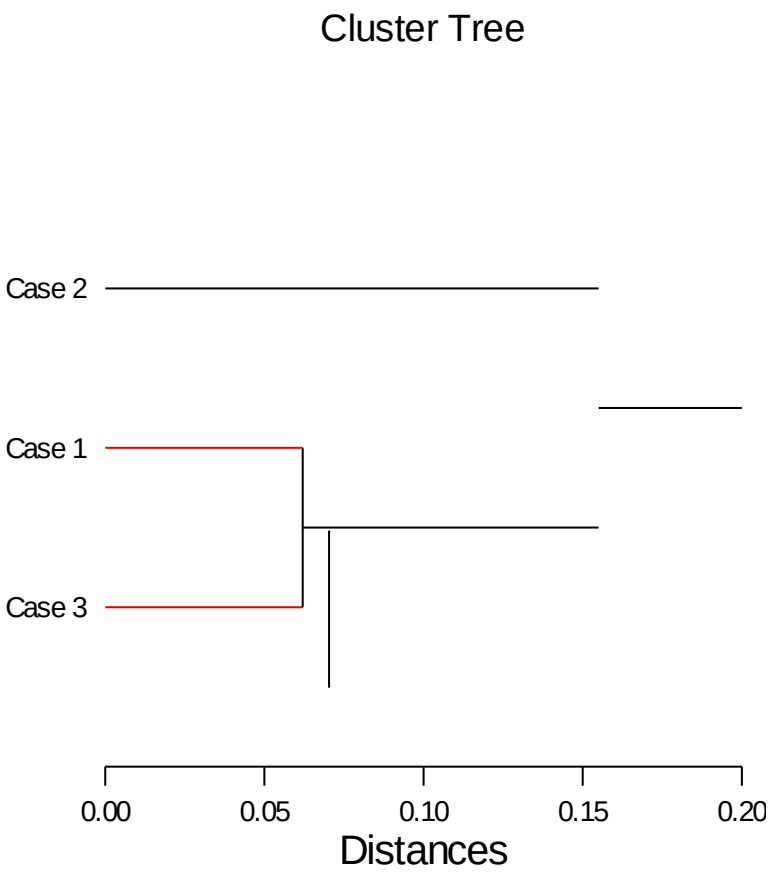

Figure Appendix 2.3. Hierarchical cluster analysis by percentage high and percentage blunt. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

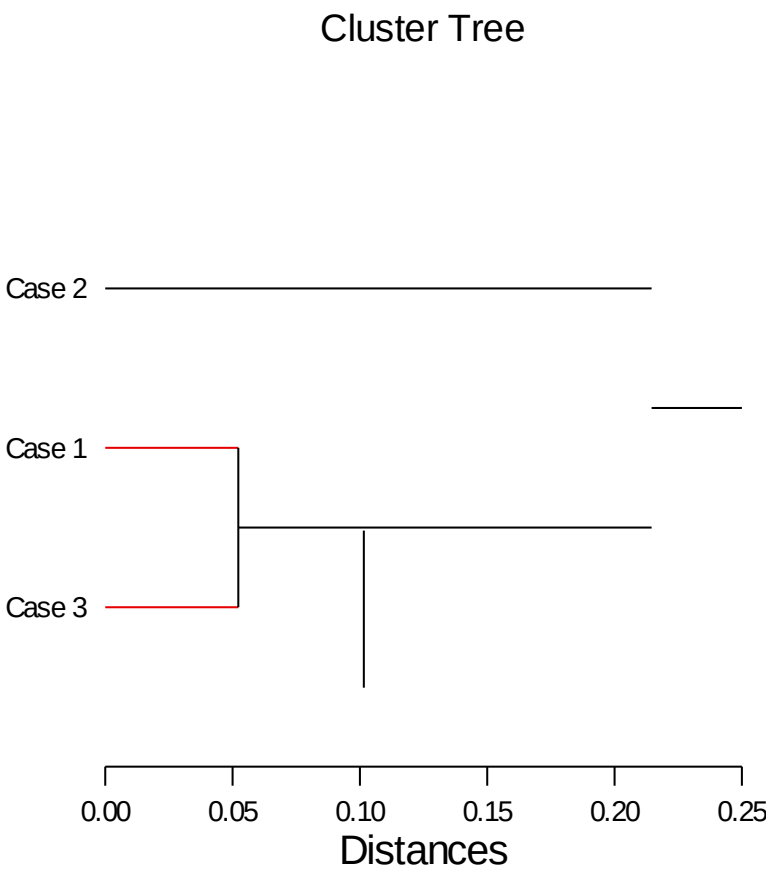

Figure Appendix 2.4. Hierarchical cluster analysis by percentage high and percent sharp and percent blunt. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

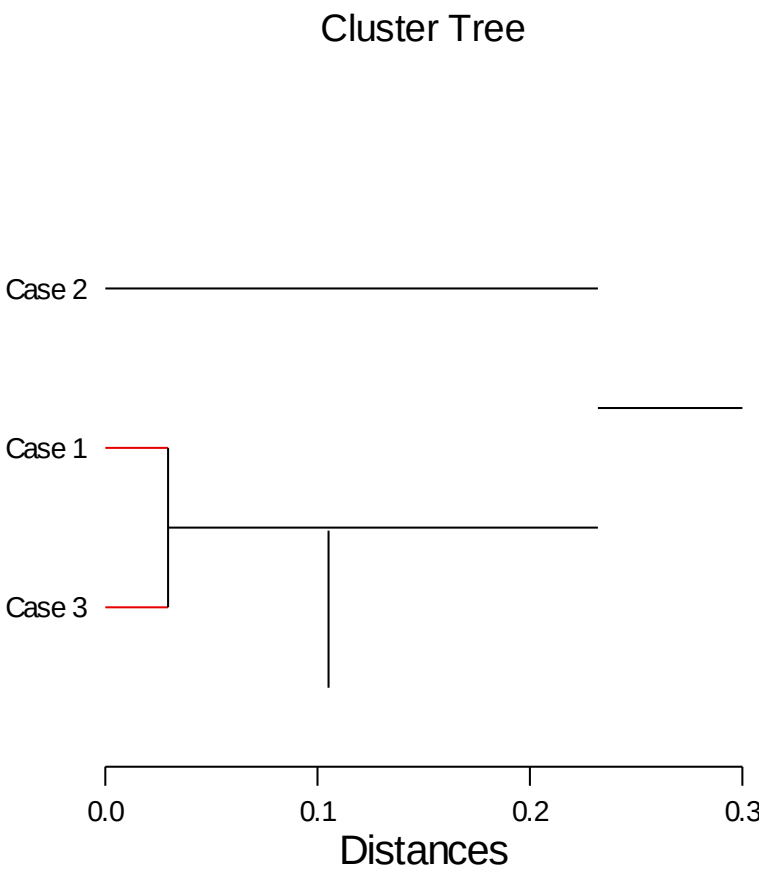

Figure Appendix 2.5. Hierarchical cluster analysis by percentage low and percentage sharp. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

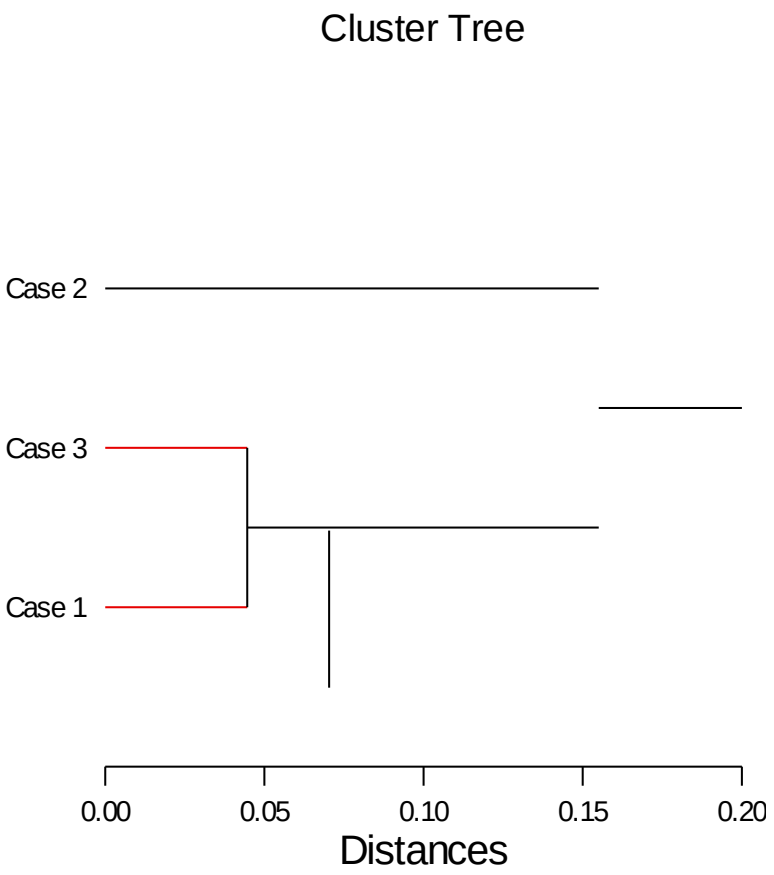

Figure Appendix 2.6. Hierarchical cluster analysis by percentage low and percentage round. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

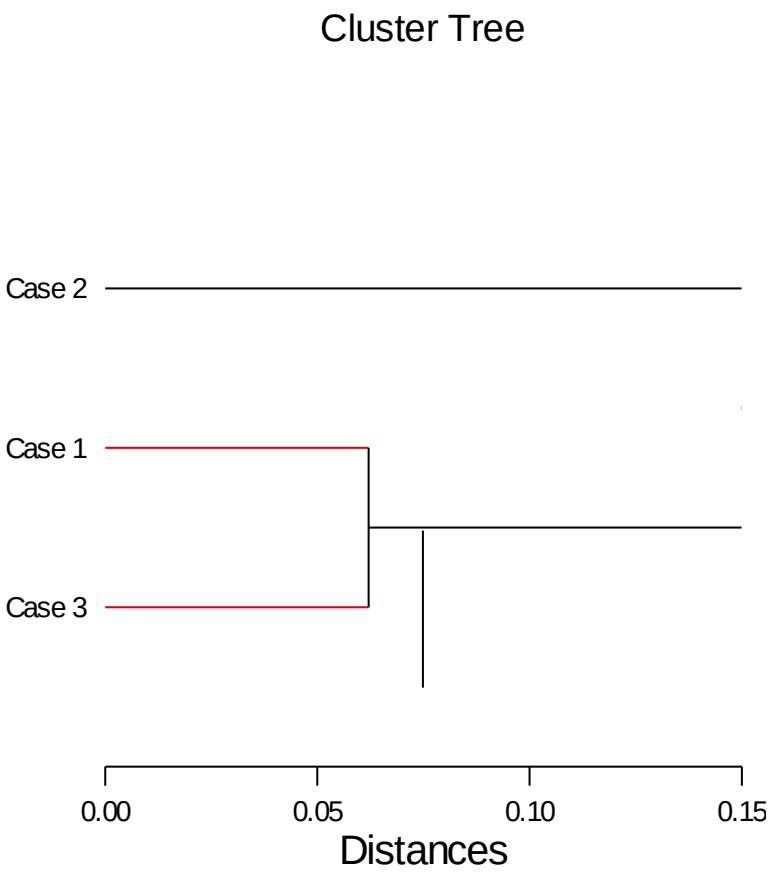

Figure Appendix 2.7. Hierarchical cluster analysis by percentage low and percentage blunt. Group 1 is Phase A, group 2 is Phase B, and group 3 Phase C

Cluster Analysis 2: Neolithic Phase and Wild Taxa

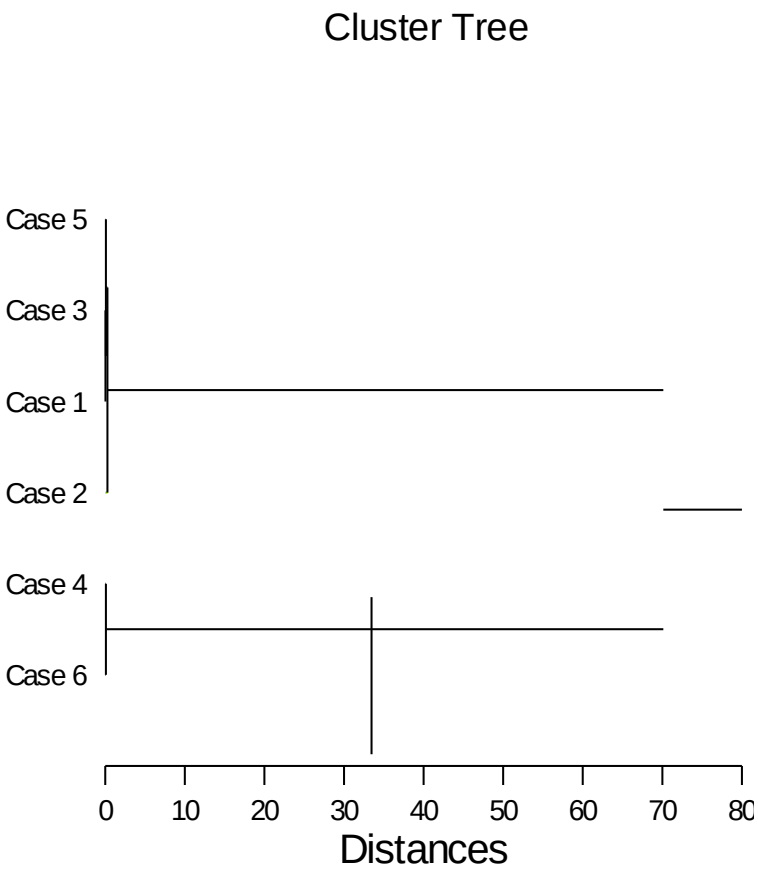

Figure Appendix 2.8. Hierarchical cluster analysis by percentage high and percentage sharp. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

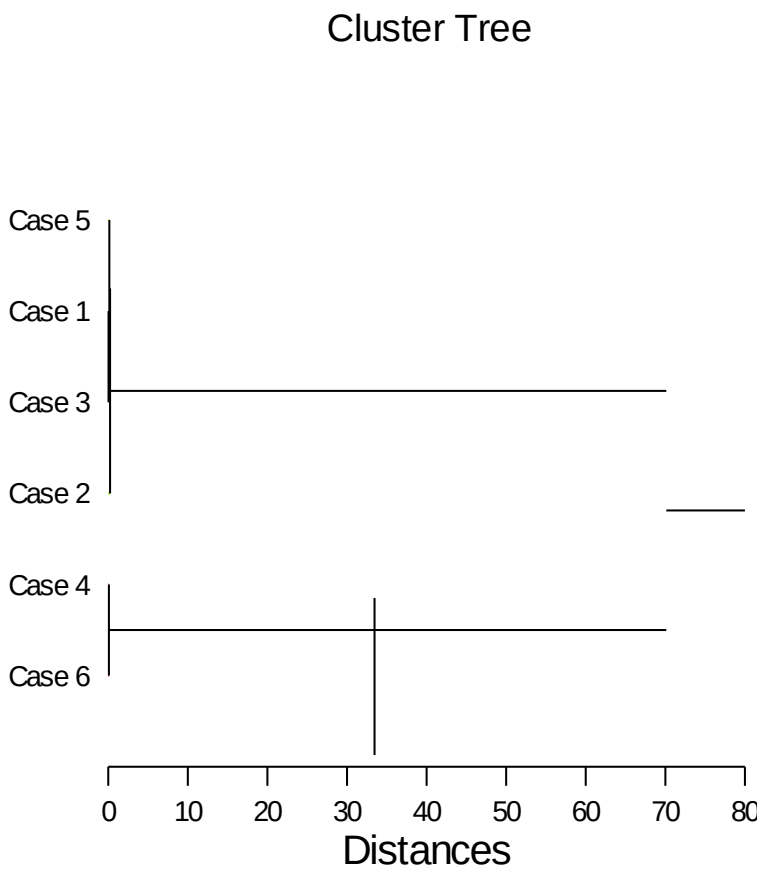

Figure Appendix 2.9. Hierarchical cluster analysis by percentage high and percentage round. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

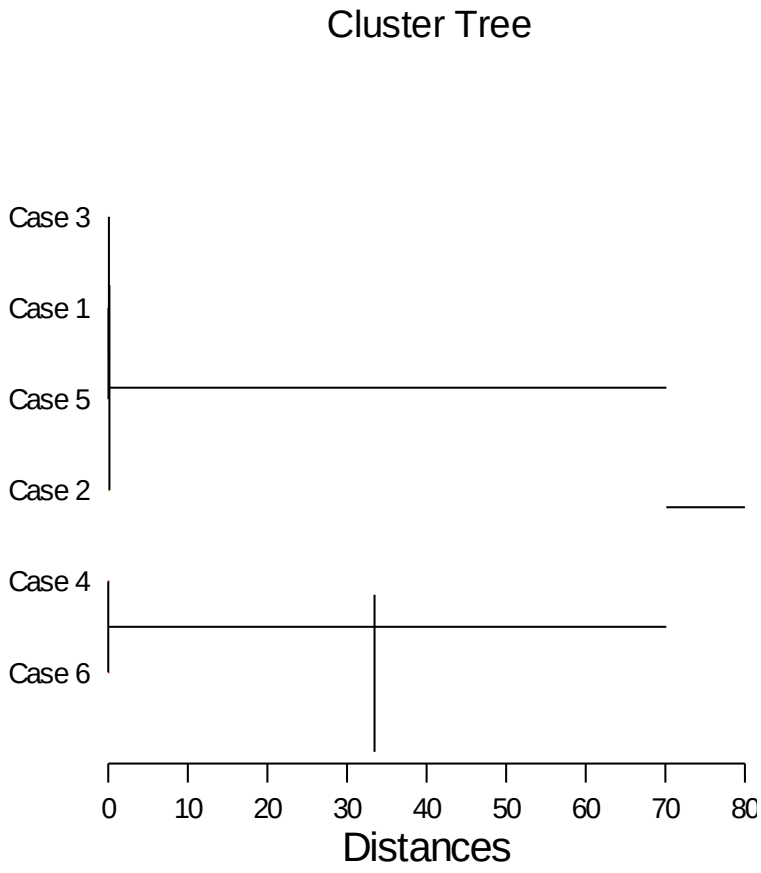

Figure Appendix 2.10. Hierarchical cluster analysis by percentage high and percentage blunt. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

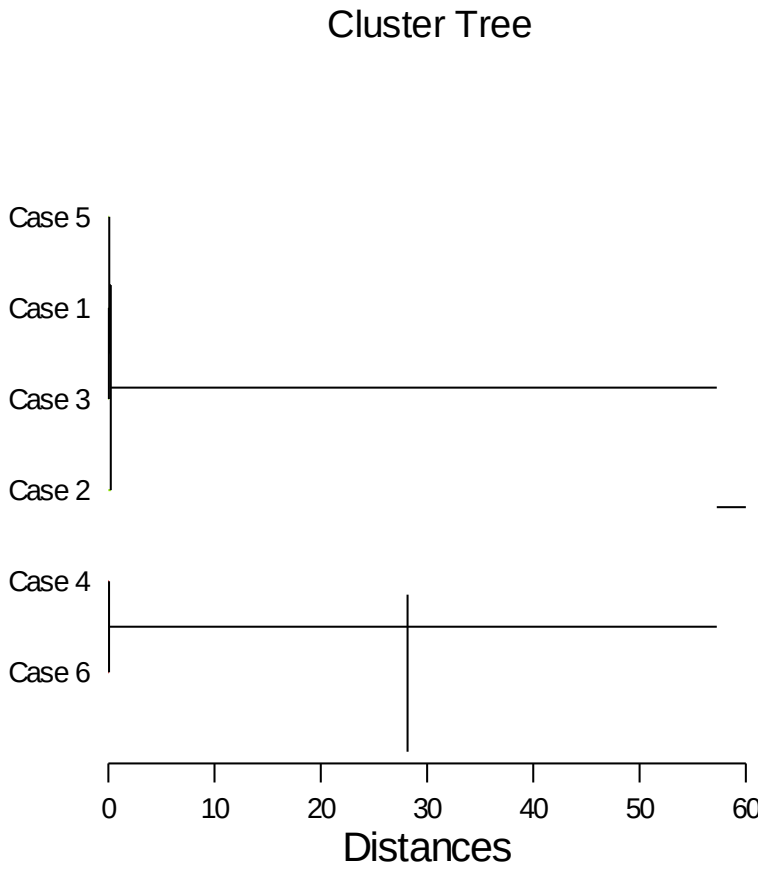

Figure Appendix 2.11. Hierarchical cluster analysis by percentage high and percent sharp and percent blunt. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

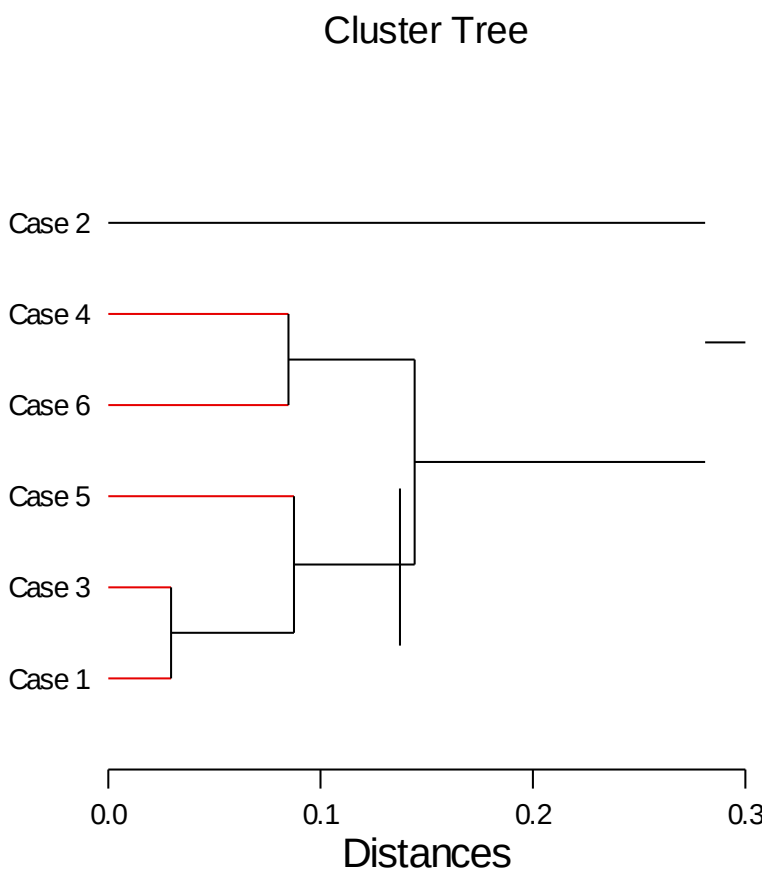

Figure Appendix 2.12. Hierarchical cluster analysis by percentage low and percentage sharp. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

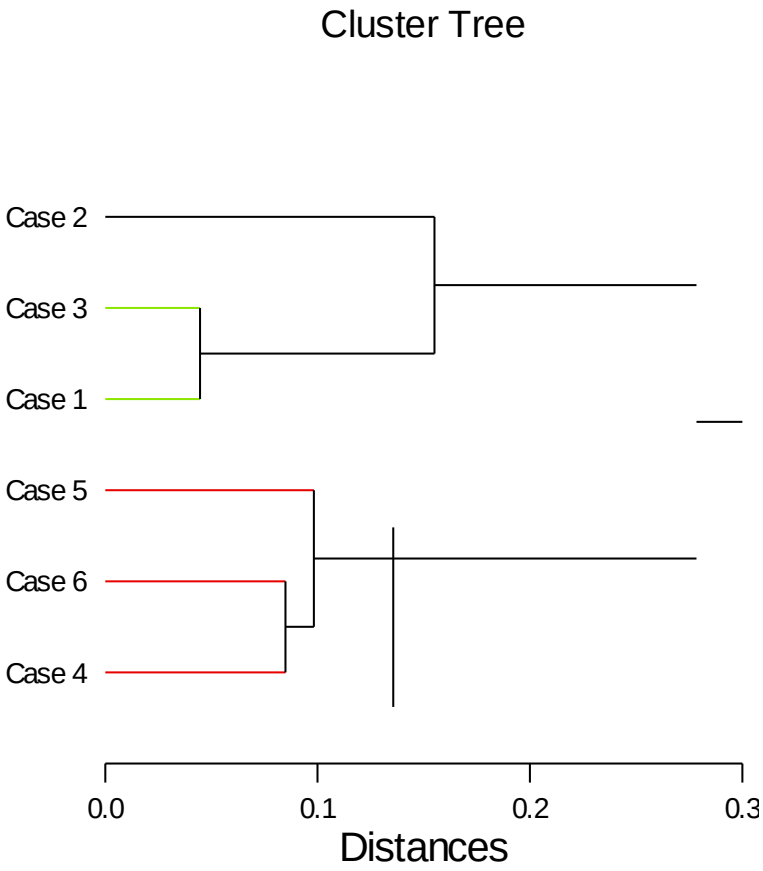

Figure Appendix 2.13. Hierarchical cluster analysis by percentage low and percentage round. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

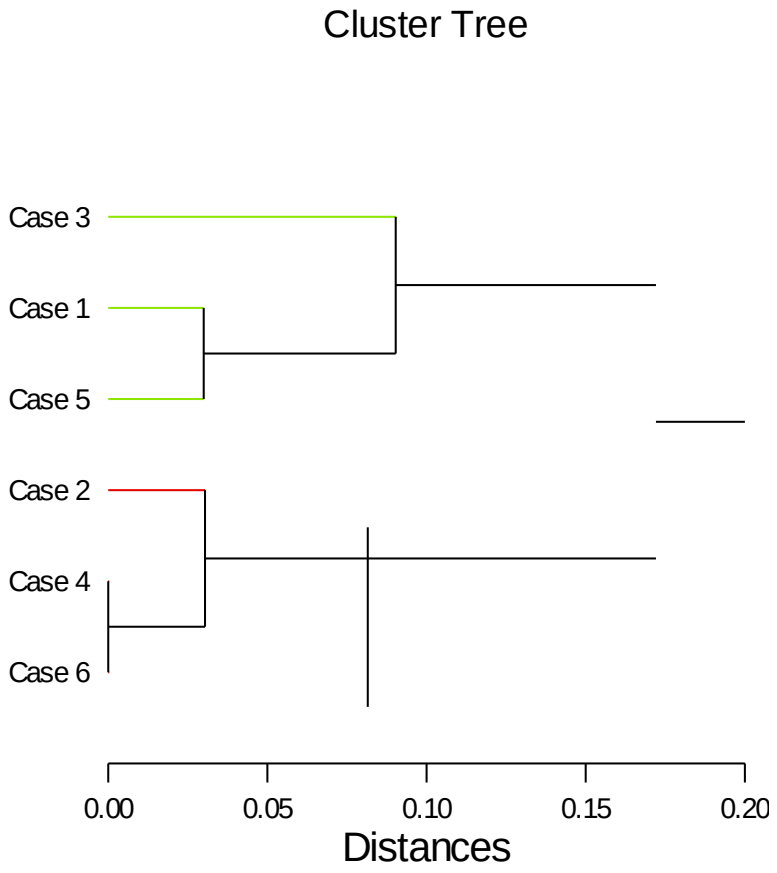

Figure Appendix 2.14. Hierarchical cluster analysis by percentage low and percentage blunt. Group 1 is Phase A, group 2 is Phase B, group 3 Phase C, group 4 goats, group 5 gazelle, and group 6 sheep

Cluster Analysis 2: Neolithic Phase and wild species

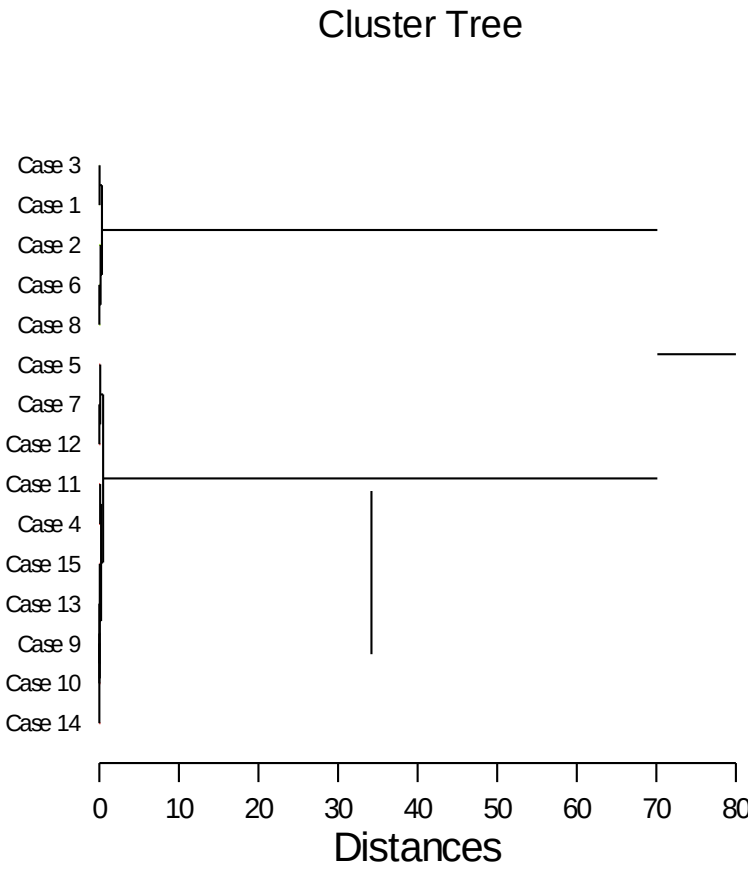

Figure Appendix 2.15. Hierarchical cluster analysis based on percentage high and percentage sharp. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus,* 6= *Gazella dorcas dorcas,* 7= *Gazella gazella bennetti,* 8= *Gazella subgutturosa subgutturosa,* 9= *Ovis aries aries,* 10= *Ovis aries gmelini,* 11= *Ovis aries isphagnaica,* 12= *Ovis aries laristanica,* 13= *Ovis aries* sp., 14= *Ovis aries urmiana,* 15= *Ovis vignei dolgopolovi*

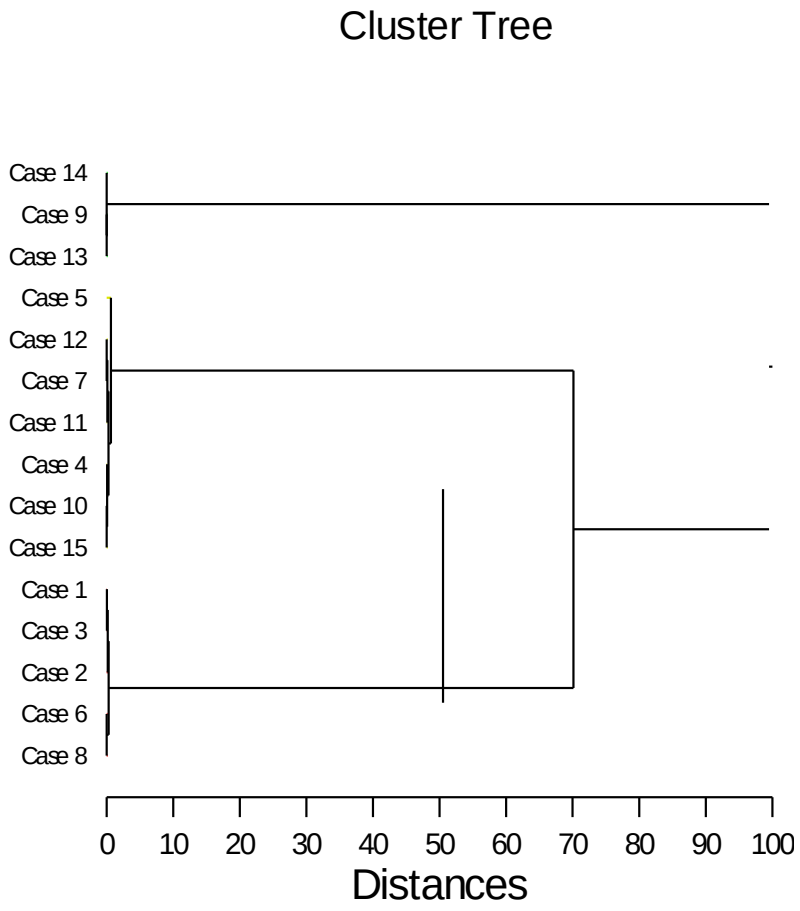

Figure Appendix 2.16. Hierarchical cluster analysis based on percentage high and percentage round. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

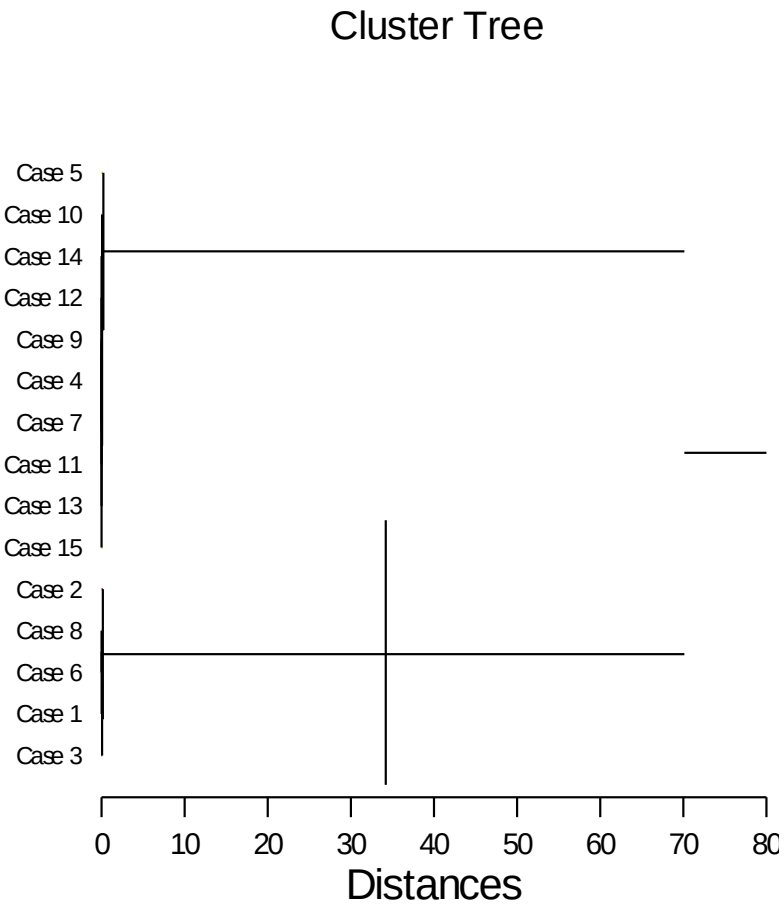

Figure Appendix 2.17. Hierarchical cluster analysis based on percentage high and percentage blunt. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

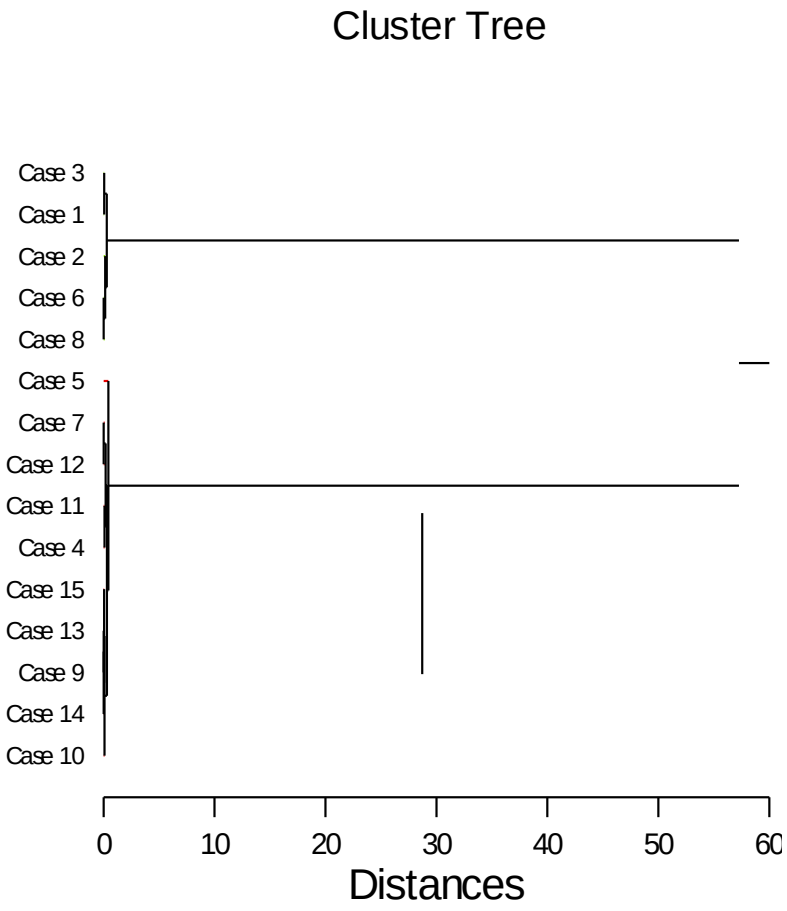

Figure Appendix 2.18. Hierarchical cluster analysis based on percentage high, percentage sharp, and percentage blunt. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

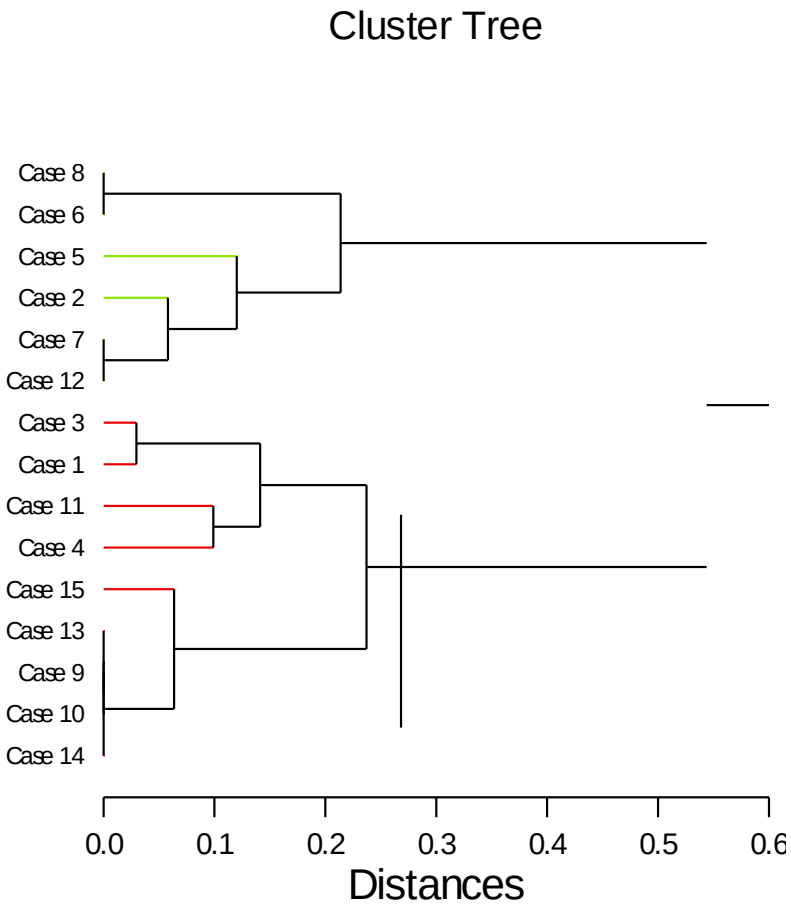

Figure Appendix 2.19. Hierarchical cluster analysis based on percentage low and percentage sharp. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

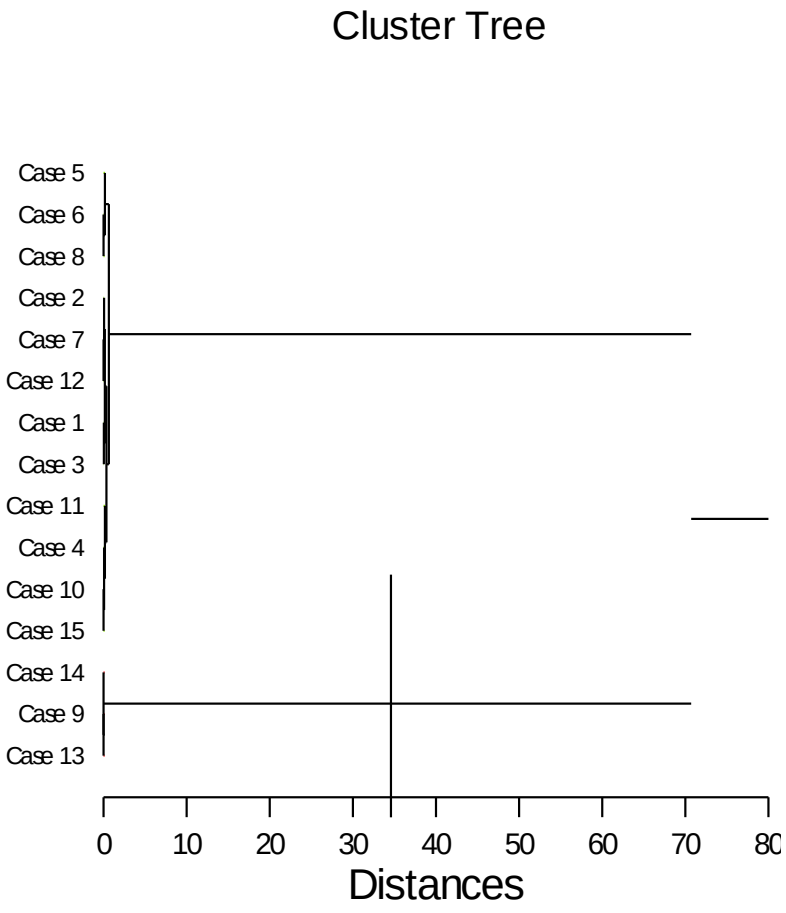

Figure Appendix 2.20. Hierarchical cluster analysis based on percentage low and percentage sharp. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

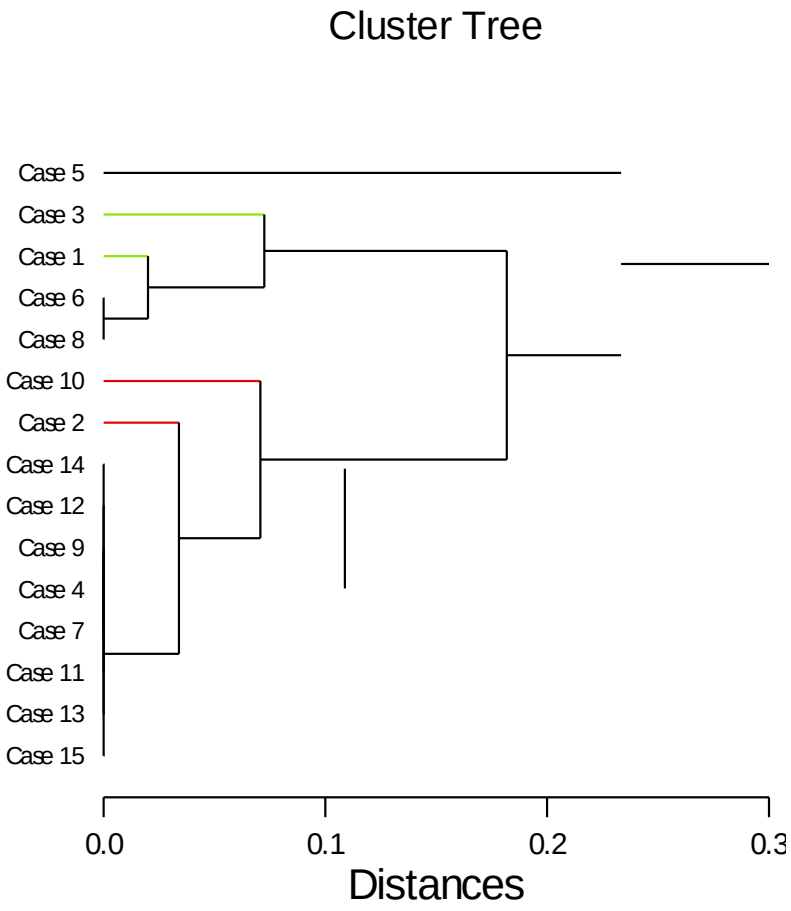

Figure Appendix 2.21. Hierarchical cluster analysis based on percentage low and percentage sharp. 1= Phase A, 2= Phase B, 3= Phase C, 4= *Capra hircus aegagrus*, 5= *Capra hircus hircus*, 6= *Gazella dorcas dorcas*, 7= *Gazella gazella bennetti*, 8= *Gazella subgutturosa subgutturosa*, 9= *Ovis aries aries*, 10= *Ovis aries gmelini*, 11= *Ovis aries isphagnaica*, 12= *Ovis aries laristanica*, 13= *Ovis aries* sp., 14= *Ovis aries urmiana*, 15= *Ovis vignei dolgopolovi*

Microwear

MANOVA 1

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.875	1.326	12, 230	0.204
Pillai Trace	0.129	1.335	12, 232	0.199
Hotelling-Lawley Trace	0.139	1.317	12, 228	0.209

Table Appendix 2.1. MANOVA results for the Neolithic Gritille periods

Pairwise Comparison for 3x3 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	22.802	0.011*	4.292	41.313
A	C	24.526	0.078	-2.140	51.192
B	C	1.724	0.983	-21.372	24.819
Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	22.802	0.004*	7.359	38.245
A	C	24.526	0.031*	2.279	46.773
B	C	1.724	0.860	-17.545	20.992

Table Appendix 2.2. Results of the pairwise comparison for 3X3 heterogeneity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results (p < 0.05) are marked by a star.

Pairwise Comparison for 9X9 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$ (j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	15.319	0.131	-3.389	34.027
A	C	27.272	0.047*	0.321	54.223
B	C	11.953	0.447	-11.390	35.295

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE $(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	15.319	0.054	-0.289	30.927
A	C	27.272	0.018*	4.787	49.756
B	C	11.953	0.227	-7.521	31.427

Table Appendix 2.3. Results of the pairwise comparison for 9X9 heterogeneity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results ($p < 0.05$) are marked by a star.

Levene's Transformed MANOVA for Neolithic Phases

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.774	2.625	12, 230	0.003
Pillai Trace	0.239	2.626	12, 232	0.003
Hotelling-Lawley Trace	0.276	2.624	12, 228	0.003

Table Appendix 2.4. MANOVA results for the Neolithic Gritille periods based on Levene's transformed dental microwear variables.

Pairwise Comparisons for Levene's Transformed Complexity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	0.158	0.022*	0.019	0.297
A	C	0.146	0.198	-0.054	0.346
B	C	-0.012	0.985	-0.186	0.161
Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	0.158	0.008*	0.042	0.274
A	C	0.146	0.086	-0.021	0.313
B	C	-0.012	0.869	-0.157	0.133

Table Appendix 2.5. Results of the pairwise comparison for complexity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results ($p < 0.05$) are marked by a star.

MANOVA 2: Neolithic Gritille Phases and Wild Taxa

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.775	2.165	30, 986	0.000
Pillai Trace	0.244	2.140	30, 1,250	0.000
Hotelling-Lawley Trace	0.267	2.175	30, 1,222	0.000

Table Appendix 2.6. MANOVA results of comparison of Neolithic periods to the wild animal taxa

Pairwise Comparison for *Tfv*

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	gazelle	-59.256	0.002	-102.951	-15.561
C	goat	69.091	0.024	5.390	132.793
gazelle	goat	81.806	0.000	31.341	132.270
gazelle	sheep	64.914	0.000	20.251	109.577

Table Appendix 2.7. Results of the Tukey's HSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	gazelle	-42.115	0.029	-79.866	-4.365
A	goat	39.690	0.031	3.717	75.664
B	C	-46.542	0.024	-86.961	-6.122
B	gazelle	-59.256	0.000	-89.454	-29.058
C	goat	69.091	0.002	25.067	113.116
C	sheep	52.200	0.013	11.278	93.122
gazelle	goat	81.806	0.000	46.929	116.682
gazelle	sheep	64.914	0.000	34.047	95.781

Table Appendix 2.8. Results of the Tukey's HSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for 3X3 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	goat	63.921	0.009	10.010	117.832
A	sheep	48.887	0.044	0.778	96.995

Table Appendix 2.9. Results of the Tukey's HSD pairwise comparison for 3X3 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	46.920	0.005	14.338	79.502
A	C	50.949	0.034	4.011	97.886
A	goat	63.921	0.001	26.663	101.179
A	sheep	48.887	0.004	15.639	82.134

Table Appendix 2.10. Results of the Fisher's LSD pairwise comparison for 3X3 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Levene's Transformed MANOVA 2

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.786	2.045	30, 990	0.001
Pillai Trace	0.230	2.020	30, 1,255	0.001
Hotelling-Lawley Trace	0.251	2.055	30, 1,227	0.001

Table Appendix 2.11. MANOVA results of comparison of Neolithic periods to the wild animal taxa using Levene's transformed microwear texture data.

Pairwise Comparison for Levene's Transformed Complexity

Tukey's Honestly-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	sheep	-0.160	0.018	-0.304	-0.017

Table Appendix 2.12. Results of the Tukey's HSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	0.158	0.024	0.021	0.295
B	goat	-0.143	0.022	-0.265	-0.021
B	sheep	-0.160	0.002	-0.260	-0.061

Table Appendix 2.13. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for Levene's Transformed 9x9 Heterogeneity

Fisher's Least-Significant-Difference Test					
C1$(i)	**C1$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	sheep	-0.083	0.007	-0.143	-0.022
gazelle	sheep	-0.091	0.030	-0.173	-0.009
goat	sheep	-0.088	0.023	-0.164	-0.012

Table Appendix 2.14. Results of the Fisher's LSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significant pairings were found with Tukey's HSD.

MANOVA 3: Neolithic Phases and Individual Wild Species

Scientific Name		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9H Asfc
A	Mean	1.957	.004	.248	9409.344	.492	.902
	N	26	26	26	26	26	26
	Std. Deviation	1.144	.001	.136	4992.238	.129	.259
	Median	1.686	.004	.208	10342.939	.494	.858
	Skewness	1.073	.374	1.854	-.356	.819	.792
B	Mean	1.831	.004	.539	8227.177	.414	.790
	N	82	82	82	82	82	82
	Std. Deviation	.772	.001	2.577	4694.084	.125	.211
	Median	1.721	.004	.153	8512.543	.392	.727
	Skewness	1.376	.204	8.898	.102	1.209	.912
C	Mean	1.688	.004	1.539	10434.783	.430	.718
	N	15	15	15	15	15	15
	Std. Deviation	.768	.001	3.412	5194.801	.184	.238
	Median	1.535	.004	.208	12023.322	.416	.684
	Skewness	1.842	.285	2.457	-.611	.887	.467

Table Appendix 2.15. Table of general statistics for each microwear variable for each of the three Neolithic phases examined from Gritille (A, B, C) and individual wild species. Continued on next page.

Scientific Name		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9H Asfc
Capra hircus aegagrus	Mean	1.825	.004	.214	6571.405	.384	.819
	N	34	34	34	34	34	34
	Std. Deviation	1.074	.001	.089	4785.593	.111	.242
	Median	1.590	.004	.152	6517.121	.364	.774
	Skewness	1.230	-.077	1.991	.062	1.079	1.992
Capra hircus hircus	Mean	.870	.007	.942	7089.365	.501	.688
	N	2	2	2	2	2	2
	Std. Deviation	.321	.001	.174	8042.102	.210	.024
	Median	.870	.007	.942	7089.365	.501	.688
	Skewness	.	.	.	.	.	.
Gazella dorcas dorcas	Mean	2.736	.003	1.792	14457.982	.421	.901
	N	11	11	11	11	11	11
	Std. Deviation	1.228	.001	5.364	2757.841	.126	.293
	Median	2.657	.003	.152	16046.348	.398	.797
	Skewness	.293	-.516	3.316	-.728	.833	1.706

Table Appendix 2.15 (Cont.). Table of general statistics for each microwear variable for each of the three Neolithic phases examined from Gritille (A, B, C) and individual wild species. Continued on next page.

Scientific Name		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9H Asfc
Gazella gazella bennetti	Mean	1.702	.005	.251	9423.885	.432	.922
	N	7	7	7	7	7	7
	Std. Deviation	.711	.000	.170	3959.117	.106	.408
	Median	2.050	.005	.152	10205.321	.463	.817
	Skewness	-1.192	.053	2.129	.230	-.333	1.765
Gazella subgutturosa subgutturosa	Mean	2.068	.004	.388	11814.754	.410	.798
	N	11	11	11	11	11	11
	Std. Deviation	.990	.001	.496	3535.505	.051	.168
	Median	1.776	.004	.209	11696.905	.393	.735
	Skewness	1.503	.798	3.002	.027	1.243	1.625
Ovis aries aries	Mean	1.071	.005	1.162	4901.077	.448	.729
	N	6	6	6	6	6	6
	Std. Deviation	.513	.001	2.277	5940.193	.197	.184
	Median	.971	.005	.267	2154.133	.372	.695
	Skewness	.355	-.830	2.447	1.191	2.027	.000

Table Appendix 2.15 (Cont.). Table of general statistics for each microwear variable for each of the three Neolithic phases examined from Gritille (A, B, C) and individual wild species. Continued on next page.

Scientific Name		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9H Asfc
Ovis aries gmelini	Mean	1.009	.003	25.999	9545.523	.506	1.098
	N	15	15	15	15	15	15
	Std. Deviation	.531	.001	79.757	4853.036	.145	.456
	Median	.842	.003	3.816	10683.154	.502	.970
	Skewness	1.482	.832	3.831	-.224	.933	1.779
Ovis aries isphahanica	Mean	1.575	.005	.242	10893.446	.347	.663
	N	4	4	4	4	4	4
	Std. Deviation	.856	.001	.082	3290.382	.048	.149
	Median	1.414	.005	.238	11489.638	.331	.656
	Skewness	1.076	-.833	.266	-1.013	1.450	.075
Ovis aries laristanica	Mean	1.351	.004	.198	6743.204	.390	.682
	N	5	5	5	5	5	5
	Std. Deviation	.941	.001	.063	5677.302	.121	.146
	Median	.833	.003	.153	8192.398	.386	.655
	Skewness	1.585	.971	.608	.221	-.109	-.541

Table Appendix 2.15 (Cont.). Table of general statistics for each microwear variable for each of the three Neolithic phases examined from Gritille (A, B, C) and individual wild species. Continued on next page.

Scientific Name		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9H Asfc
Ovis aries sp.	Mean	1.525	.005	.205	6601.021	.387	.703
	N	11	11	11	11	11	11
	Std. Deviation	.788	.002	.058	3995.961	.098	.274
	Median	1.480	.006	.208	5446.990	.361	.558
	Skewness	1.377	-.277	1.291	.263	2.293	1.410
Ovis aries urmiana	Mean	2.243	.002	.185	7917.636	.399	.895
	N	5	5	5	5	5	5
	Std. Deviation	.694	.001	.051	4748.642	.136	.266
	Median	2.540	.003	.151	9054.443	.354	.906
	Skewness	-.551	-.047	1.258	-1.557	.379	-1.265
Ovis vignei dolgopolovi	Mean	2.244	.003	.173	7467.986	.395	.841
	N	24	24	24	24	24	24
	Std. Deviation	.884	.001	.040	5047.834	.144	.309
	Median	1.984	.003	.152	7214.856	.364	.753
	Skewness	1.723	.401	1.671	.054	2.189	1.206

Table Appendix 2.15 (Cont.). Table of general statistics for each microwear variable for each of the three Neolithic phases examined from Gritille (A, B, C) and individual wild species. Continued on next page.

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.468	2.305	84, 1,327	0.000
Pillai Trace	0.693	2.255	84, 1,452	0.000
Hotelling-Lawley Trace	0.836	2.342	84, 1,412	0.000

Table Appendix 2.16. MANOVA for Gritille phases and individual wild species

Pairwise Comparisons for Complexity

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Ovis aries gmelini*	80.813	0.026	4.480	157.146
B	*Ovis aries gmelini*	83.893	0.002	17.781	150.006
Gazella dorcas dorcas	*Ovis aries aries*	125.712	0.028	6.229	245.195
Gazella dorcas dorcas	*Ovis aries gmelini*	136.012	0.000	42.558	229.466
Gazella subgutturosa subg	*Ovis aries gmelini*	98.830	0.026	5.376	192.284
Ovis aries aries	*Ovis vignei dolgopolovi*	-110.042	0.038	-217.498	-2.585
Ovis aries gmelini	*Ovis aries urmiana*	-124.467	0.039	-246.040	-2.894
Ovis aries gmelini	*Ovis vignei dolgopolovi*	-120.342	0.000	-197.830	-42.854

Table Appendix 2.17. Results of the Tukey's HSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Gazella dorcas dorcas*	-55.199	0.028	-104.384	-6.015
A	*Ovis aries aries*	70.513	0.026	8.580	132.446
A	*Ovis aries gmelini*	80.813	0.000	36.475	125.150
A	*Ovis vignei dolgopolovi*	-39.529	0.045	-78.237	-0.821
B	*Capra hircus hircus*	99.927	0.045	2.061	197.792
B	*Gazella dorcas dorcas*	-52.119	0.020	-96.027	-8.210
B	*Ovis aries aries*	73.593	0.013	15.761	131.426
B	*Ovis aries gmelini*	83.893	0.000	45.492	122.295
B	*Ovis vignei dolgopolovi*	-36.448	0.025	-68.184	-4.712
C	*Gazella dorcas dorcas*	-66.012	0.017	-120.294	-11.730
C	*Ovis aries gmelini*	70.000	0.006	20.068	119.932
C	*Ovis vignei dolgopolovi*	-50.342	0.029	-95.350	-5.333

Table Appendix 2.18. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus aegagrus	*Gazella dorcas dorcas*	-64.604	0.008	-112.037	-17.171
Capra hircus aegagrus	*Ovis aries aries*	61.108	0.048	0.556	121.660
Capra hircus aegagrus	*Ovis aries gmelini*	71.408	0.001	29.022	113.794
Capra hircus aegagrus	*Ovis vignei dolgopolovi*	-48.934	0.009	-85.391	-12.477
Capra hircus hircus	*Gazella dorcas dorcas*	-152.045	0.005	-257.162	-46.929
Capra hircus hircus	*Gazella subgutturosa subg*	-114.864	0.032	-219.980	-9.747
Capra hircus hircus	*Ovis aries urmiana*	-140.500	0.016	-254.909	-26.091
Capra hircus hircus	*Ovis vignei dolgopolovi*	-136.375	0.008	-237.017	-35.733
Gazella dorcas dorcas	*Ovis aries aries*	125.712	0.000	56.311	195.113
Gazella dorcas dorcas	*Ovis aries gmelini*	136.012	0.000	81.730	190.294
Gazella dorcas dorcas	*Ovis aries isphahanica*	83.795	0.040	3.954	163.637

Table Appendix 2.18 (Cont.). Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella dorcas dorcas	*Ovis aries laristanica*	107.745	0.004	33.991	181.500
Gazella dorcas dorcas	*Ovis aries sp.*	83.182	0.005	24.874	141.490
Gazella gazella bennetti	*Ovis aries gmelini*	86.038	0.007	23.445	148.631
Gazella subgutturosa subg	*Ovis aries aries*	88.530	0.013	19.130	157.931
Gazella subgutturosa subg	*Ovis aries gmelini*	98.830	0.000	44.548	153.112
Ovis aries aries	*Ovis aries urmiana*	-114.167	0.007	-196.970	-31.363
Ovis aries aries	*Ovis vignei dolgopolovi*	-110.042	0.001	-172.457	-47.626
Ovis aries gmelini	*Ovis aries urmiana*	-124.467	0.001	-195.081	-53.852
Ovis aries gmelini	*Ovis vignei dolgopolovi*	-120.342	0.000	-165.350	-75.333
Ovis aries laristanica	*Ovis aries urmiana*	-96.200	0.029	-182.685	-9.715
Ovis aries laristanica	*Ovis vignei dolgopolovi*	-92.075	0.007	-159.298	-24.852
Ovis aries sp.	*Ovis vignei dolgopolovi*	-67.511	0.008	-117.302	-17.721

Table Appendix 2.18 (Cont.). Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for *EpLsar*

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Capra hircus hircus*	-116.538	0.028	-220.116	-12.961
B	*Capra hircus hircus*	-105.939	0.040	-206.958	-4.920
B	*Gazella dorcas dorcas*	54.106	0.019	8.783	99.430
B	*Ovis aries urmiana*	68.561	0.039	3.540	133.582
B	*Ovis vignei dolgopolovi*	46.603	0.005	13.844	79.361
C	*Gazella dorcas dorcas*	60.845	0.033	4.814	116.877
C	*Ovis aries urmiana*	75.300	0.043	2.410	148.190
C	*Ovis vignei dolgopolovi*	53.342	0.025	6.883	99.800
Capra hircus aegagrus	*Gazella dorcas dorcas*	57.590	0.021	8.628	106.551

Table Appendix 2.19. Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significance was found with Tukey's HSD. Continued next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus aegagrus	*Ovis aries urmiana*	72.044	0.037	4.437	139.652
Capra hircus aegagrus	*Ovis vignei dolgopolovi*	50.086	0.009	12.454	87.718
Capra hircus hircus	*Gazella dorcas dorcas*	160.045	0.004	51.541	268.550
Capra hircus hircus	*Gazella subgutturosa subg*	114.500	0.039	5.996	223.004
Capra hircus hircus	*Ovis aries gmelini*	143.033	0.009	36.778	249.289
Capra hircus hircus	*Ovis aries urmiana*	174.500	0.004	56.404	292.596
Capra hircus hircus	*Ovis vignei dolgopolovi*	152.542	0.004	48.657	256.427
Gazella gazella bennetti	*Ovis vignei dolgopolovi*	87.327	0.005	26.694	147.961
Ovis aries aries	*Ovis aries gmelini*	78.033	0.025	9.851	146.216
Ovis aries aries	*Ovis aries urmiana*	109.500	0.012	24.028	194.972
Ovis aries aries	*Ovis vignei dolgopolovi*	87.542	0.008	23.115	151.968

Table Appendix 2.19 (Cont.). Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significance was found with Tukey's HSD.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Ovis aries gmelini	*Ovis aries sp.*	-69.533	0.015	-125.565	-13.502
Ovis aries isphahanica	*Ovis aries urmiana*	99.000	0.041	4.313	193.687
Ovis aries isphahanica	*Ovis vignei dolgopolovi*	77.042	0.048	0.811	153.272
Ovis aries sp.	*Ovis aries urmiana*	101.000	0.010	24.868	177.132
Ovis aries sp.	*Ovis vignei dolgopolovi*	79.042	0.003	27.647	130.436

Table Appendix 2.19 (Cont.). Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significance was found with Tukey's HSD.

Pairwise Comparison for *Smc*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Ovis aries gmelini*	-92.910	0.004	-170.566	-15.255
B	*Ovis aries gmelini*	-98.236	0.000	-165.494	-30.977
Capra hircus aegagrus	*Ovis aries gmelini*	-105.157	0.000	-179.395	-30.919
Gazella dorcas dorcas	*Ovis aries gmelini*	-107.833	0.010	-202.906	-12.760
Ovis aries gmelini	*Ovis aries sp.*	101.788	0.022	6.715	196.861
Ovis aries gmelini	*Ovis vignei dolgopolovi*	123.771	0.000	44.940	202.601

Table Appendix 2.20. Results of the Tukey's HSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Capra hircus hircus*	-111.577	0.032	-213.659	-9.495
A	*Ovis aries gmelini*	-92.910	0.000	-138.016	-47.805
B	*Capra hircus hircus*	-116.902	0.022	-216.464	-17.341
B	*Ovis aries gmelini*	-98.236	0.000	-137.302	-59.169
C	*Ovis aries gmelini*	-73.600	0.005	-124.397	-22.803
C	*Ovis vignei dolgopolovi*	50.171	0.032	4.383	95.959
Capra hircus aegagrus	*Capra hircus hircus*	-123.824	0.017	-225.044	-22.603
Capra hircus aegagrus	*Ovis aries gmelini*	-105.157	0.000	-148.277	-62.036
Capra hircus hircus	*Gazella dorcas dorcas*	126.500	0.021	19.562	233.438
Capra hircus hircus	*Ovis aries sp.*	120.455	0.027	13.516	227.393
Capra hircus hircus	*Ovis aries urmiana*	142.000	0.017	25.609	258.391

Table Appendix 2.21. Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus hircus	*Ovis vignei dolgopolovi*	142.438	0.007	40.052	244.823
Gazella dorcas dorcas	*Ovis aries gmelini*	-107.833	0.000	-163.056	-52.611
Gazella gazella bennetti	*Ovis aries gmelini*	-91.619	0.005	-155.297	-27.941
Gazella subgutturosa subg	*Ovis aries gmelini*	-66.970	0.018	-122.192	-11.747
Gazella subgutturosa subg	*Ovis vignei dolgopolovi*	56.801	0.028	6.148	107.454
Ovis aries aries	*Ovis vignei dolgopolovi*	78.604	0.015	15.107	142.101
Ovis aries gmelini	*Ovis aries laristanica*	93.533	0.011	21.695	165.372
Ovis aries gmelini	*Ovis aries sp.*	101.788	0.000	46.565	157.010
Ovis aries gmelini	*Ovis aries urmiana*	123.333	0.001	51.495	195.172
Ovis aries gmelini	*Ovis vignei dolgopolovi*	123.771	0.000	77.983	169.559

Table Appendix 2.21 (Cont.). Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Pairwise Comparisons for *Tfv*

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	*Gazella dorcas dorcas*	-93.347	0.003	-170.136	-16.558
Capra hircus aegagrus	*Gazella dorcas dorcas*	-116.944	0.000	-199.897	-33.991
Gazella dorcas dorcas	*Ovis aries aries*	139.258	0.009	17.887	260.628
Gazella dorcas dorcas	*Ovis aries sp.*	116.455	0.009	14.483	218.427
Gazella dorcas dorcas	*Ovis vignei dolgopolovi*	101.924	0.006	14.849	188.999

Table Appendix 2.22. Results of the Tukey's HSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Capra hircus aegagrus*	40.738	0.028	4.548	76.927
A	*Gazella dorcas dorcas*	-76.206	0.003	-126.169	-26.243
A	*Ovis aries aries*	63.051	0.050	0.138	125.965
B	*C*	-46.542	0.023	-86.711	-6.372
B	*Gazella dorcas dorcas*	-93.347	0.000	-137.950	-48.744
B	*Gazella subgutturosa subg*	-53.074	0.020	-97.678	-8.471
C	*Capra hircus aegagrus*	70.139	0.002	26.028	114.250
C	*Ovis aries aries*	92.452	0.008	24.672	160.233
C	*Ovis aries sp.*	69.649	0.015	13.681	125.617
C	*Ovis vignei dolgopolovi*	55.119	0.021	8.404	101.834
Capra hircus aegagrus	*Gazella dorcas dorcas*	-116.944	0.000	-165.128	-68.760
Capra hircus aegagrus	*Gazella subgutturosa subg*	-76.671	0.002	-124.855	-28.487

Table Appendix 2.23. Results of the Fisher's LSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Capra hircus aegagrus	*Ovis aries gmelini*	-43.053	0.050	-86.110	0.004
Gazella dorcas dorcas	*Gazella gazella bennetti*	77.948	0.023	10.786	145.110
Gazella dorcas dorcas	*Ovis aries aries*	139.258	0.000	68.759	209.757
Gazella dorcas dorcas	*Ovis aries gmelini*	73.891	0.009	18.750	129.032
Gazella dorcas dorcas	*Ovis aries laristanica*	112.891	0.003	37.969	187.813
Gazella dorcas dorcas	*Ovis aries sp.*	116.455	0.000	57.224	175.686
Gazella dorcas dorcas	*Ovis aries urmiana*	99.291	0.010	24.369	174.213
Gazella dorcas dorcas	*Ovis vignei dolgopolovi*	101.924	0.000	51.346	152.502
Gazella subgutturosa subg	*Ovis aries aries*	98.985	0.006	28.486	169.484
Gazella subgutturosa subg	*Ovis aries sp.*	76.182	0.012	16.951	135.413
Gazella subgutturosa subg	*Ovis vignei dolgopolovi*	61.652	0.017	11.073	112.230
Ovis aries aries	*Ovis aries isphahanica*	-89.667	0.050	-179.332	-0.001

Table Appendix 2.23 (Cont.). Results of the Fisher's LSD pairwise comparison for texture fill volume. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Pairwise Comparisons for 3x3 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Capra hircus aegagrus*	67.057	0.032	2.586	131.527

Table Appendix 2.24. Results of the Tukey's HSD pairwise comparison for 3X3 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	46.920	0.005	14.569	79.271
A	C	50.949	0.032	4.344	97.553
A	*Capra hircus aegagrus*	67.057	0.001	29.609	104.504
A	*Ovis aries isphahanica*	89.365	0.023	12.166	166.565
A	*Ovis aries sp.*	63.615	0.016	11.916	115.315
A	*Ovis vignei dolgopolovi*	67.115	0.001	26.428	107.803
B	*Ovis aries gmelini*	-51.705	0.012	-92.070	-11.340
C	*Ovis aries gmelini*	-55.733	0.038	-108.219	-3.248
Capra hircus aegagrus	*Ovis aries gmelini*	-71.841	0.002	-116.395	-27.288
Ovis aries gmelini	*Ovis aries isphahanica*	94.150	0.023	13.265	175.035
Ovis aries gmelini	*Ovis aries sp.*	68.400	0.019	11.342	125.458
Ovis aries gmelini	*Ovis vignei dolgopolovi*	71.900	0.003	24.590	119.210

Table Appendix 2.25. Results of the Fisher's LSD pairwise comparison for 3X3 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Pairwise Comparisons for 9x9 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Ovis aries gmelini	*Ovis aries sp.*	105.855	0.020	8.061	203.648

Table Appendix 2.26. Results of the Tukey's HSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	32.459	0.048	0.252	64.665
A	C	56.421	0.017	10.024	102.817
A	*Ovis aries sp.*	73.608	0.005	22.140	125.077
B	*Ovis aries gmelini*	-64.705	0.002	-104.889	-24.520
C	*Ovis aries gmelini*	-88.667	0.001	-140.918	-36.416
Capra hircus aegagrus	*Ovis aries gmelini*	-55.518	0.014	-99.872	-11.163
Capra hircus aegagrus	*Ovis aries sp.*	50.337	0.047	0.701	99.973
Gazella dorcas dorcas	*Ovis aries sp.*	72.000	0.021	10.984	133.016
Gazella gazella bennetti	*Ovis aries sp.*	69.883	0.048	0.697	139.069
Ovis aries aries	*Ovis aries gmelini*	-79.900	0.024	-149.022	-10.778
Ovis aries gmelini	*Ovis aries isphahanica*	104.650	0.011	24.126	185.174
Ovis aries gmelini	*Ovis aries laristanica*	96.200	0.011	22.306	170.094

Table Appendix 2.27. Results of the Fisher's LSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Ovis aries gmelini	*Ovis aries sp.*	105.855	0.000	49.052	162.657
Ovis aries gmelini	*Ovis vignei dolgopolovi*	61.733	0.010	14.635	108.832
Ovis aries sp.	*Ovis aries urmiana*	-81.055	0.040	-158.235	-3.875

Table Appendix 2.27 (Cont.). Results of the Fisher's LSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Levene's Transformed Data MANOVA 3

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.440	2.516	84, 1,332	0.000
Pillai Trace	0.717	2.354	84, 1,458	0.000
Hotelling-Lawley Trace	0.955	2.688	84, 1,418	0.000

Table Appendix 2.28. MANOVA for Gritille phases and individual wild species based on Levene's transformed microwear

Pairwise Comparison for Levene's Transformed Complexity

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	*Ovis aries gmelini*	-0.362	0.002	-0.653	-0.072

Table Appendix 2.29. Results of the Tukey's HSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	0.158	0.022	0.023	0.293
A	*Ovis aries gmelini*	-0.204	0.040	-0.399	-0.010
B	*Capra hircus aegagrus*	-0.130	0.038	-0.252	-0.007
B	*Gazella dorcas dorcas*	-0.229	0.020	-0.421	-0.036
B	*Ovis aries aries*	-0.262	0.043	-0.516	-0.008
B	*Ovis aries gmelini*	-0.362	0.000	-0.531	-0.194
B	*Ovis aries laristanica*	-0.287	0.042	-0.563	-0.010
C	*Ovis aries gmelini*	-0.350	0.002	-0.570	-0.131
Capra hircus aegagrus	*Ovis aries gmelini*	-0.233	0.014	-0.419	-0.047
Gazella subgutturosa subg	*Ovis aries gmelini*	-0.358	0.003	-0.596	-0.120
Ovis aries gmelini	*Ovis aries sp.*	0.264	0.030	0.025	0.502
Ovis aries gmelini	*Ovis aries urmiana*	0.314	0.047	0.004	0.624

Table Appendix 2.30. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued on next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Ovis aries gmelini	*Ovis vignei dolgopolovi*	0.320	0.002	0.122	0.518

Table Appendix 2.30 (Cont.). Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparisons for Levene's Transformed SMC

Tukey's Honestly-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
A	*Ovis aries gmelini*	-92.910	0.004	-170.566	-15.255
B	*Ovis aries gmelini*	-98.236	0.000	-165.494	-30.977
Capra hircus aegagrus	*Ovis aries gmelini*	-105.157	0.000	-179.395	-30.919
Gazella dorcas dorcas	*Ovis aries gmelini*	-107.833	0.010	-202.906	-12.760
Ovis aries gmelini	*Ovis aries sp.*	101.788	0.022	6.715	196.861
Ovis aries gmelini	*Ovis vignei dolgopolovi*	123.771	0.000	44.940	202.601

Table Appendix 2.31. Results of the Tukey's HSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
SCIENTIFIC_NAME-_$(i)	**SCIENTIFIC_NAME-_$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	*Capra hircus hircus*	-111.577	0.032	-213.659	-9.495
A	*Ovis aries gmelini*	-92.910	0.000	-138.016	-47.805
B	*Capra hircus hircus*	-116.902	0.022	-216.464	-17.341
B	*Ovis aries gmelini*	-98.236	0.000	-137.302	-59.169
C	*Ovis aries gmelini*	-73.600	0.005	-124.397	-22.803
C	*Ovis vignei dolgopolovi*	50.171	0.032	4.383	95.959
Capra hircus aegagrus	*Capra hircus hircus*	-123.824	0.017	-225.044	-22.603
Capra hircus aegagrus	*Ovis aries gmelini*	-105.157	0.000	-148.277	-62.036
Capra hircus hircus	*Gazella dorcas dorcas*	126.500	0.021	19.562	233.438
Capra hircus hircus	*Ovis aries sp.*	120.455	0.027	13.516	227.393
Capra hircus hircus	*Ovis aries urmiana*	142.000	0.017	25.609	258.391
Capra hircus hircus	*Ovis vignei dolgopolovi*	142.438	0.007	40.052	244.823

Table Appendix 2.32. Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. Continued next page.

SCIENTIFIC_NAME-_$(i)	SCIENTIFIC_NAME-_$(j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Gazella dorcas dorcas	*Ovis aries gmelini*	-107.833	0.000	-163.056	-52.611
Gazella gazella bennetti	*Ovis aries gmelini*	-91.619	0.005	-155.297	-27.941
Gazella subgutturosa subg	*Ovis aries gmelini*	-66.970	0.018	-122.192	-11.747
Gazella subgutturosa subg	*Ovis vignei dolgopolovi*	56.801	0.028	6.148	107.454
Ovis aries aries	*Ovis vignei dolgopolovi*	78.604	0.015	15.107	142.101
Ovis aries gmelini	*Ovis aries laristanica*	93.533	0.011	21.695	165.372
Ovis aries gmelini	*Ovis aries sp.*	101.788	0.000	46.565	157.010
Ovis aries gmelini	*Ovis aries urmiana*	123.333	0.001	51.495	195.172
Ovis aries gmelini	*Ovis vignei dolgopolovi*	123.771	0.000	77.983	169.559

Table Appendix 2.32 (Cont.). Results of the Fisher's LSD pairwise comparison for scale of maximum complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Appendix 3: Archaeological Statistical Output

Mesowear

Cluster Analysis 1: by Archaeological Phase

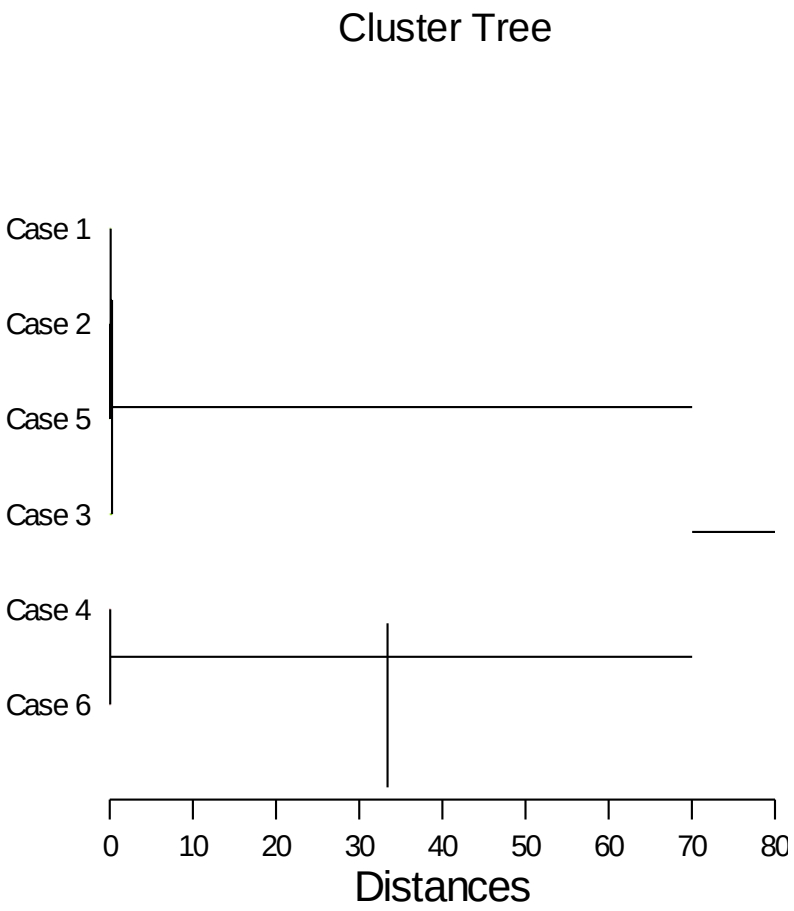

Figure Appendix 3.1. Hierarchical cluster analysis by percentage high and percentage sharp. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

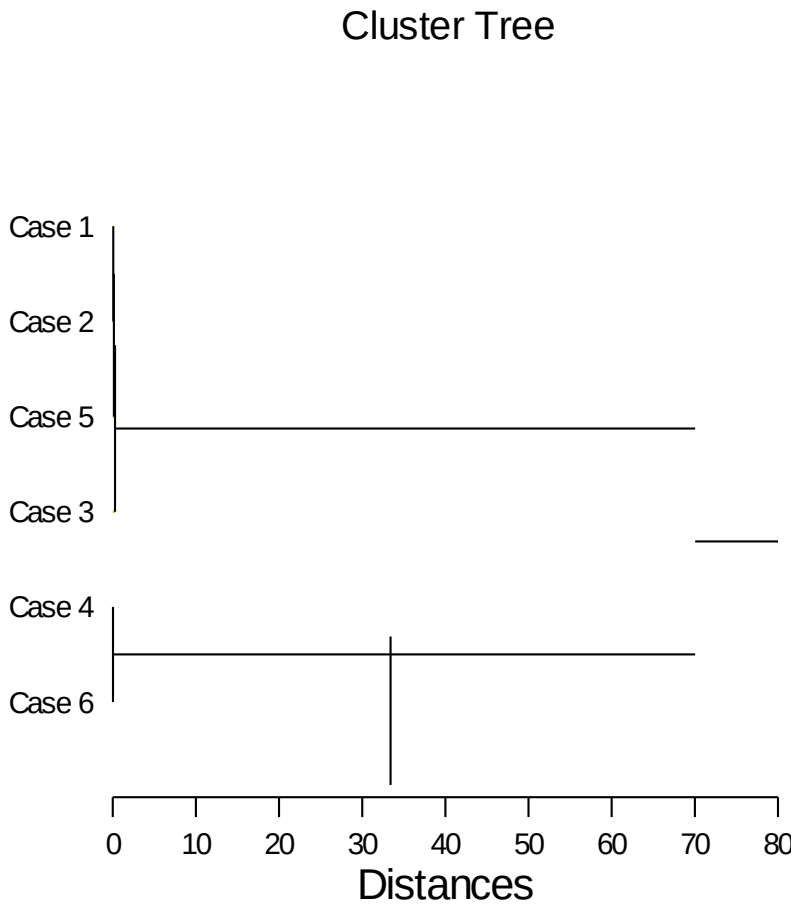

Figure Appendix 3.2. Hierarchical cluster analysis by percentage high and percentage round. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

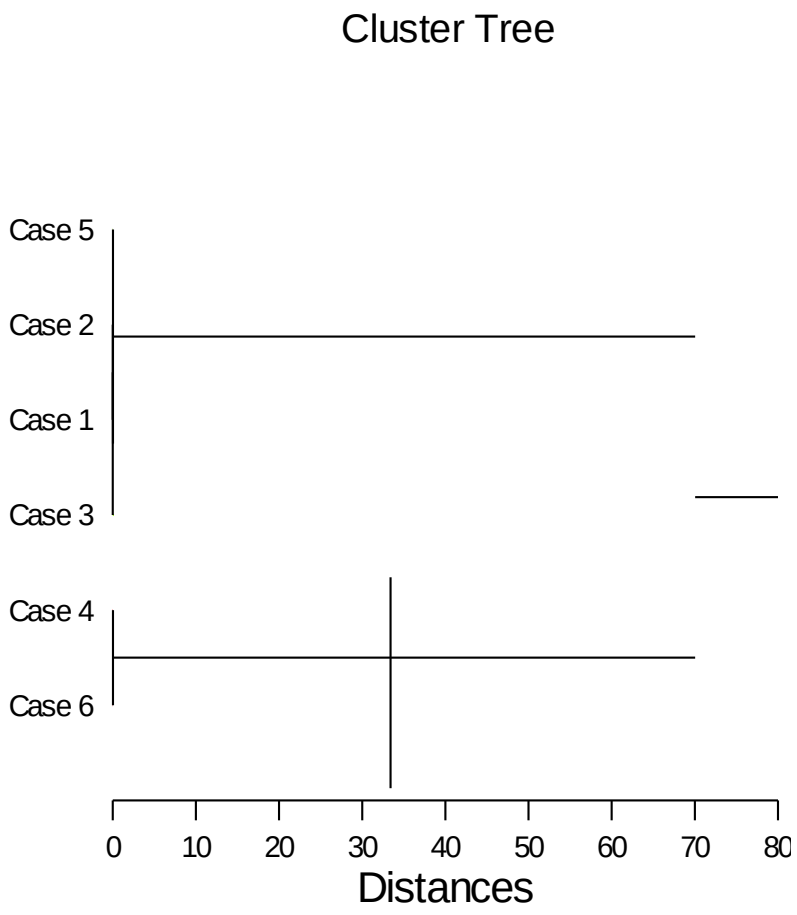

Figure Appendix 3.3. Hierarchical cluster analysis by percentage high and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

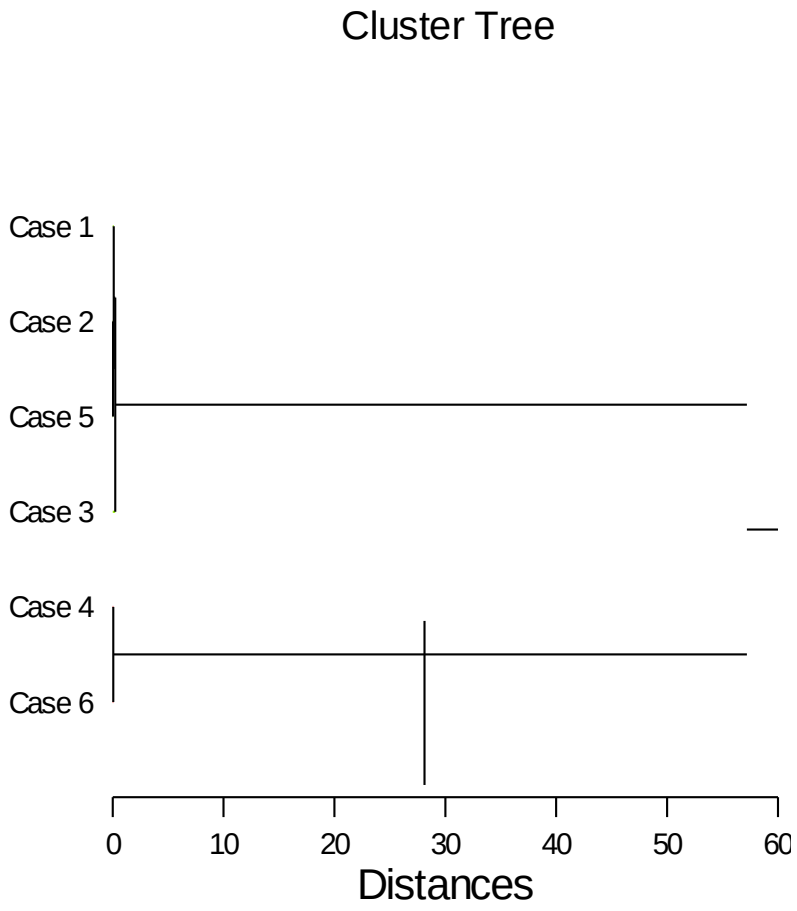

Figure Appendix 3.4. Hierarchical cluster analysis by percentage high and percentage sharp and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

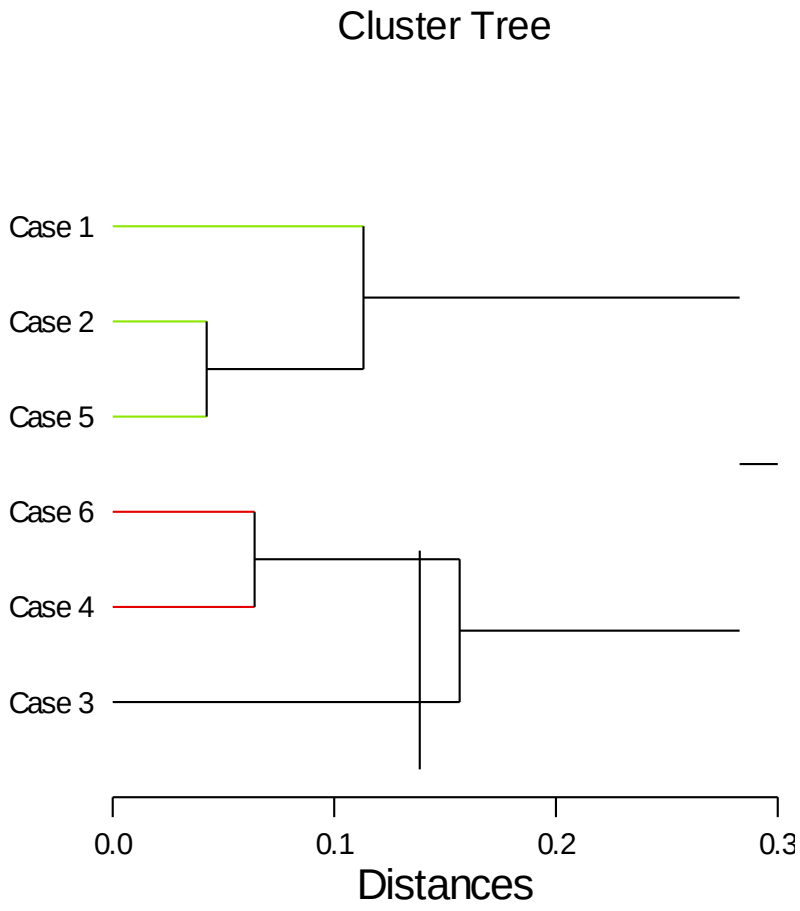

Figure Appendix 3.5. Hierarchical cluster analysis by percentage low and percentage sharp. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

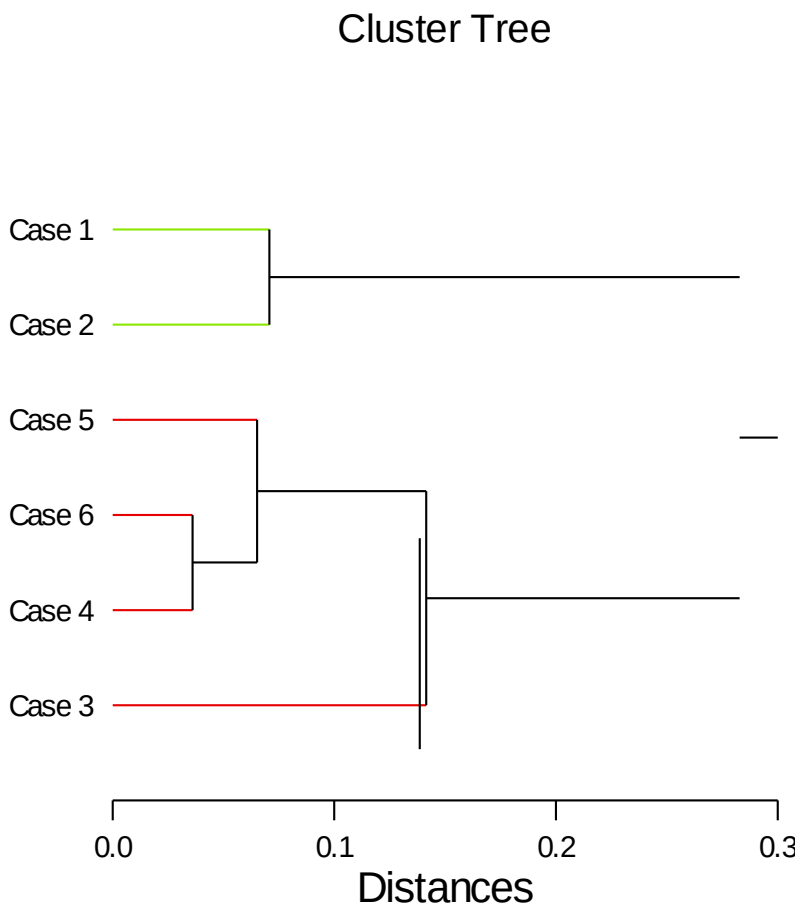

Figure Appendix 3.6. Hierarchical cluster analysis by percentage low and percentage round. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

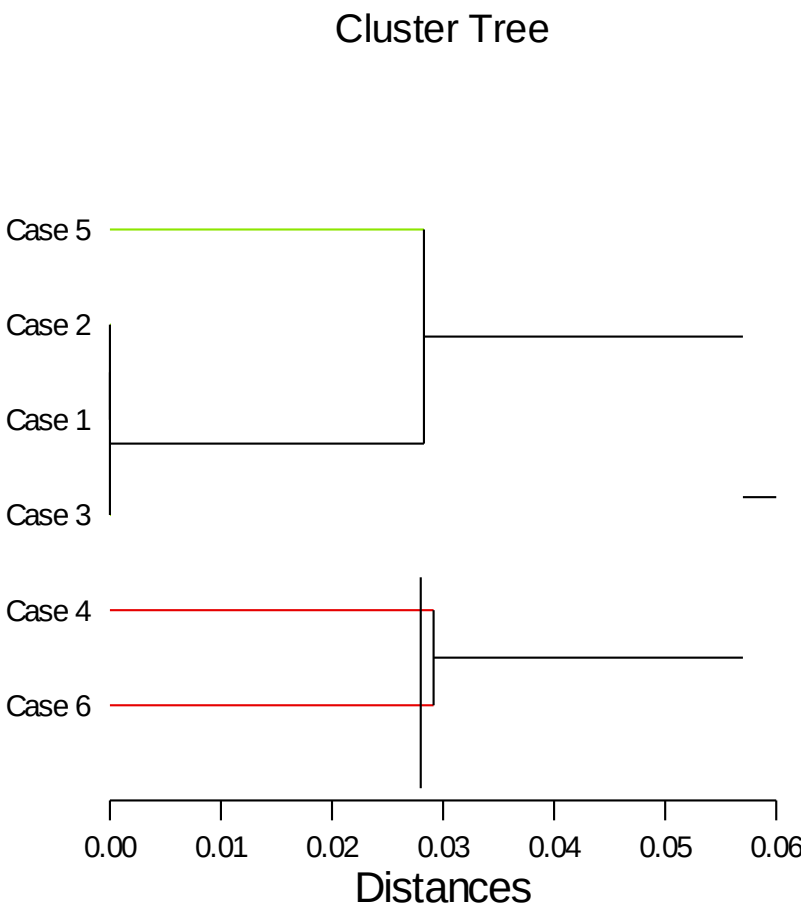

Figure Appendix 3.7. Hierarchical cluster analysis by percentage low and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

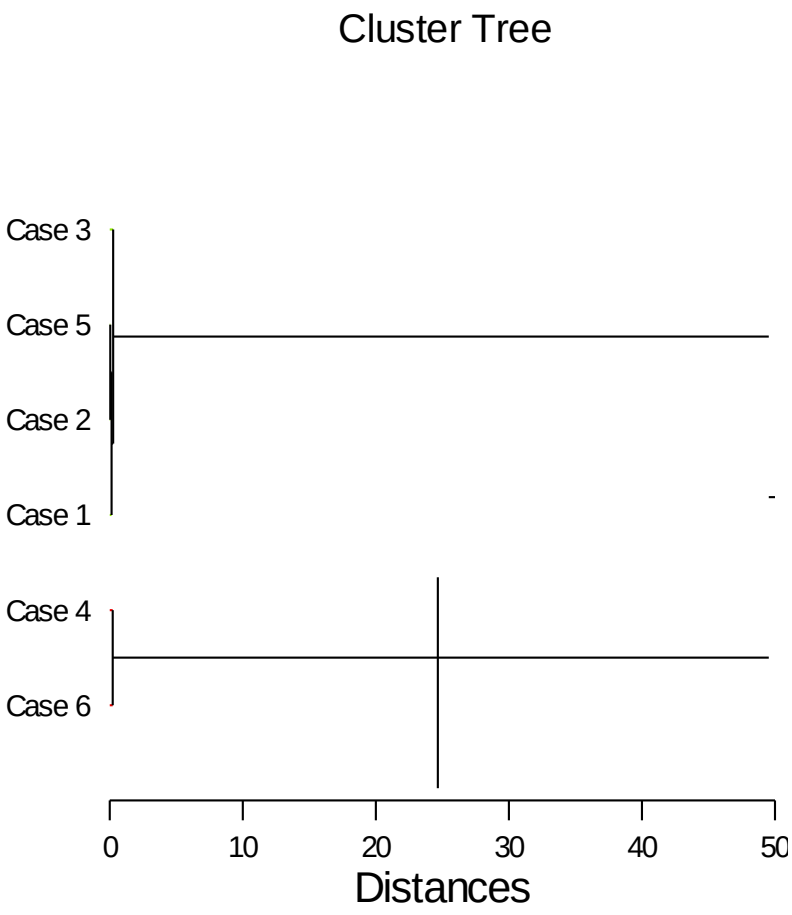

Figure Appendix 3.8. Hierarchical cluster analysis by percentage high, percentage sharp, percentage blunt, and hypsodonty index. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

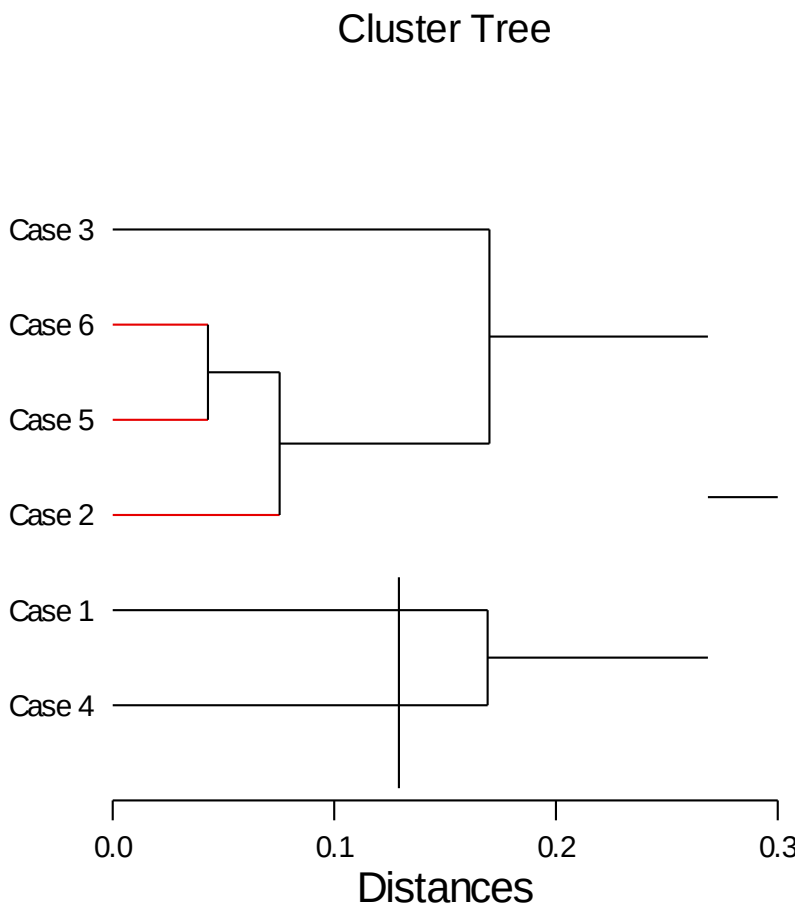

Figure Appendix 3.9. Hierarchical cluster analysis by percentage low, percentage sharp, percentage blunt, and hypsodonty index. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, and group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition.

Cluster Analysis 2: by Archaeological Phase including Neolithic

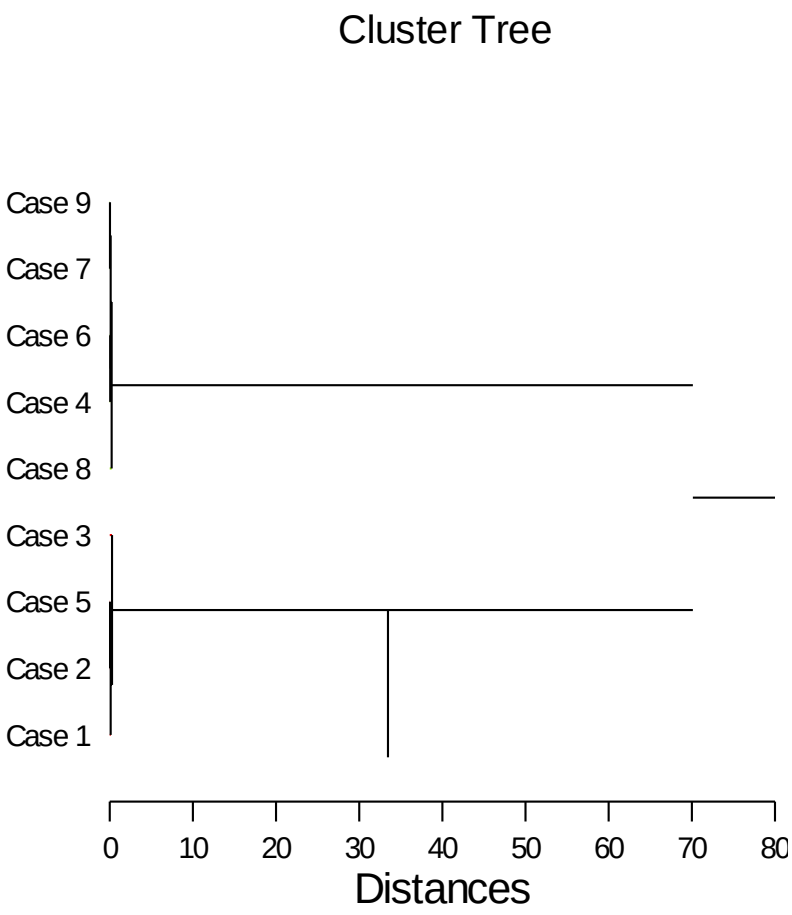

Figure Appendix 3.10. Hierarchical cluster analysis by percentage high and percentage sharp. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

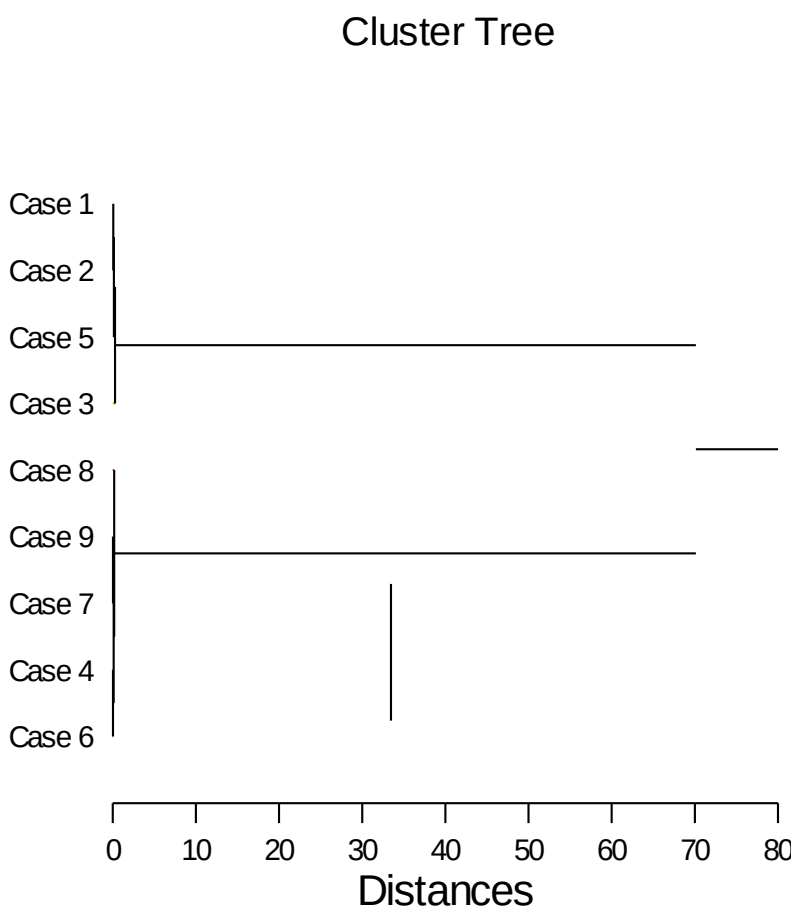

Figure Appendix 3.11. Hierarchical cluster analysis by percentage high and percentage round. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

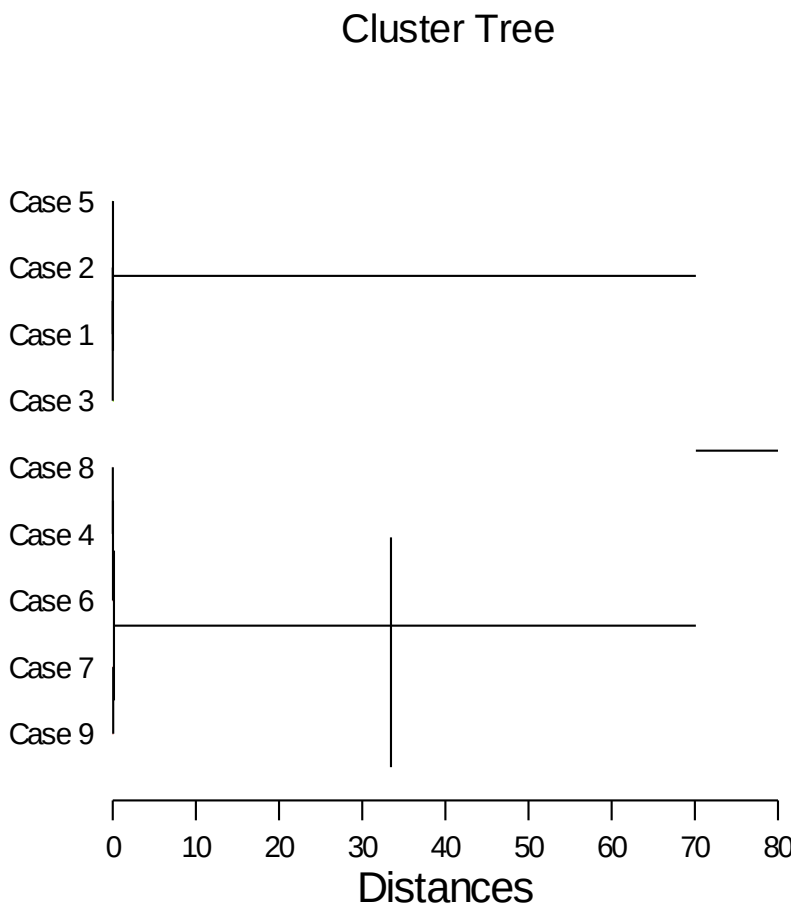

Figure Appendix 3.12. Hierarchical cluster analysis by percentage high and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

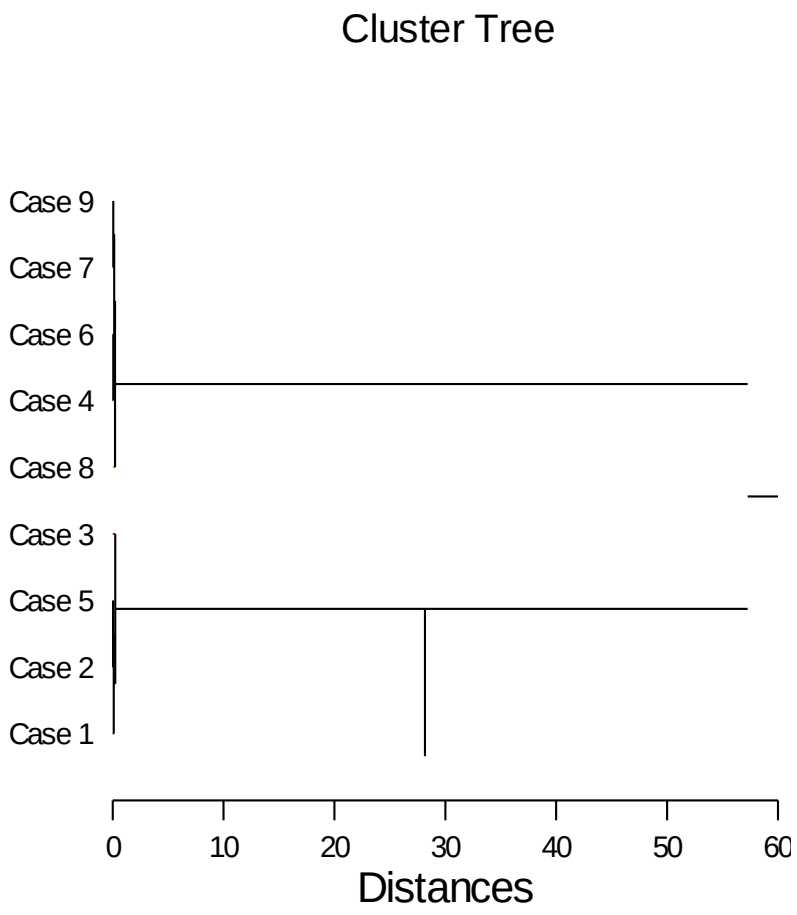

Figure Appendix 3.13. Hierarchical cluster analysis by percentage high and percentage sharp and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

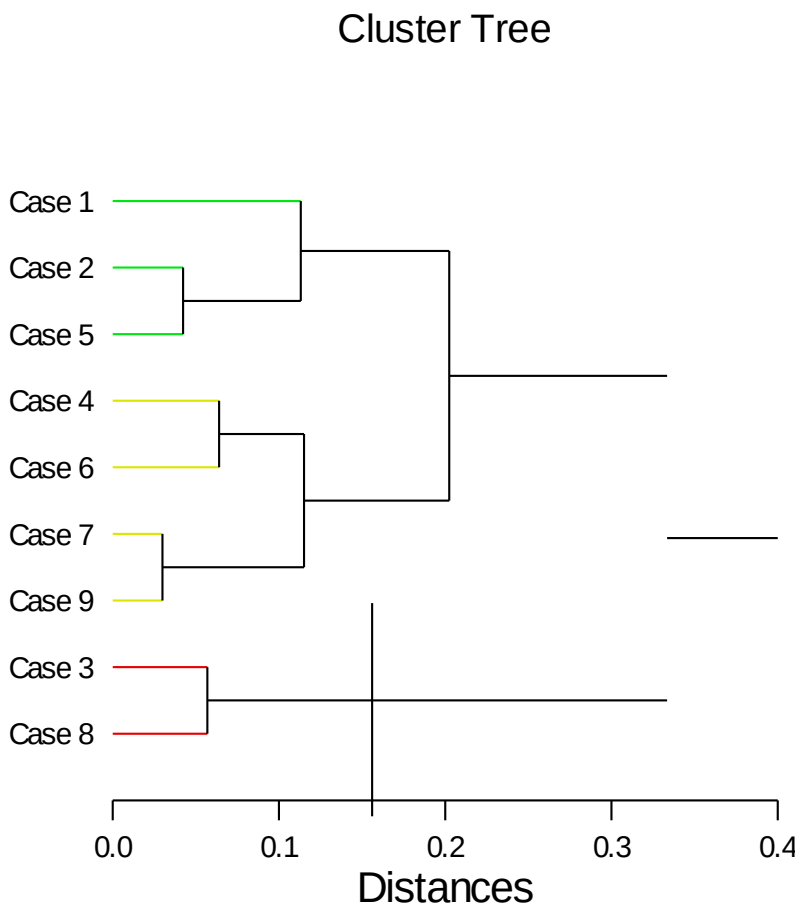

Figure Appendix 3.14. Hierarchical cluster analysis by percentage low and percentage sharp. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

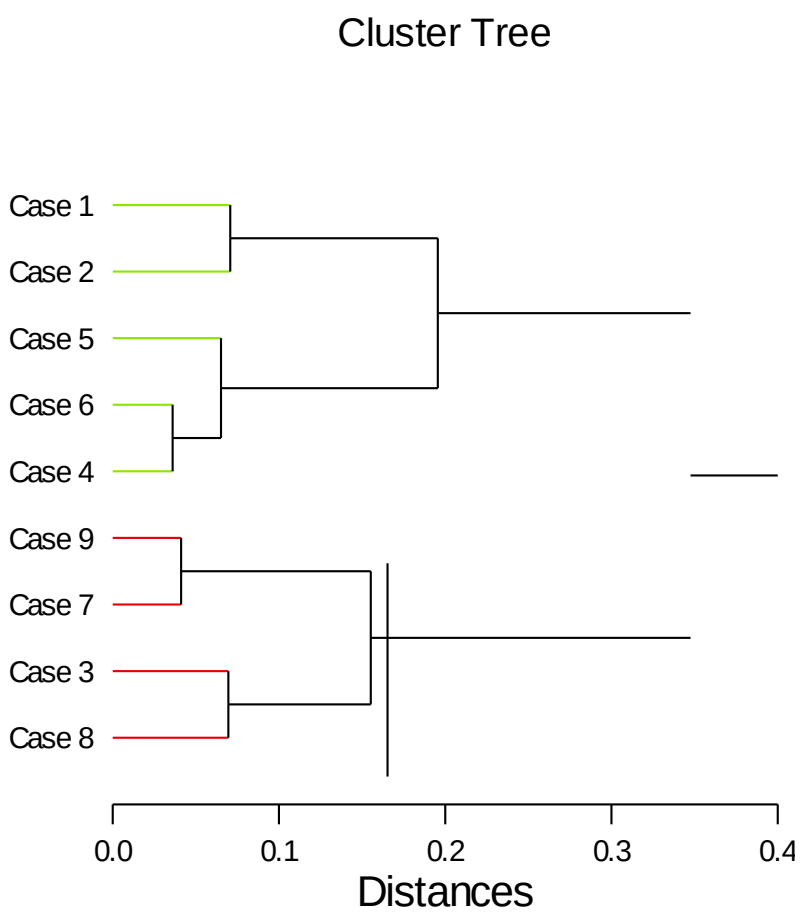

Figure Appendix 3.15. Hierarchical cluster analysis by percentage low and percentage round. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

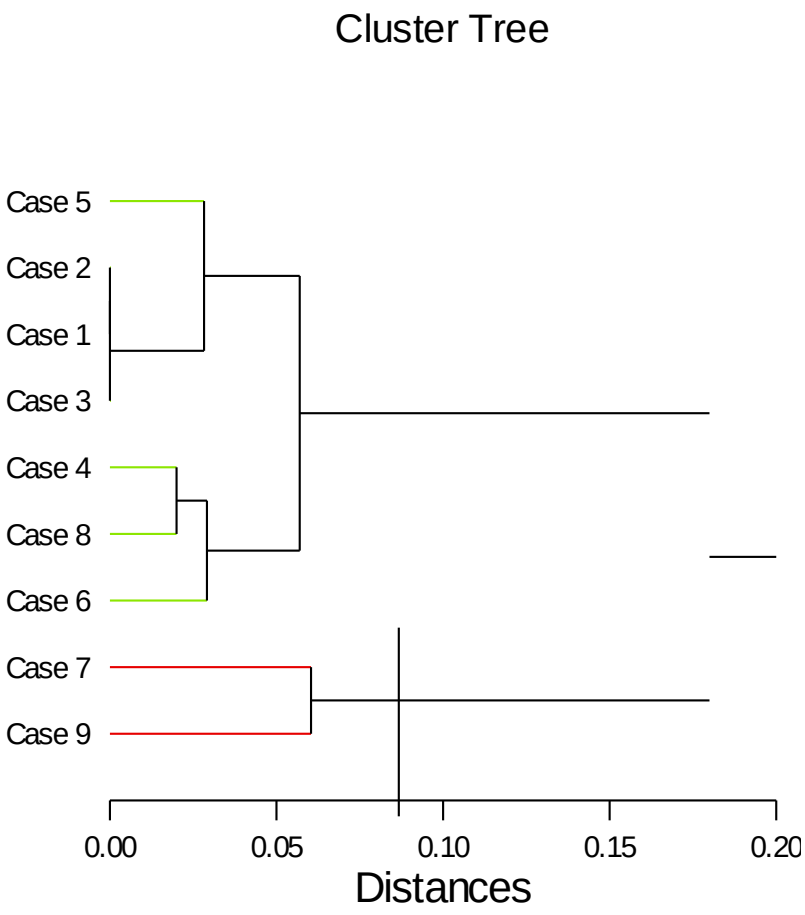

Figure Appendix 3.16. Hierarchical cluster analysis by percentage low and percentage blunt. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

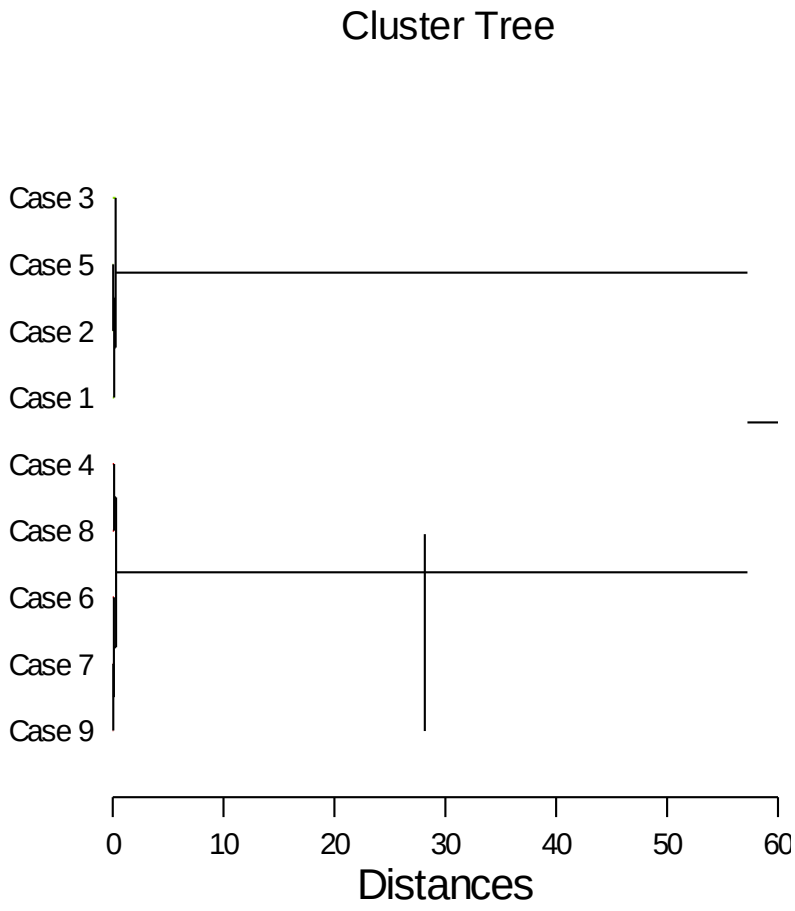

Figure Appendix 3.17. Hierarchical cluster analysis by percentage high, percentage sharp, percentage blunt and hypsodonty. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

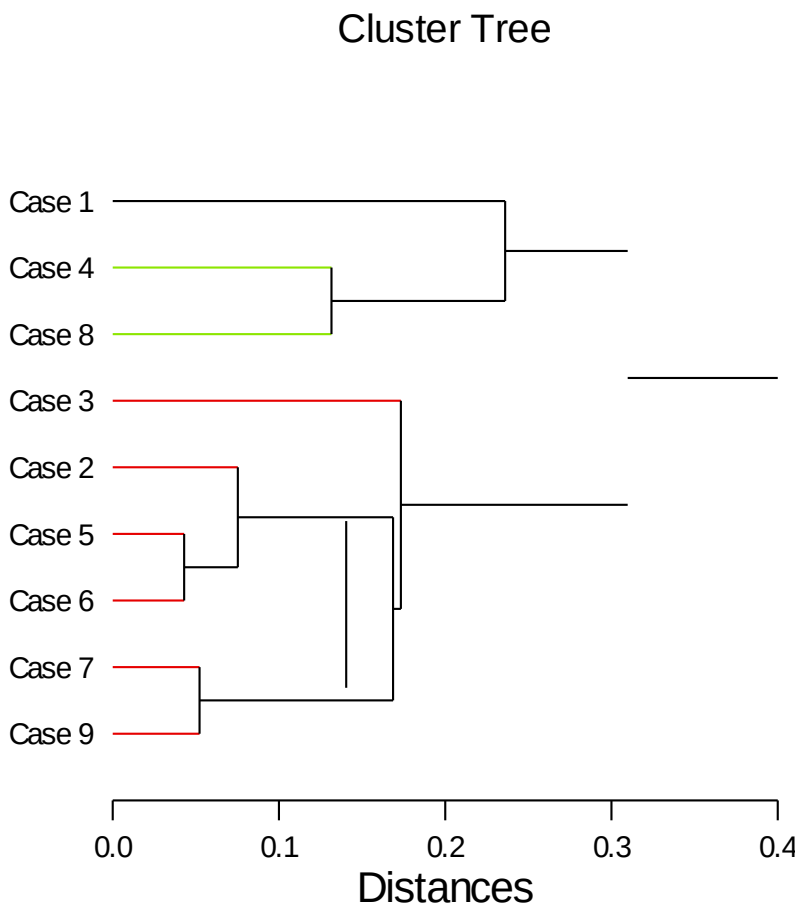

Figure Appendix 3.18. Hierarchical cluster analysis by percentage low, percentage sharp, percentage blunt and hypsodonty. Group 1 Gritille Medieval, group 2 is Hacınebi Early Bronze age, group 3 is Hacınebi Late Chalcolithic A, group 4 is Hacınebi Late Chalcolithic B1, group 5 is Hacınebi Late Chalcolithic B2 Local tradition, group 6 is Hacınebi Late Chalcolithic B2 Uruk tradition, group 7 is Neolithic Gritille Phase, A, group 8 is Neolithic Gritille Phase B, and group 9 is Neolithic Gritille Phase C

Microwear

MANOVA 1

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.849	1.785	12, 252	0.051
Pillai Trace	0.155	1.784	12, 254	0.051
Hotelling-Lawley Trace	0.171	1.786	12, 250	0.051

Table Appendix 3.1. MANOVA results for archaeological site comparison

Levene's Transformed MANOVA 1

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.882	1.359	12, 252	0.186
Pillai Trace	0.121	1.363	12, 254	0.184
Hotelling-Lawley Trace	0.130	1.354	12, 250	0.189

Table Appendix 3.2. MANOVA results for archaeological site comparison based on Levene's transformed data.

Pairwise Comparison for Levene's Transformed Complexity

Tukey's Honestly-Significant-Difference Test					
SITE$(i)	**SITE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
GT	HN	0.267	0.009*	0.054	0.481
GT	q	0.269	0.048*	0.001	0.537
HN	q	0.002	1.000	-0.186	0.190
Fisher's Least-Significant-Difference Test					
SITE$(i)	**SITE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
GT	HN	0.267	0.004*	0.087	0.447
GT	q	0.269	0.020*	0.043	0.495
HN	q	0.002	0.982	-0.157	0.160

Table Appendix 3.3. Results of the pairwise comparison for complexity. Tukey's HSD is on the top and Fisher's LSD pairwise comparison for complexity is on the bottom. Significant results ($p < 0.05$) are marked by a star.

MANOVA 2

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.669	1.436	36, 538	0.051
Pillai Trace	0.382	1.438	36, 762	0.048
Hotelling-Lawley Trace	0.425	1.422	36, 722	0.054

Table Appendix 3.4. MANOVA results for archaeological sites by phase

MANOVA 2 based on Levene's transformed data

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.704	1.247	36, 538	0.157
Pillai Trace	0.334	1.249	36, 762	0.153
Hotelling-Lawley Trace	0.370	1.238	36, 722	0.162

Table Appendix 3.4. MANOVA results for archaeological sites by phase based on Levene's transformed microwear data

MANOVA 3

PHASE		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
A	Mean	1.957	.004	.248	9409.344	.492	.902
	N	26	26	26	26	26	26
	Std. Deviation	1.144	.001	.136	4992.238	.129	.259
	Median	1.686	.004	.208	10342.939	.494	.858
	Skewness	1.073	.374	1.854	-.356	.819	.792
B	Mean	1.831	.004	.539	8227.177	.414	.790
	N	82	82	82	82	82	82
	Std. Deviation	.772	.001	2.577	4694.084	.125	.211
	Median	1.721	.004	.153	8512.543	.392	.727
	Skewness	1.376	.204	8.898	.102	1.209	.912
C	Mean	1.688	.004	1.539	10434.783	.430	.718
	N	15	15	15	15	15	15
	Std. Deviation	.768	.001	3.412	5194.801	.1842	.238
	Median	1.535	.004	.208	12023.322	.416	.684
	Skewness	1.842	.285	2.457	-.611	.887	.467

Table Appendix 3.5. Table of general statistics for each microwear variable for each of the three comparison sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence(LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur) and the Neolithic Phases at Gritille (A, B, C).

PHASE		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
EB	Mean	1.622	.005	.169	7781.612	.478	.873
	N	10	10	10	10	10	10
	Std. Deviation	.578	.001	.028	4933.562	.198	.229
	Median	1.565	.004	.153	9221.575	.422	.804
	Skewness	.752	.379	1.033	-.603	2.181	1.305
LC A	Mean	1.673	.003	.375	14125.857	.637	1.090
	N	2	2	2	2	2	2
	Std. Deviation	1.010	.000	.318	3478.503	.078	.267
	Median	1.673	.003	.375	14125.857	.637	1.090
	Skewness	.	.	.	.	.	.
LC B1 (LOCAL)	Mean	2.004	.004	.191	6841.471	.481	.881
	N	30	30	30	30	30	30
	Std. Deviation	.780	.001	.080	4758.377	.248	.220
	Median	2.106	.003	.152	6801.454	.443	.814
	Skewness	.272	.228	2.095	.068	4.074	.651

Table Appendix 3.5 (Cont.). Table of general statistics for each microwear variable for each of the three comparison sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence(LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur) and the Neolithic Phases at Gritille (A, B, C).

PHASE		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
LC B2 (NON-URUK)	Mean	1.742	.003	9.581	8094.784	.501	1.209
	N	29	29	29	29	29	29
	Std. Deviation	.704	.001	44.830	4733.412	.173	.984
	Median	1.656	.003	.208	8042.042	.472	1.002
	Skewness	.020	.642	5.256	-.109	.718	4.207
LC B2 URUK	Mean	2.041	.004	.244	9406.255	.509	.969
	N	35	35	35	35	35	35
	Std. Deviation	.938	.001	.137	5072.201	.217	.383
	Median	1.969	.004	.208	9454.544	.446	.934
	Skewness	.920	.469	1.680	-.273	1.329	.940
Med	Mean	2.225	.003	.286	8691.525	.413	.738
	N	12	12	12	12	12	12
	Std. Deviation	1.389	.001	.344	5124.952	.130	.181
	Median	1.935	.003	.152	10784.577	.409	.776
	Skewness	.489	.756	3.330	-1.108	.214	-.078

Table Appendix 3.5 (Cont.). Table of general statistics for each microwear variable for each of the three comparison sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence(LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur) and the Neolithic Phases at Gritille (A, B, C).

PHASE		Asfc Median	epLsar Median	Smc Median	Tfv	3x3HAsfc	9x9HAsfc
Qarqur	Mean	1.606	.003	.273	8408.692	.440	.876
	N	16	16	16	16	16	16
	Std. Deviation	.653	.001	.165	3837.843	.096	.260
	Median	1.471	.003	.267	9209.603	.426	.836
	Skewness	.906	.839	2.813	-.062	.843	.355

Table Appendix 3.5 (Cont.). Table of general statistics for each microwear variable for each of the three comparison sites (Non-Neolithic Gritille, Hacınebi, Tell Qarqur) broken down by phase sampled (Hacınebi Early Bronze (EB), Hacınebi Late Chalcolithic A (LC A), Hacınebi Late Chalcolithic B1 (LC B1), Hacınebi Late Chalcolithic B2 exhibiting Anatolian culture (LC B2 local), Hacınebi Late Chalcolithic B2 with Uruk influence(LC B2 Uruk), Gritille Medieval (Med), and Tell Qarqur) and the Neolithic Phases at Gritille (A, B, C).

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.720	1.519	54, 1,233	0.010
Pillai Trace	0.315	1.515	54, 1,476	0.010
Hotelling-Lawley Trace	0.342	1.518	54, 1,436	0.010

Table Appendix 3.6. MANOVA results for comparison between Neolithic Gritille and archaeological sties

Pairwise Comparison for Anisotropy

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	LC B2 (NON-URUK)	36.892	0.020	5.831	67.953
B	Medieval	55.303	0.015	10.868	99.738
B	Qarqur	49.532	0.014	10.240	88.824
C	Medieval	61.017	0.032	5.336	116.697
C	Qarqur	55.246	0.036	3.576	106.915
EB	LC B2 (NON-URUK)	57.472	0.033	4.750	110.195
EB	Medieval	75.883	0.016	14.326	137.441
EB	Qarqur	70.112	0.018	12.158	128.067
LC B2 URUK	Medieval	48.498	0.048	0.404	96.591

Table Appendix 3.7. Results of the Fisher's LSD pairwise comparison for anisotropy. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significant pairwise comparisons were indicated by Tukey's HSD.

Pairwise Comparison for 3x3 Heterogeneity

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	45.365	0.006	13.026	77.704
B	LC A	-116.134	0.027	-218.966	-13.302
B	LC B2 (NON-URUK)	-41.341	0.009	-72.384	-10.298
B	LC B2 URUK	-35.677	0.016	-64.688	-6.666
C	LC A	-115.400	0.037	-223.562	-7.238
LC A	Medieval	114.167	0.042	4.426	223.908

Table Appendix 3.8. Results of the Fisher's LSD pairwise comparison for 3X3 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance. No significant pairwise comparisons were indicated by Tukey's HSD.

Pairwise Comparison for 9x9 Heterogeneity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	LC B2 (NON-URUK)	-56.527	0.010	-105.707	-7.347
C	LC B2 (NON-URUK)	-77.225	0.026	-149.621	-4.829

Table Appendix 3.9. Results of the Tukey's HSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	C	52.197	0.026	6.248	98.147
B	LC B1 (LOCAL)	-30.402	0.049	-60.640	-0.163
B	LC B2 (NON-URUK)	-56.527	0.000	-87.145	-25.909
B	LC B2 URUK	-37.797	0.010	-66.410	-9.183
C	LC A	-107.967	0.047	-214.647	-1.286
C	LC B1 (LOCAL)	-51.100	0.026	-95.915	-6.285
C	LC B2 (NON-URUK)	-77.225	0.001	-122.297	-32.154
C	LC B2 URUK	-58.495	0.009	-102.230	-14.761
LC B2 (NON-URUK)	Medieval	67.842	0.006	19.199	116.485
LC B2 URUK	Medieval	49.112	0.042	1.705	96.519

Table Appendix 3.10. Results of the Fisher's LSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Levene's Transformed MANOVA 3

Multivariate Test Statistics				
Statistic	**Value**	**F-Ratio**	**df**	**p-Value**
Wilks's Lambda	0.697	1.682	54, 1,238	0.002
Pillai Trace	0.345	1.674	54, 1,482	0.002
Hotelling-Lawley Trace	0.378	1.682	54, 1,442	0.002

Table Appendix 3.11. MANOVA results for comparison between Neolithic Gritille and archaeological sites based on Levene's transformed microwear values

Pairwise Comparison for Levene's Transformed Complexity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	Medieval	-0.332	0.004	-0.603	-0.062

Table Appendix 3.12. Results of the Tukey's HSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	B	0.159	0.011	0.036	0.281
B	Medieval	-0.332	0.000	-0.501	-0.164
C	Medieval	-0.320	0.003	-0.531	-0.109
EB	Medieval	-0.342	0.004	-0.575	-0.109
LC B1 (LOCAL)	Medieval	-0.272	0.004	-0.458	-0.086
LC B2 (NON-URUK)	Medieval	-0.259	0.007	-0.446	-0.072
LC B2 URUK	Medieval	-0.237	0.011	-0.419	-0.054
Medieval	Qarqur	0.292	0.006	0.084	0.500

Table Appendix 3.13. Results of the Fisher's LSD pairwise comparison for complexity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Pairwise Comparison for Levene's Transformed 9x9-Heterogeneity

Tukey's Honestly-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
B	LC B2 (NON-URUK)	-0.180	0.003	-0.324	-0.037

Table Appendix 3.14. Results of the Tukey's HSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.

Fisher's Least-Significant-Difference Test					
PHASE$(i)	**PHASE$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
A	LC B2 (NON-URUK)	-0.118	0.038	-0.230	-0.007
B	LC B2 (NON-URUK)	-0.180	0.000	-0.270	-0.091
B	LC B2 URUK	-0.116	0.007	-0.199	-0.032
EB	LC B2 (NON-URUK)	-0.185	0.017	-0.337	-0.034
LC B1 (LOCAL)	LC B2 (NON-URUK)	-0.172	0.002	-0.280	-0.065
LC B1 (LOCAL)	LC B2 URUK	-0.107	0.041	-0.210	-0.005
LC B2 (NON-URUK)	Medieval	0.153	0.035	0.011	0.295

Table Appendix 3.15. Results of the Fisher's LSD pairwise comparison for 9X9 heterogeneity. Only significant results listed ($p < 0.05$). All other comparisons not listed did not meet the level of significance.