Central Asian Economies And Ecologies In The Late Bronze Age: Geometric Morphometrics of the Caprid Astragalus And Zooarchaeological Investigations Of Pastoralism

Submitted by Ashleigh Francis Haruda to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Archaeology in November 2014

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

Sheep and goat formed the foundation of pastoral activity across the Central Asian steppe through the Bronze Age. Theories of pastoral activity have assumed that flocks were uniform in association with ethnic groups that crossed the steppe with new ceramic forms and technologies. This study investigated differences between flocks of sheep and goat across the eastern Kazakh steppe in the Late and Final Bronze Age to elucidate the potential for animal exchange and mobility.

Geometric morphometric techniques were applied to archaeological astragali from *Ovis aries* and *Capra hircus*. The methods for measurement and analysis were carefully developed to control only for inherited characteristics that relate to environmentally driven adaptations in the movement of the hind limb. Efficiency of movement in this limb is tied to survival and reproductive success of animals. Specimens were selected from three archaeological sites located in different ecozones across the steppe to maximize ecological variability. Geometric morphometric results revealed that flocks of sheep exhibited unique astragalus morphology, indicating that crossbreeding and exchange did not occur between sites.

These sites were also subjected to full zooarchaeological analyses to investigate variability of economic subsistence patterns. The total number of species as well as investigations into survival and skeletal body part representation revealed that each site had unique subsistence patterns that were related to local ecological resource availability, despite material culture links. This variability in subsistence patterns and flock uniformity indicate that animal trade was not a feature of steppe networks. Local lifeways were specific to small patches of the steppe, despite overarching shared material cultures.

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Chapter 1: Introduction

The 'inherent' mobile nature of pastoralism has been used to explain the similarities of burial customs and material culture across the steppe in prehistory (Kuzmina 1994, 2003, 2008, Salzman 1980). Zooarchaeological research from Central Asia before the fall of the Soviet Union was largely relegated to species lists in the palaeozoological tradition, often with palaeontologists and biologists providing analysis of zooarchaeological data (e.g. Tutkova 2001). Horse domestication, as well as investigations of secondary products exploitation, form the main body of zooarchaeological research by western researchers (Anthony and Brown 2003, Bendrey 2011a, 2011b, Benecke and von den Driesch 2003, Frachetti and Benecke 2009, Koryakova and Hanks 2006, Levine 1983, 1990, 1999, Morales Muniz and Antipina 2003, Olsen 2003, Outram and Kasparov 2007, Outram *et al.* 2009, 2011, 2012). Only recently with the interdisciplinary application of scientific approaches in archaeology are essential assumptions about mobility and ethnic exchange tested (Bendrey 2011a, Lightfoot *et al.* 2014, Ventresca Miller *et al.* 2014a and 2014b). This project follows in this interdisciplinary mode by utilising traditional zooarchaeological methods in combination with geometric morphometric methods to test assumptions about animal exchange, mobility, and ethnic migration across the steppe. This thesis seeks to explore the variability of ovicaprid landraces between three sites from the Late and Final Bronze Age in the eastern Kazakh steppe.

A lack of a historical narrative has reduced steppe cultures to uniform vectors between the civilizations of the east and west, tainted by their liminal location (e.g. Abramson 2003, Said 1978). Historical events that originated from the steppes, such as the conflict between the Hsiung-nu nomads and the settled Chinese, were characterised by the settled as uncontrollable acts of nature, robbing the steppe peoples of agency and stereotyping them as peripheral parasites (The Book of Han in Torday 1997). This characterisation of steppe people as peripheral to settled society has endured through to contemporary studies of pastoralism (Barfield 1989, Lattimore 1940,1994, Khazanov 1984, Salzman 2008). More recently, this stereotype has come under attack for the lack of specificity and agency accorded to those under study (Bendrey 2011a, Frachetti 2004, 2008, Hanks and Linduff 2009, Outram 2012, Spengler 2013, Stark and Rubinson 2012, Ventresca Miller 2013). These works suggest that a more accurate characterisation of the steppic peoples and their interaction with each other is to imagine an immense diffusion of material culture, each with a unique subsistence economy that responds to a specific ecozone within this vast region.

Regional analyses of settlement sites across the steppe have suggested that economic responses were localised and specific, but linked by an overall uniformity of material culture and simultaneous widespread adaptation to new technologies (Outram *et al.* 2012, Ventresca Miller *et al.* 2014a, 2014b). Uniform material culture change across time has traditionally been attributed to ethnic migration in the culture history model of Central Asia prehistory (Kuzmina 1994, 2000, 2004, 2008). Attendant with material culture change are associated changes in languages, technology, and animal populations (Anthony 2007, Balaresque *et al.* 2015, Kuzmina 2008). Therefore, according to this model, material culture change in the Bronze Age should indicate a complete repopulation of the steppe by uniform morphotypes of ovicaprids that are associated with a new ethnic group.

The viability of pastoralism without the presence of settled agricultural centres has been questioned by theorists such as Khazanov (1984), who suggest that pastoralists must act as parasites on fringes of settled civilisation in order to have access to the products of settled civilisations, such as metal and grain. Yet recent research has suggested that pastoralists also practised agriculture alongside mobile forms of pastoral activity (Rosen *et al.* 2000, Spengler, Chang, Tourtellotte 2013, Spengler Frachetti, Fritz 2013). Indeed a variety of subsistence strategies may or may not be used as necessity demands. Pastoralists may practice agriculture (Spengler, Chang, Tourtellotte 2013, Rosen *et al.* 2000), and agriculturalists may practice pastoralism and even hunter-gatherers may practice informal pastoralism by managing the herds of the animals that they hunt (Ingold 1980). Cultural knowledge of famine foods, such as the edible seeds of *Chenopodium* sp., was widespread ethnographically and individuals may exploit this knowledge as the need arises (Shayakhmetov 2006).

Pastoralism is a sophisticated subsistence strategy. Animals are the medium that transmute grass into nearly all the necessities for subsistence, from food to leather, wool, felt, rope, and bone tools (Stark and Rubinson 2012). In Central Asia, ovicaprids are the most ubiquitous vectors that transform grass into consumable animal products (Anthony and Brown 2003, Bendrey 2011a, 2011b, Benecke and von den Driesch 2003, Frachetti 2009, Frachetti and Benecke 2009, Koryakova and Hanks 2006, Levine 1983, 1990, 1999, Morales Muniz and Antipina 2003, Olsen 2003, Outram and Kasparov 2007, Outram *et al.* 2009, 2011, 2012, Spengler, Chang, Tourtellotte 2013, Spengler, Frachetti, Fritz 2013.).

New methods are required in order to test whether flocks of ovicaprids were of a uniform morphotype. Distinguishing different types of animals that are adapted to the local environment is difficult archaeologically. Most breed types are defined by characteristics that do not survive, such as coat colour, wool type, and body conformation. Other characteristics, such as skull shape, are useful if complete and undamaged skulls can be recovered intact. Unfortunately, complete skulls are rarely found in archaeological contexts.

As animals inhabit specific ecozones, their ability to thrive and pass on their genes is determined by their phenotype's suitability to that particular environment. Animals that are resistant to heat and carry coarse wool would tolerate the hottest summers of the arid steppe in which alpine sheep would falter. So too would the efficiency of movement have an effect on survival: constant movement for forage was critical. Animals on the semi-arid and arid steppe would have to cover great distances to find sufficient fodder. Conversely, animals in vertiginous slopes would benefit from agile joints to reach high summer pastures. Over time, attrition, likely in combination with human selection, would have favoured flocks fit for particular ecozones.

Attempts to track animal breeds or changes in animal populations over time have traditionally focused on the size of animals using the withers height (the height at the shoulder), ratios of linear measurements and scaling methods (Albarella 1997, 2002, Albarella *et al.* 2005, 2009, Albarella and Payne 2005, Davis 2000, in press, Holmes 2014, Johnstone 2004, Popkin *et al.* 2012, Sykes *et al.* 2013, Thomas 2005, Thomas *et al.* 2013). Bone size has been used successfully to track changes in animal size and shape that have been tied to the development of new landraces (Albarella 1997, Albarella *et al.* 2009, Thomas *et al*. 2013). Changes in animal size are most apparent across broad expands of time and measures of variation can display size dimorphism (Popkin *et al*. 2012), but the number of morphotypes and their specific conformation is not determinable from this type of study. Furthermore, landraces that vary by shape from a similar landrace will not be detected by explorations of size.

Changes between sites within a shorter timeframe are harder to interpret and detect. For example, a study of variation through the Saxon period of assemblages in the UK found that while there was a size change in sheep, this change was not conclusive evidence for different landraces of sheep (Holmes 2014). Other studies of animal morphological change (e.g. Albarella *et al.* 2006) found some evidence for a change in animal morphotypes through time. At Launceston castle, sheep and cattle increased in size from the medieval to the post-medieval period. A slight change in the slenderness of cattle metapodials, detected by ratio methods, in the post-medieval period was interpreted as a change in the breeding stock of cattle (Albarella *et al.* 2006). Yet the shape change noted by this research is in a bone which can be affected by ontogenetic variables which can overwhelm inherited traits (Chapter 4).

The size and shape of a bone is dependent upon phenotypic and ontogenetic variables. Ontogenetic variables will affect overall bone shape, but have a greater effect on size (Sykes 1983, Young 1988). Long bone growth is dependent upon longitudinal growth at the growth plates that is determined by a variety of factors after birth which can confuse phenotype (Young 1988). For example, the most obvious size variabilty is driven by testosterone. Ovicaprid males are larger than females, and sometimes larger than castrates, depending upon the measurement in question and the timing of the castration. As testosterone, or lack of it, is critical to bone growth, the effect of sex can obscure patterns between breeds (Popkin *et al.* 2012). Furthermore, while specific bones can be sexed (e.g. Wilson *et al.* 1982), they are often fragmented or inconclusive, making interpretations of hormone driven size difference difficult. Testosterone, as well as a number of other factors (Chapter 4), interferes with bone growth, especially along the length of the bone. This size variation can distort inherited phenotypic shape variation, reducing the efficacy of methods that utilise size measurements.

While new research utilising metric measurements with more advanced statistical methods is promising in detecting long term size change through a region (e.g. Sykes *et al.* 2013), a method which exclusively measures significant variation in shape is a much simpler way to detect morphotypes within a narrow band of time. Geometric morphometric methods (GMM) offer such a solution to remove size.

In traditional metrical analysis, size variation can account for up to 95% of variation (Klein *et al.* 2010) which can hide intra- and inter-group shape based structures. By removing size as variable, phenotypic variation is the only variable that is explored, allowing much clearer investigations of inherited characteristics. Furthermore, descriptive statistical analyses such as principal component analysis (PCA) and canonical variate analysis (CVA) can describe and evaluate variation between morphologies. This makes GMM ideal to confirm flock heterogeneity across the steppe.

The strategies for human subsistence and, furthermore, the creation of economic surplus are many and varied, and rarely inflexible. Despite visions of uniform seas of grass, the steppe ecosystem is filled with ecozones and each provides a unique assortment of resources, be it water, pasturage, shelter, or wild foods. These ecozones and the gradated ecotones in between demand specialised knowledge in order to survive and thrive. Such an ecologically variegated landscape is not congruent with a uniform animal exploitation pattern and flocks of uniform morphotypes as suggested by the culture history model traditionally applied to Central Asian archaelogical contexts.

1.1 Archaeological Sites

The sites that were selected for this study are located in a variety of ecozones across the eastern Central Asian steppe between 75 degrees and 78 degrees longitude. The steppe extends from the Danube to the Great Wall of China (Kuzmina 2008), from the Black Sea to eastern Mongolia (Spengler 2013, Stark 2012), or from the Ukraine to the Pacific Coast (Masson and Taylor 1989) depending upon the source cited. The uniform definition of the steppe is a grassland with a continental climate and less than 500 mm of precipitation per annum (Kuzmina 2008, Spengler 2013). This broad definition of the steppe zone encompasses a variety of precipitation rates, soil types, topography, and plant communities (Dincauze 2000).

The Central Asian steppe, which encompasses the Kazakh steppe, also includes the drainage of the Amu and Syr Darya in modern day Uzbekistan. The Central Asian steppe does not have the rich productive black chernozem of the steppe further west in the Ukraine. Instead, the soil is a dark-chestnut or chestnut soil with high salt content, which encourages the growth of xerophytes such as *Artemesia* sp. (Dergachev 1989). This woody scrub is ubiquitous across the Central Asian steppe, and is only relieved in small patches around rivers and lakes or in microregions in which precipitation is above average.

The Kazakh steppe comprises most of the landmass within the boundaries of the modern country of Kazakhstan. Clear ecozones emerge on a north to south gradient defined by precipitation and soil type as well as surface contours and resources (Kuzmina 2008, Spengler 2013).

Above 51 degrees latitude is the forest-steppe, characterized by patches of birch and pine, interspersed with patches of steppe grassland and laced with watercourses and lakes. The soil that underlies this region is rich dark-chestnut chernozem which retains water. Further south, the soils become lighter and have a reduced ability to retain water. The majority of precipitation south of 51 degrees latitude is lost to evaporation (Kuzmina 2008, Spengler 2013).

Between 51 and 49 degrees latitude is the semi-arid steppe which is comprised of a patchwork of smaller ecozones with varying proportions of grass and scrub species. In the hilly region of Saryarka near the city of Karaganda, the underlying soil is a chestnut-brown and a floral community of fescue and feather grass steppe (Esnazarova 2000). Small local variations occur in alluvial valleys which are rich in vegetation while hilltops are bare (Kuzmina 2008). Localised uprising of granite and small hill ranges such as the Kent mountain range, provide windbreaks (Ivashenko 2008). These small mountain ranges have relic pine, birch and aspen forests with accompanying sylvan faunal species. The surrounding semi-arid steppe is host to a variety of wild ungulates and steppic fauna (Ivashenko 2008).

Between 49 and 46 degrees latitude is the arid steppe, defined by a severe lack of rainfall. The soils in this region are uniformly grey-brown and do not support plant communities year round. Spring rains and snowmelt bring annual grasses and flowers to the surface, but this growth soon disappears in the extreme aridity that is constant for the remainder of the year (Ivashenko 2008).

South of 46 degrees latitude is the alluvial plain which drains the Tien Shan mountains. This region, which stretches alongside the southern border of Kazakhstan, is called the Semirech’ye and is fed year-round by glacial melt and springs from the Tien Shan. These rivers drain into the half saline and half freshwater Lake Balkhash to the north. To the east of the Semirech'ye is a pass through the mountains along the Ili River to the steppes and deserts of Western China and Mongolia. This pass is a natural channel for animals and people north of the Tien Shan (Goriachev 2004).

The ecozone of the Semirech'ye is complex, and may more precisely be imagined as a mosaic of small localised ecozones with ecotones in between (Rosen *et al.* 2000, Spengler, Chang, Tourtellotte 2013). Lush vegetation along the rivers is strikingly different from the plant communities to the north in the semi-arid and arid steppe as well as from the alpine meadows and forests in the Tien Shan foothills and peaks. The brown chestnut soils of the mountains and riparian environments are in stark contrast to the grey-brown dry soil of the rest of the Semirech'ye (Esnazarova 2000). The biodiversity of the Semirech'ye is the greatest in Kazakhstan, as plant and animal communities vary orographically from alpine forest species to arid communities in a 70 kilometre north to south range. Ecozones on the edge of the Semirech'ye are considerably different than ecozones in the foothills. As Spengler describes, 'In the territory of Semirech'ye, lowland semiarid and arid steppe zones yield a mosaic of saline surfaces, exposed sandy soils, *Artemisia* and dry-grass patches, rock outcroppings, and springs and riparian areas' (Spengler, Frachetti, Fritz 2013, 129).

There are few pollen data from the steppe and desert zones in Central Asia. Data for palaeoclimatic reconstruction originate from sediment cores sampled from Lake Baikal in Siberia. Analyses of these samples are based upon European models (Khotinskiy 1984 and Krementski 1997 in Rosen *et al.* 2000). Interpretations of data roughly correlate with each other and agree that there was a warming trend with a maximum at 2000 BCE. There are contradictory interpretations regarding the climate change at the end of the Final Bronze Age which is approximately the middle of the first millennium B.C. (Krementski 1997 and Khotinskiy 1984 in Rosen *et al.* 2000). It is unclear what change occurred after the drying trend reached its peak around 800 BCE (Late Suboreal). Khotinskiy (1984) interprets the pollen data as a transition into warmer and wetter period while Krementski (1997) suggests the development of a warm and arid period. This discrepancy does not affect this research, which is restricted to sites dated before the peak of aridity at 800 BCE. Furthermore, these palaeoenvironmental models are from Siberian data using European models. Kuzmina points out that these models may not apply to the Eurasian steppe, and that they do not account for local ecological variation (Kuzmina 2008). She further notes that these climatic fluctuations would likely have affected the spread of forests south at the forest-steppe border much more than the grasslands of the steppe, which are adapted to shifting precipitation and humidity levels (Kuzmina 2008).

The sites in this study were chosen for their locations in a variety of ecozones within the steppe zone in eastern Kazakhstan. Serektas and Turgen vary considerably by respective ecozones, despite their location within the Semirech'ye. Serektas and Kent are located in similar ecozones with limited precipitation but are over 500 kilometres apart and have access to different types of water resources and forage. All sites are dated by ceramic typologies to the Late and Final Bronze Age. Each site has its own particular suite of ceramic typologies and funerary customs which determine the date range for habitation. The ceramic typologies form only part of the archaeological cultures of the steppe region. Funerary traditions which include burial type, orientation, and associated artefacts, form a major part of the definition of specific archaeological cultures in the Soviet tradition. The architecture of settlement sites does not influence the definition of archaeological cultures in the Late

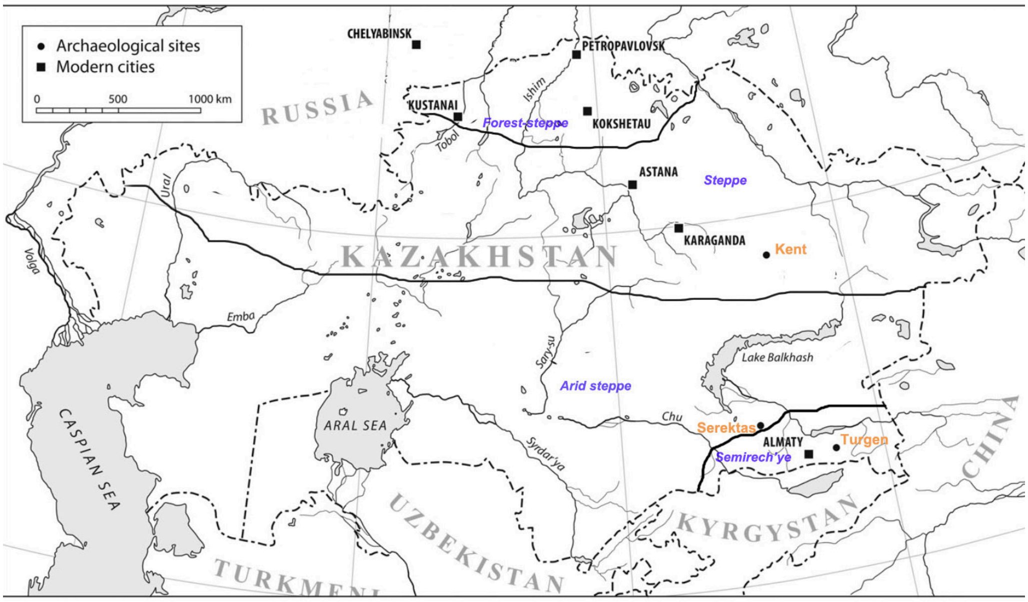


Figure 1.1 Map of sites in Kazakhstan located in approximate ecoregions. Map after Outram *et al.* 2012 with permission. Ecological data from Schwartz and Maclean 2010.

and Final Bronze Age, although they are crucial for earlier Bronze Age culture definitions (e.g. Anthony 2007, Hanks 2000).

1.1.1 Kent

Kent is located at 925 metres above sea level in a river valley within the Kent mountain range on dark chestnut dry soils (Figure 1.1). The river valley is flat bottomed and leads out onto a hilly semi-arid steppe. The Kizlykinesh River is next to the site, while Lake Karasor and wetlands are located 60 kilometres to the north. The highest peak of the Kent mountain range is located at an altitude of 1469 meters above sea level and the range is a granitic mountainous outcrop in the a dry fescue- feather grass steppe. Within this small area there are a wide variety of trees that are relics from the last glacial period in the Pleistocene. Sylvan species flourish in the Kent mountain range, such as pine, birch, and aspen. Other woodland plants include the raspberry, stone berry, black currant, wintergreens, barberry, onions, and a wide variety of woodland mushroom species. Woodland animals, such as deer and squirrels, are native to this region

Figure 1.2: Site plan of Kent. Specimens taken from Excavation (раскоп) 11 in the centre of the site (plan provided by V.V. Varfolomeev).

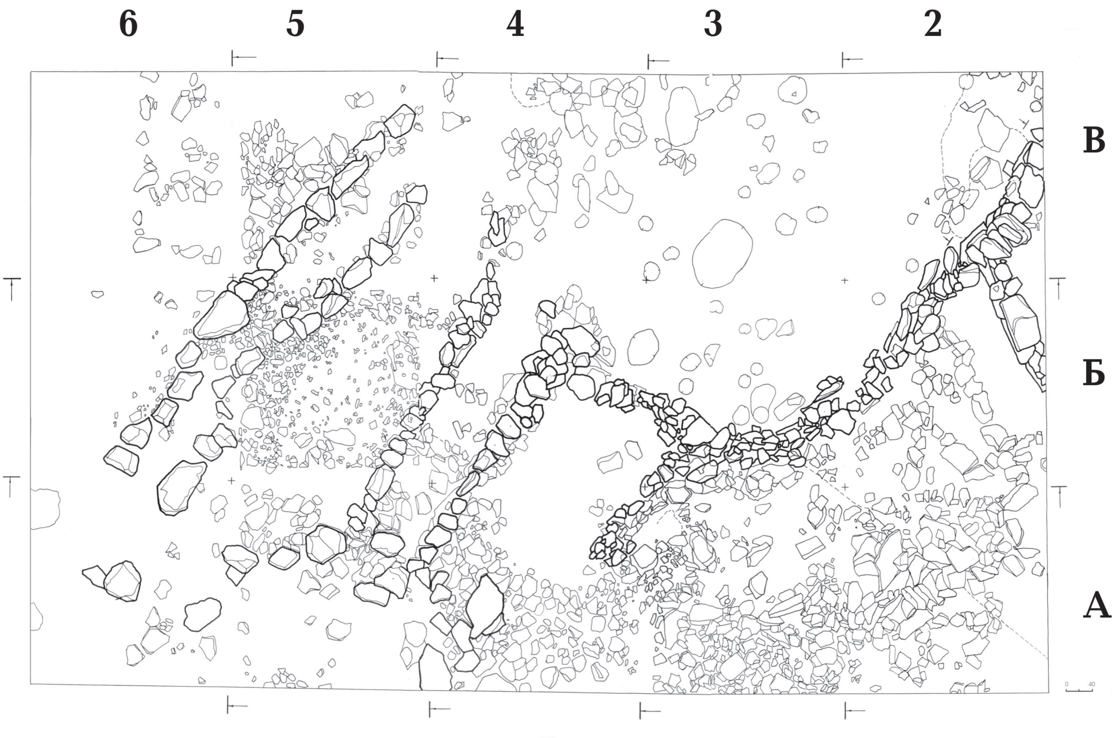


Figure 1.3: Site plan of Serektas (plan provided by A.S. Ermolaevna)

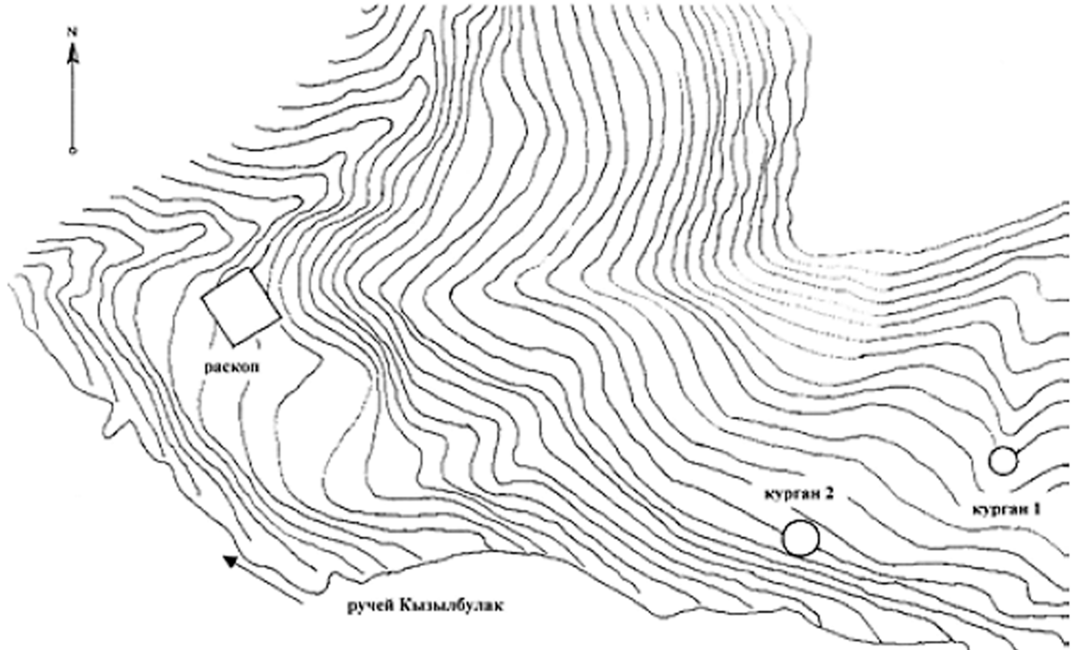


Figure 1.4: Site plan of Turgen. Excavation is at (раскоп) to the left (plan provided by A.A. Goriachev).

largely because of the constant availability of water in local lakes and rivers (Ivashenko 2008). Copper deposits are known in the region today (Schwartz and Maclean 2010).

Kent is a large Final Bronze Age settlement (13th to 9th centuries BCE) from the Begazy-Dandybaevsky material culture group (Epimakhov 2005, Evdokimov and Varfolomeev 2002). This settlement site is large compared to other settlements in this region and is composed of 130 pit houses within the 15-hectare site. Open cast mines and kurgans (e.g. Akimbek) surround Kent, but cluster towards the west where the Kizilkinesh River spills onto the steppe. Due to its scale, density of settlement, and metallurgical extraction, it may well have represented a significant regional centre (Evdokimov and Varfolomeev 2002). Few human skeletons have been recovered from Kent itself. The surrounding kurgans have provided most of the skeletal and funerary assemblages for dating purposes.

The animal bones for this study are from Excavation 11. This excavation focused on the examination of a large platform and surrounding walls in the centre of the site (Figure 1.2, Varfolomeev, pers. comm.) Alongside a large amount of animal bone, numerous ceramic fragments from the Begazy-Dandybaevsky culture were recovered. Multiple, elaborately carved, bone tools and ornaments as well as bronze artefacts were also recovered for which a use is not yet known.

1.1.2 Serektas

Serektas is located at 776 metres above sea level in the semi-arid steppe on the edge of the Semirech'ye region near a seasonal stream and underlain by grey-brown dry soils which do not retain precipitation (Figure 1.1). Serektas is nearly flat, with small undulations in the steppe stretching away south to the foothills of the Tien Shan for 100 kilometres. One hundred and fifty kilometres north are the shores of Lake Balkhash. The environment is open, with no trees or shrubs, and only occasional outcroppings of rock.

This site is located approximately 17 kilometres from the site of Tamgaly, which is a large petroglyph site with a history of use from the Bronze Age to the modern period (1500 BC- AD 1900) (UNESCO 2004). Serektas lies outside of the UNESCO boundaries for the Tamgaly complex and outlying settlement sites. There are no C_{14} dates from Serektas; instead ceramic typologies locate Serektas in the Late and Final Bronze Age in the first half of the second millennium BC (Ermolaeva pers. comm.).

A. Maryashev excavated Serektas in 1999 and work was continued in 2000 and 2001 by A.S. Ermolaeva (Ermolaeva 2000, Ermolaeva 2001). All excavations focused on the clearance of a pit house with multiple stone foundations and mud brick wall (Figure 1.3). Habitation levels and pit fills were located inside the house (Figure 1.3, Ermolaeva 2001). Finds from these cultural contexts include not just animal bone, but also charcoal and ceramics (Ermolaeva 2000, 2001). A previous zooarchaeological report was conducted by L.A. Tyutkova, a palaeontologist at the Siberian Academy of Sciences (Tyutkova 2001). As only species were recorded in this previous study, data are not directly comparable with that found by this author, but NISP proportions were broadly similar.

1.1.3 Turgen

Turgen is located in the Turgen mountain ravine in the foothills of the Tien Shan Mountains in the Semirech’ye region and underlain by dark chestnut mountain soils (Figure 1.1). The Turgen ravine is a complex environment at 1900 meters above sea level. The ground is rocky and vertiginous, and patches of pine and aspen line the mountain slopes. The nearest flat grazing is at the mouth of the ravine, sixteen kilometres away.

The site is located in the upper part of the ravine in an alpine meadow and surrounded by patches of spruce. Birch, willow, and poplar line these river valleys that descend onto the alluvial plain that drains into Lake Balkhash (Dzhanyspaev 2008, Goriachev 2004). Local animal populations include alpine species such as the snow leopard (*Panthera unica)* and brown bear (*Ursos arctos*) as well as species that inhabit both alpine meadows and the alluvial plain, such as red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*).

Ceramic typologies and archaeomagnetic dating of hearth features date Turgen to the Late and Final Bronze Age (1500-800 BCE) in two separate phases. Detailed stratigraphic relationships between these two levels are not yet available. Ceramics from these two levels are similar to the ceramics from nearby settlement sites in the Semirech'ye such at Talapty I, but are also similar to ceramics from Sargaryn and Dongal which are located in the semi-arid steppe of central Kazakhstan. The Central Kazakhstan material cultures of Sargaryn and Dongal date from the 13th to 9th centuries BCE (Loman 1986, Evdokimov 1987) and the ceramics from the Semirech'ye site of Talapty date to the Final Bronze Age (13-9th centuries BCE).

The settlement at Turgen is a series of rectangular pit houses ranging from 8x8m to 10x10m dug into a southern slope that open to the north (Figure 1.4). Each house had a central hearth, surrounded by storage pits. Storage pits were also located outside of the houses. In the fill of these pits were domestic items such as mortars, pestles and quern stones (Goriachev 2011).

Turgen is associated with two burial monuments a few thousand metres upstream, Kyzlbulak I and II (Figure 1.4). These burial features are the highest archaeological monuments from the Bronze Age in this ravine, and are typical of the local burial traditions. The kurgans are timbered burial chambers to house funerary remains and enclosed on the surface by an ellipsoid of stones. A mix of cremated remains and inhumations are buried along with ceramics and bronze jewellery. Goriachev (2004) suggests that this mixture of artefacts and burial types is unique to the highlands of this eastern end of the Tien Shan Mountain range. Burial sites at this altitude are usually located near pastures still in use today, evidence of the pastoral nature of the subsistence economy (Goriachev 2004). The burial artefacts suggest the influence of the Fedorovo material culture, which originated in the foothills of the Altai in eastern Kazakhstan, as well as the influence of the local Kulsai ceramic and metalworking traditions. The Kulsai archaeological culture originated much higher up the Tien Shan, in modern day Kyrgyzstan, which also dates to the Late and Final Bronze Age (16th-9th centuries BCE) (Goriachev 2004). There are no ceramics of the Talapty, Sargaryn, and Dongal tradition these funerary contexts. This combination of ceramic and artefactual forms creates a unique funerary assemblage that is specific to this microregion of the Semirech’ye.

The principal investigator concludes that Turgen was in use through the Late and Final Bronze Age based on ceramic typologies despite evidence for earlier hearth features as identified by the archaeomagnetometry. It is likely that there was habitation at the site throughout the Late and Final Bronze Age, and the ceramic traditions that make up the infill of the settlement are from the final period of inhabitation.

1.2 Conclusion

The local availability of water, forage, and shelter would encourage different economic strategies (Bendrey 2011a, Frachetti 2008, Spengler 2013). This has been demonstrated by investigations into zooarchaeological remains (Bendrey 2011a, Outram *et al.* 2012) as well as with palaeobotanical work (Spengler 2013). Spengler suggests that due to the high variation in resource availability that regional populations came into contact at locations of shared resource catchments (Spengler 2013). The human utilisation of specific environmental resources in specific locations directed social exchange and community links, as well as shape economic exploitation patterns (Spengler *et al.* 2013b).

In the next chapter, the archaeological background of Central Asia is explored. Theoretically, social evolutionary thought is still influential for defining culture histories. New investigations that involve ecofacts- such as palaeobotanical, zooarchaeological, and isotopic studies are refining ceramic typology based culture definitions. Radiocarbon dating is more precisely locating cultures on a timeline that is not reliant on typological lineages.

Chapter 3 presents the zooarchaeological evidence at the three sites chosen in Kazakhstan. Identified and fragmentary material for all recovered bone material is presented as well as taphonomic data. Each of the three main domesticated species, *Bos taurus, Equus caballus,* and ovicaprids are examined in detail. This includes skeletal part abundance and survivorship patterns.

Chapter 4 introduces the background of geometric morphometric analysis and delves into the background to the biological variables which affect bone size and shape which must be eliminated or controlled for in this study. The astragalus and corresponding landmarks are chosen with reference to these variables and the methodology for capturing GMM data is described in detail.

The results of the GMM analysis at all three sites for sheep and goat astragali specimens are presented in Chapter 5. Each site is examined for intra-site variation between all specimens and within species groups using principal component analysis. Intersite comparisons between all sites and species in combination are analysed with principal component analysis and a canonical variate analysis.

The results of the zooarchaeological and GMM analyses are discussed thoroughly in Chapter 6. Speciation and significance is discussed for the GMM results. Morphological variation is interpreted with relation to functional morphology and earlier examinations of post-cranial morphology in relation to palaeohabitat. The zooarchaeological results are discussed in full, both by site and by region. The variations in pastoral activities at each of these sites are apparent and in comparison with regional data reveal economic, ecological, and cultural trends in subsistence economies.

In Chapter 7, all of the strands of the above analyses are drawn together to address if the exchange of *Ovis aries* across steppe was concurrent with material culture exchange in the Late and Final Bronze Age to support or reject the culture history model.

Chapter 2: Archaeological Background

The Bronze Age of the Central Asian steppes is bookmarked at one end by a paucity of Eneolithic settlement sites and a profusion of large and rich Iron Age kurgans. The Bronze Age roughly runs through the third and second millennium BCE to the development of the Iron Age cultures of the Scythians, Sarmatians and the Saka/Wusun cultures that date from the middle of the first millennium BCE (Herodotus and The Book of Han both in Torday 1997). In this large span of nearly two millennia, metal technologies were introduced to the steppe and social complexity waxed and waned.

The suite of domestic animals of steppe peoples remained the same throughout this period. Horses had been domesticated at the northern edge of the steppe around 3500 BCE (Outram *et al* 2009) and are omnipresent at settlement and funerary sites. Cattle and ovicaprids are also present at all sites. Domesticated dog and camel also appear in small numbers at nearly every site. These six domesticated species formed the basis of the subsistence economy.

Agriculture is indirectly signposted by finds of querns and grinding stones at settlements sites such as Sintashta (2040-1700 BCE) and Turgen (1300-900 BCE). The only direct evidence of the cultivation for domesticated wheat and millet in the Bronze Age is from a cremation dated to the latter half of the third millenium (Frachetti *et al.* 2010). While there is direct evidence for the cultiavation of domesticated wheat, millet, and rice in the Iron age, particularly in the Semirech'ye, it is unclear how extensive agriculture was practiced in the Bronze Age (Jones *et al.* 2011, Lightfoot *et al.* 2013, Motuzaite-Matuzeviciute *et al.* 2013, Rosen *et al.* 2000).

The degree of interaction between people both within and across the steppe is a long disputed. Material cultural change in the archaeological record has been attributed to the immigration of new peoples by those who subscribed to the culture history model (Chernyk 2009, Kuzmina 2008). More recent arguments point to heterogeneous localised traditions that share an overarching homogenous material culture which change due to the diffusion of material culture (Frachetti 2009, Lightfoot *et al.* 2014, Spengler *et al.* 2013, Ventresca-Miller 2013, 2014a, 2014b).

During the course of the Bronze Age, settlement and funerary forms changed drastically, from ephemeral settlements and small kurgans in the Early Bronze Age, to large fortified towns with large oligarchical kurgans in the Middle Bronze Age, and finally return to single-phase small settlements and small, localised cemeteries in the Late and Final Bronze Age (Anthony 2007, Hanks and Linduff 2008, Kuzmina 2008).

2.1 Nomads in Theory

Pastoralism is a mode of subsistence that relies upon the primary and secondary products of ruminant animals (Chang and Koster 1986, Lefébre 1977). The form of this mode varies through environments and cultures in a bewildering array of unique subsistence patterns. Often mobility is assumed to be inherent characteristic of pastoral subsistence activities and pastoralism is at times interchangeable with nomadic pastoralism (Clutton-Brock 1989b, Harris 1996a). Yet mobility is not a uniform characteristic of pastoral societies and conversely mobile societies do not always practise pastoralism (see Rosen 2008 and Wendrich and Barnard 2008 refute Cribb 1991).

Rooted in the theoretical writings of Gordon Childe (1965), pastoralists have long been considered a step along the social evolutionary path. Pastoral nomads are located on this linear path above loose bands of foragers but below the more socially complex sedentary agricultural societies. This model was based upon degrees of vertical hierarchy, assuming that social complexity derived from the development of vertical power structures (Chernyk 2009).

The archaeology of pastoralists, particularly within Central Asia, has long shown that the data do not completely fit with these theoretical models. The excavations of large complex settlements, such as Kent and Arkaim raise questions about the applicability of social evolutionary theories to physical archaeological contexts (Hanks 2009, Lightfoot *et al.* 2014, Evdokimov and Varfolomeev 2002). Modern archaeological studies that integrate scientific techniques such as isotope analysis are revealing that Central Asian pastoral subsistence strategies may in fact be a local adaption that was endlessly repeated and reproduced with slight modifications for microclimate across the whole of the larger environmental clime of the steppe rather than an indication of social complexity (Ventresca-Miller 2013, Spengler 2013, Spengler, Frachetti and Fritz 2013).

2.1.1. Culture History

The archetype of the mounted steppe warrior, riding across the steppe, followed by his family, yurt, and flocks, is one that has endured. Idealised as an adventurous raider of innocent farming peoples, the nomad has a hold on the modern imagination that has proven hard to shake, despite increasing archaeological evidence to the contrary. Our latest conception of pastoral nomads is a varied and much more complex ideal. We now think of nomads as not just exploiters of animals, but also as metalworkers, potters, and even agriculturalists. These people may or may not have moved extensively through their environment, but we assume that their mode of subsistence was above all resilient in times of economic or environmental stress.

The history of the study of pastoralism is largely an etymological exercise which traces how people have attempted to define and classify a group of people who are primarily economically based upon animal products and incorporate a degree of mobility into their cultures to accommodate their animals' needs for fodder.

In Central Asian archaeology, the logical place to start is with Marxist archaeology. The famous economic theorist penned a manifesto of class revolution (1867) and his contemporary, Engels, wrote about the development of human society through history (1884). Marxist historical theorists drew on Engels (1884) to develop a social evolutionary theory of history that progressed along an evolutionary trajectory of increasing social hierarchy and complexity towards the climax of communism (Trigger 2007). The divisions of the human past are based upon inherent social conflict in the human experience which drives social change from within cultures (e.g. Rodvinkas 1930). The Palaeolithic is imagined as an ideal egalitarian society, which was quickly abandoned once agriculture and settlement developed. The creation of capital led to the creation of social ranking and conflicts between classes naturally arise. This Marxist interpretation of history, which largely views the past through an economic lens, is a technique for discerning social complexity.

Gordon Childe was an influential archaeological theorist who lived in the early part of the twentieth century. Rather than excavate sites himself, his strength lay in synthesizing the finds from across Europe, Egypt, the Middle East and India. His many books laid the foundation for a new approach to archaeology and anthropology that was highly influential on both sides of the Iron Curtain (Childe 1923, 1925, 1929, 1965). Childe was heavily influenced by Marxist social theory to describe history in terms of social stratification, and he synthesised the structural implications of Marx's interpretations of history. Childe used this structure to define critical boundaries between the Palaeolithic and the Neolithic in terms of population, technology and social structure, stimulated was generated by economic surplus.

The ‘Neolithic Revolution’ defined by Childe in *Man Makes Himself* (1965), was driven by economic change and precipitated by the exploitation of resources, through the human manipulation of the natural world via the domestication of plants and animals. The changes in human social structure, such as permanent settlements and the appearance of ritual sites were predicated upon a change in the economic mode of production, which demanded a year round commitment to a particular location, but rewarded agriculturalists with a surplus of goods with which to trade or to store.

Childe's ideas regarding the Bronze Age were also critical for laying the groundwork for nearly all later archaeological theory about human social complexity- both how to describe it and how to study it. He postulated that the appearance of metal technology was only possible with the right conditions for its exploitation- long distance trade and agricultural economic surplus. The Bronze Age, with its booming population and agricultural societies, soon gave rise to an urbanised class of specialists, such as soldiers, priests and metal smiths sprang up to act as a middle class between the agriculturalists living around cities, and the oligarchy, which lived at the centre.

Childe identified the surplus with which social complexity increased throughout the past. By doing so, Childe laid the foundation for looking beyond the artefacts to elucidate larger driving forces and theories. Particularly influential was his idea that ceramic styles were representative of different culture types. As ceramic styles spread, this was indicative of the spread of a particular people who practiced a particular kind of culture. His Marxist explanation of the past was to prove extremely influential particularly in the archaeological circles of the U.S.S.R. (Mertz 2011).

Other critical theories that were to have later implications in the search for pastoralism in the archaeological record were, most significantly, the Soviet culture histories that developed to the east of the Iron Curtain. Working in an environment that was strongly influenced by Marxist social theory, the cultural historical approach is a model which is based upon human social evolution across the millennia (Trigger 2007). Culture history used a materialistic approach and attributed suites of material culture to ethnic groups located within a specific geographic region. Culture change was explained by the migration of ethnic groups into new areas, rather than by diffusion or internal change (Trigger 2007). Migration of groups into a new area could be clearly seen in the archaeological record with the appearance of new material forms, for example a new ceramic style.

Chernyk took a long sweeping view of pre-Iron Age Central Asia by dividing up the culture histories by metallurgical region, rather than by ceramic typology. Metallurgical complexes were delineated by region and time period, and encompassed multiple ceramic typologies within their limits. Cultures were associated with metallurgical centres of production, most of which were located in the western steppe (Chernyk 2009). Other culture historical traditions have been based upon ceramics found within funerary contexts (detailed in Ventresca-Miller 2013).

Metallurgical complexes and ceramic styles are descriptive, but culture histories imply the presence of ethnic groups. The adoption of different cultural forms is assumed to be an indication of migration of different peoples (Kuzmina 1994, 2008, Evdokimov and Varfolomeev 2002). Each culture history is associated with an ethnic group which practised specific funerary customs, spoke unique languages and even possessed unique physiognomy (Anthony 2007). Change does not originate within a culture, but instead is introduced by outside groups. External forces for change are easily imagined if pastoral peoples are also inherently mobile.

2.1.2 Core and Periphery

In response to changing research objectives of anthropology in the post-war period, ethnographical examples and ecological variables were included in the study of nomadic pastoralists. In the West, the element of nomadism was not a separate attribute of pastoral societies, but inherently assumed. Early processual theories of pastoral nomadism sought to define nomadic pathways and pastoral activities concurrently through ethnographic examples. Systems of rigid movement or exchange were discussed in volumes such as *The Nomadic Alternative* (Weissleder 1978) and *When Nomads Settle* (Salzman 1980).

Analyses of pastoralism in Greece and Africa (Dyson-Hudson 1980, Chang 1986) revealed an incredible complexity of social structures, herd management strategies, and ecological variables. Broader regional theories of understanding pastoralism in archaeological contexts were emphasised in the relations between the mobile pastoralists and settled agriculturalists (Salzman in Dyson-Hudson 1980). Rather than a focus on data collection, a trend emerged to define pastoral nomads in larger regional and theoretical terms that were largely relational in order to define an overarching social category rather than focus on local forms.

The delineation between the shepherd and the famer is critical with pastoral theory. In his book, *Nomads and the Outside World* (1984), Khazanov describes in extraordinary detail the varying kinds of pastoralism. Pastoralism is defined as an inherently mobile form of subsistence, as opposed to a settled form of agricultural subsistence (Khazanov 1984). The definitions of pastoral nomadism that Khazanov laid out were based upon a combination of Marxist ideals of social evolution and a focus on production in association with the Western preoccupation with mapping mobility. He created terms such as 'semi-nomadic pastoralism' and relegated forms of animal management that are practiced by settled populations into subsets of a form of pastoralism called 'transhumance'. Furthermore, Khazanov focused on the interaction between these various nomadic archetypes and settled populations. Khazanov characterises the nomadic pastoralist as a parasite, who must have contact with settled peoples for agricultural and manufactured products and cannot survive without these goods. Furthermore, the inherently mobile nature of pastoral peoples precludes their production of these goods. Khazanov sees pastoral nomadism as symbiotic. While agricultural peoples could live without contact from nomadic pastoralist, nomadic pastoralists must have contact with settled agricultural societies for survival.

His work takes the idea of the difference between the Steppe and the Sown (coined in 1928 in the book by Peake and Fleure) and specifies a firm boundary between the two types of subsistence. Khazanov’s theory is simultaneously both reductionist and expansive. By reducing economic subsistence strategies of mobile peoples to solely pastoral activities, the further classification of pastoralist activities must be based upon fine gradations of mobility, rather than subsistence. These micro-definitions based on peripheral mobility in relation to a settled agricultural centre were highly influential (Barfield 1989, Barnard and Wendrich 2008, Harris 1996b, Harmatta *et al.* 1994, Lattimore 1994, Litvinskii *et al.* 1996).

These theories and descriptions of pastoral nomadism which follow in Khazanov's wake further refine ever more intricate classifications of pastoral societies based upon their degree of mobility. Examples range from ethnographic examples in Mongolia to historical works written in civilised centres. These historical accounts describe the military attacks by pastoralists on the settled in language that renders these pastoralists barbarians, who are only seen as opportunistic raiders on the rich borderlands of these empires. (E.g. The Book of Han, Herodotus in Torday 1997).

Phil Salzman recognised that a dichotomy between the nomad and the settled was not necessarily an impenetrable boundary. He evaluated ethnographic examples in which tribes of pastoral nomads chose to settle or move. He explored the degree of resource utilisation and the amount of dependency on agricultural products which measured the degree of pastoral activity (Salzman 1980). While he acknowledged the range of variability in mobility and subsistence strategies, he maintained the boundary between the settled and the nomad (1980, 2008). He drew a line between livestock which are pastured on unimproved land and not foddered (pastoralists) and those which are penned and fed with supplementary fodder (livestock of settled agriculturalists). Conversely, he acknowledged that mobility is not a necessary requirement for pastoral activities.

Owen Lattimore was perhaps one of the earliest to discuss the dichotomy of the pastoral and the settled with reference to early Chinese history (Lattimore 1940). The influence of Mongolian pastoralists was greater on the agricultural society of Han China than that of Han China on the Mongolians. The mobility of pastoralists allowed them to act as vectors of Western technology and styles, introducing chariots and mounted warfare. As Lattimore saw it, the dichotomy was largely controlled by the incipient Chinese state around the all important northern frontier (Lattimore 1994). In his eyes, pastoralists were the ‘other’- characterised only by their carrying capacity between civilised centres.

Thomas Barfield expanded Lattimore’s line of research (Barfield 1989). He explored the boundaries between the early Chinese state and surrounding nomads by focusing on the interaction in the early common era between the Hsiung-nu nomadic confederacy and the incipient Han dynasty. His portrayal of the Hsiung-nu as the 'other' drew heavily on Khazanov's conception of a firm delineation between these two forms of subsistence strategy. He asserted that the pastoral nomads must attack sedentary societies in order to have access to agricultural products and manufactured goods. He dismissed the steppe as a potential centre of civilisation, and reframes pastoralists as fringe members of civilisations.

Elena Kuzmina crystallized this view of a dichotomy with her survey of the development of pastoralism on the Central Asian steppe from the Neolithic (6th -5th millennia BCE) to the early Iron Age (1st millennium BCE) (Kuzmina 1994). In her review of pastoralism across this broad time and geographical scale, she assumed that all of the sites were those of mobile nomads. With this assumption of pure mobile pastoralism, and her further conclusion that this pastoralism was a necessary step on the way towards the more advanced and complex agricultural sedentism, Kuzmina excluded all other subsistence strategies and mobility patterns.

While all of these theoretical characterisations of the pastoral nomads who lived on the borderlands on these great empires may have merit, they do not seem to accurately describe the peoples living far from civilisation centres. For all of these historical imaginings of the roaming nomad, archaeological evidence from settlement sites on the steppe clearly disproves this stereotype.

2.1.4 Heterogeneous Tessellation: Cosmopolitan interactions as markers of complexity

The latest pastoral research on the Central Asian steppe has come about in a struggle against rigid definitions of pastoralism and broad regional studies, as laid out in Khazanov (1984) and Salzman (1980). In a throwback to Dyson-Hudson's 1980 essay, complexity across many variables through this system of subsistence is recognized while rejecting the overarching definition of pastoral nomad. Furthermore, nomads are recognised not as the 'other' and may be, at various times, partially sedentary and practice agriculture. An acceptance of this has led to increasing attempts to separate the terms nomadic and pastoralism, exploring mobility and pastoralism separately in micro-studies (Frachetti 2008, Houle 2009, 2010, Ventresca-Miller *et al.* 2014a, 2014b, Spengler *et al.* 2013).

One of the seminal thinkers for this return is Nicola DiCosmo, whose 1994 essay on recognizing the complexity of nomadic interaction with the state raised questions about the feasibility of a dichotomy between settled agriculturalists and mobile pastoralists (DiCosmo 1994). DiCosmo questioned the feasibility of understanding pastoralism primarily as a mode of production. By pointing out that there was evidence for agriculture within ‘mobile' pastoral complexes, he called into question not only the mobility of these pastoralists, but also the necessity of viewing them in relation to sedentary peoples. By viewing steppe people independently, complexity across the vast swathe of pastoral complexes could more easily be defined and understood without the limits of a core-periphery structure and socio-cultural evolution. Instead pastoralism should be understood as a complex and multifaceted system that could contain its own multitudes.

David Anthony (2007) explored the reason for the settlement of previously more mobile cultures of the Abashevo in the Uralic steppe. By analysing available resources, such as ore deposits and desirable pastures, he approaches the development and change in archaeological culture from with a processual perspective. He postulated that the mining of ore for copper and tin from Central Asia, combined with the drying of the climate encouraged settlement and defence of limited winter grazing grounds. With this competitive stress came the demand for high value prestige metal goods, which was available from the mines in the southern Urals near the Tobol River. Hence, pastoralists did not become agriculturalists before exploiting metallurgical resources, as postulated in social evolutionary theory, but rather exploited natural resources while maintaining their pastoral character. This combination of ecological, technological, and social analysis at a micro-level informs the macro-level and is an example of the multi-faceted approach.

Claudia Chang, who began work on ethnographic examples of pastoralism in Greece (Chang 1986), began excavating in southeastern Kazakhstan in 1995 (Chang 1999). Her work with Perry Tourtellotte mapping settlement and burial mounds, as well as excavating settlement sites, tell an intricate story. They and Arlene Rosen (Rosen *et al.* 2000) found evidence for agriculture and realised that there was no distinct boundary between purely pastoral nomads and the settled complex centres of sedentary agriculturalism. Instead, pastoralism mixed freely in niches on the steppe with agricultural practice (Chang 2003).

Chang postulated that this was evidence of social complexity in a nomadic society, pointing away from social evolution, and instead suggesting that production, and subsistence, was not tied into a ranked system of social complexity. Furthermore, production was not limited by a rivalry between pastoral and agricultural systems (Chang 2008). This work stimulated current investigations and redefinitions of pastoral nomadism in the English language.

Frachetti (2004, 2005, 2009) modified the idea of surplus as the basis of inequality and specialisation. He postulated that surplus was not productive, but instead cultural and based on interactions between different groups. Groups are conceptualised as nodes, which are points of interaction. Nodes in ideal locations between multiple other nodes are well placed to accrue cultural capital in the form of contact and interaction. He applied complex systems theory to this nodal theory to investigate trade and contact across the steppe in the Middle and Late Bronze Age (Frachetti 2005, Koryakova and Epimakov 2007).

In rejecting the idea that pastoral nomads were extremely mobile, and instead kept to regions in which they moved in a yearly round, he explored the idea of contact as a diffuse and unbureaucratic system that was heuristic. This is in sharp contrast to the heavily regulated systems of trade and production that characterise sedentary societies (Frachetti 2009). Small-scale local societies picked and chose particular forms of material culture that changed through time, likely as people made ties with other communities or broke them. Throughout the longe dureé of the Bronze Age localised fluctuations in the degrees of interaction and institutional cohesion occurred between groups of pastoralists (Frachetti 2009).

In the Mongolian context, systems theory and mapping have also been applied in Eigiin Gol (Honeychurch 2009) and the Khanuy Valley (Houle 2010). Honeychurch's evaluation of cemetery re-use with network theory is similar to Frachetti's nodal networks. The cultural wealth of an individual originated from connections outside of his community as that individual acted as a nodal 'actor' in a social network (Honeychurch 2009). The oligarchy of the Iron Age in Mongolia is composed of individuals which have amassed cultural, rather than material, wealth.

In the Khanuy Valley, systematic survey and mapping of ritual sites in an ecological niche alongside the excavation of temporary settlement sites created a map of mobility (Houle 2006). This map reflected the circumscribed annual movements of nomadic pastoralists as they exploited the best pasturage for their animals through a small niche over a year (Houle 2006). This case study describes the degree of mobility across the steppe and is an analogue on which to base ideas about movement within a region. This and theories by Frachetti and Honeychurch use complex ideas also utilized by post-processualists, such as chaos and systems theory, to describe mobility and to create maps of interaction.

Zooarchaeological methods combined with new quantification techniques have explored the nature of pastoral activity in regional swathes. Those data syntheses raise questions about the specific localised subsistence strategies and their relation to overarching culture histories. Bendrey published one of the first comparisons of the three main domesticated animals, *Bos taurus, Equus caballus,* and ovicaprids, between sites (Bendrey 2011a). Using all of Central Asian zooarchaeological data published in English, he concluded that variation in the proportions between these three main species was driven by climatic variation. More detailed work by Outram *et al.* (2012) included sites published in

Russian and was limited to northern and eastern Kazakhstan. This revealed that the proportions of horse are not limited by climatic variation, but instead are also driven by cultural and ritual values and confirmed the horse as a high-status animal.

The development of scientific subfields such as palaeoethnobotany within archaeology combined with the opening of Kazakhstan to western researchers has answered questions about trade and mobility. The search for the earliest domesticated millet outside of China has driven isotopic investigations into diet and the nature of agriculture on the steppe. Research has largely focused on the forest-steppe boundary (Lightfoot *et al.* 2013, Motuzaite-Keen *et al.* 2013, Ventresca-Miller *et al.* 2014) with some exceptions in the Semirech'ye and central Kazakhstan (Lightfoot *et al.* 2014, Spengler *et al.* 2013a, 2013b). Archaeobotanical research into millet and other domesticated agricultural plants in the Altai and Semirech'ye have provided some of the earliest direct evidence for agriculture in the steppe and refuted assertions that pastoralists must have relied upon settled agriculturalists for survival (Khazanov 1984, Barfield 1989, Lattimore 1994).

Isotopic research into the diets of the Bronze Age suggests that exploitation of resources extended beyond domestic animal products. High nitrogen signatures indicate that riverine fish likely formed part of the diet of people in and around Kent, Lisakovsk and Temirkash (Lightfoot *et al.* 2014, Ventresca Miller *et al.* 2014). This is despite a relative paucity of fish bones found at these sites (Outram *et al.* 2012). The exploitation of this resource not only varied between sites but also between individuals, suggesting that the local exploitation of resources was one based on a wide variety of choice or status, rather than circumscribed by cultural taboo.

Investigations of human dental pathologies at Lisakovsk and Bestamak indicated a high protein diet with few carbohydrate induced caries. These data, in addition to isotopic evidence and lipid analysis (Outram *et al.* 2012), suggests a diet highly reliant upon ruminant protein, and to a lesser degree, foraged fish and wild foods. Evidence in the Karaganda region of Central Kazakhstan supports these findings, but also finds the addition of millet into the diet with an increased C_4 signature in the Final Bronze Age (Svyatko *et al.* 2013).

Archaeobotanical evidence has revealed that millet was present in the Late Bronze Age (2450 BCE; Frachetti *et al.* 2010, Spengler *et al.* 2013b) and extensively in the Semirech'ye in the Iron Age (Spengler *et al.* 2013b). Direct archaeobotanical evidence for agriculture in the Final Bronze Age is still lacking, but finds of querns and grinding stones suggest that agriculture was part of local subsistence strategies south of the forest-steppe (Goriachev 2004).

Further research into the forage consumed by flocks and herds at Begash indicate that animals selectively foraged for low silica plant material found around streams and rivers (Spengler 2013). Riverside settlements are common in the Late Bronze Age and were likely selected for their shelter and over-wintering potential (Spengler *et al.* 2013b). Links between people were generated between groups of pastoralists when there were few riverine sites, increasing the potential for exchange and meeting at these nodal points (Spengler *et al.* 2013b).

Despite this encouraging advance into the particulars of local subsistence strategies and the diet of Late Bronze Age peoples, there are still issues with the chronologies. Few C_{14} dates have been published for this region. Those that have been published have significantly pushed back or moved forward ceramic typologies. The C_{14} date for the earliest Bronze Age settlement is at Begash (2450 BCE), but is classified as a Late Bronze Age Andronovo (1900-1400 BCE) settlement by ceramic typology. This overlap of the Andronovo with the precursor Afanasievo culture introduces doubt as to the validity of the ceramic typological chronologies.

There is a significant gap between the C_{14} dates at Botai, an Eneolithic site (3500 BCE) and the earliest Abasheivo and Sintashta dates (2100-1700 BCE). Some archaeologists have resolved this by simply assuming that the Bronze Age begins from the Eneolithic, despite a lack of C_{14} dates from more than three sites in this gap from the Early Bronze Age Afanasievo culture (Anthony 2007, 3700-2340 BCE). Further issues with the study of the Afanasievo and later Middle Bronze Age cultures are discussed below.

2.1.5 Conclusion

In conclusion, it may be useful to disregard the line between sedentary and pastoral. Humans use both modes of production for subsistence and often these modes can vary dramatically. Pastoral nomadism is not the negation of sedentism, nor is it restricted to the alternative form of subsistence where agriculture is not possible or has not yet taken hold.

Laura Popova accurately encompassed the current challenge to old models (Popova 2006). To test the plausibility of core/periphery models, Popova calls for more detailed zooarchaeology reports, which include more than simple species lists in order to more fully, investigate the difference in subsistence patterns between groups. Evidence for wild grain harvesting as seen by large quantities of *Chenopodium spp.* promotes a model in which subsistence strategies in Central Asia vary between foraging, pastoralism, and agriculture to form a fluid and adaptable model for survival.

The idea of regarding pastoral nomadism as a complex system reflects the change in our own time from understanding progression in linear terms to the development of complex webs that we now use to organise data, understand theory, and manage our administrative and bureaucratic streams. While the idea of complex systems is enticing as a way of describing complexity, most especially for the hard to comprehend 'otherness' of pastoral nomadism, we risk assigning our own worldview onto what is essentially a very simple way to survive.

Rather, detailed scientific analysis of artefacts and ecofacts from each site can only help to characterize life on the steppe in the Bronze Age. Comparisons between sites with regions can be useful, but must refrain from expanding the frame of reference to cover the entire steppe region. Until there is more data, such analyses give a false impression of uniformity. By focusing on small tessellations, the bigger picture will emerge, with or without the social theory.

2.2. Archaeological Culture Histories of Kazakhstan

The Palaeolithic through to the Middle Bronze Age (c. 2100 BCE) is not well documented in English language literature, with a few notable exceptions such as at Botai and Sintashta. While a few Neolithic sites have been excavated in the north-eastern corner in the forest-steppe, the focus of these sites has been on lithic technology (Mertz 2011). Prehistoric archaeological research focus has centred on the organisation of material culture of the Bronze and Iron Ages into culture-histories. Culture history is the dominant theoretical framework that organizes archaeological cultures in the steppe. They are defined by suites of material culture, funerary practices and organized by region and era. While these culture histories are challenged by radiocarbon dating, they are still the primary descriptor of steppic sites.

2.2.1 Eneolithic: Botai

The site and culture of Botai is the one exception to the dearth of research before the MBA. Botai was first studied in the 1980s and immediately its unique reliance on equids and lack of burial sites made it distinctive in Kazakhstan, and indeed across the steppe. The Botai culture is not limited to the site of Botai, but extends to other settlements sites in the northern forest-steppe of Kazakhstan, such as Krasni Yar (Olsen 2003, Olsen *et al.* 2006, Outram *et al.* 2011).

Recent research has shown this culture, which centred upon the horse, is the earliest known location of the modern domesticated horse (Outram *et al.* 2009). Horses formed the basis of consumption and economy for these people, who had few ceramic remains and still utilized lithic technology. Few human burials have been found at Botai culture sites (Outram *et al.* 2011).

Like much of the useful theory of animal exploitation and its attendant pastoral and mobile theories, the best modern evidence for the complexity of Central

Asian animal based cultures comes from explorations of other topics. Horse domestication remained a mystery long after the location and time of sheep, cattle and dog domestication had generally been agreed upon (Olsen 2006). The horse's natural environment was on wet grassland, such as the western and northern steppe. Hence, the logical places to search for the earliest horse domestication were in Neolithic or Bronze Age sites in these regions. The trouble was how to tell if horses had been domesticated. These issues had been resolved with cattle and sheep by a decrease in their overall size, which had been consistently recorded on sites of known and uncertain domestic status. However, for horses, it was unclear whether this size change occurred as there were no longer any wild examples with which to compare archaeological and modern samples (Olsen 2003).

Through much of the 1980s and 1990s the debate focused on the sites of Derievka and Botai (Olsen 2003, 2006, Levine 1990, 1993, 1999a, 1999b, Anthony and Brown 1991, 2000, Brown and Anthony 1998). Both had very large concentrations of horse bone and were candidates as the earliest site of horse domestication. Derievka is a Copper Age (4470-3530 BCE) site and was located on the edge of the western steppe in the Ukraine, while Botai was an Eneolithic site located on the northern boundary of the steppe in Kazakhstan (Olsen 2003).

Various zooarchaeological methods were employed to explore the presence or absence of domesticated horses on these sites. With horse domestication, it assumed that horse riding must follow. David Anthony explored how to look for horses riding by identifying bit wear on the teeth of horses. His original methodology was disputed but a recent revision has proven effective in tracing metal bitting (Anthony and Brown 1998, Anthony and Brown 2003). Other indications of horse riding, such as spinal pathologies, remain largely untested in archaeological practice (Levine 2005).

Interestingly, the most common way to look for horse domestication was not systematic measuring across a variety of sites, but instead in the use of kill-off patterns. In the course of the debate, these patterns, with all of their attendant problems, were used to discern between hunting of a wild population and meat culling from a domesticated herd. Interestingly, the debate was not over secondary products, but instead whether it was possible to see a meat profile as opposed to a hunted herd of horses (Levine 1993, 1999). These are in essence two sides of the same coin. As Tim Ingold explored in 1980, there is a very fine line between pastoralism for meat purposes and managed wild herds that are hunted by humans. Unsurprisingly the debate largely stalled on this track. If there is such a fine line between hunted and pastoral meat herds, it is hard to suppose that this fine gradation could be seen with a kill-off pattern, which has been widely acknowledged to only show large differences between exploitation patterns. Taphonomic difficulties make fine graduations difficult as taphonomic processes bias against young bones, and these same bones are critical for creating kill-off patterns. Further, while kill-off patterns on individual sites may suggest a form of animal exploitation, it is only in context with other sites in the region and in other epochs in which the value of the profile is revealed.

The debate was finally resolved with a surprising conclusion. Instead of finding evidence for tame ridden horses being bitted or management a herd of horses for meat, Outram *et al.* 2009 found evidence that horses were being milked. With the use of lipid analysis on ceramic shards, as well as the concurrent evidence of additional metric data from other archaeological sites in the region, Outram reimagined the progression of the Secondary Products Revolution on the steppe and established an early location for horse domestication. The specificity of the subsistence pattern at Botai reveals the extreme reliance of animals in the development of pastoralism on the steppe.

2.2.2 Early Bronze Age: Afanasievo/Yamnaya

There is currently little published literature regarding the sites in the transition between the Eneolithic to the Middle Bronze Age (Mertz 2011). This issue is addressed in various ways. Some scholars prefer to date the EBA as following on directly from the Eneolithic while others simply ignore the issue (e.g. Popova 2009). The introduction of radiocarbon dating into the traditional typological ceramic chronologies have pushed back the dates of some cultures and created overlaps in previously non-synchronistic cultures.

The Early Bronze Age cultures on the steppe are located on the forest-steppe border between Kazakhstan and Russia. The Kazakh Early Bronze Age culture, the Afanasievo, is believed to have derived from the Yamnaya Pit-Grave culture which originated north of the Caspian Sea. The Afanasievo ceramic culture is situated to the east of the Botai culture in the Altai Mountains.

Radiocarbon dating for the Yamnaya range from 3650 to 2030 BCE (uncalibrated) from 13 cemeteries in the Ukraine (Anthony 2007). Ceramic culture typologies assigned a date of around 2800 BCE to the Yamnaya horizon (Popova 2009). The radiocarbon dates from the derivative Afanasievo range from 3700-2500 cal BCE from three sites in the Altai (Anthony 2007, Gryaznov 1969 and Vadetskaya 1986 in Svyatko *et al.* 2013). The radiocarbon dates clearly identify an issue with the sequencing of the Eneolithic and the Early Bronze Age in Kazakhstan. The conflict between the radiocarbon dates and the linear ceramic typologies has still not been resolved in the literature (Kohl 2007, Spengler 2013, Ventresca Miller 2013,). It does seem that the traditional cultures based on ceramic typologies are due for revision. At the present moment, it appears that until the chronologies have been adjusted with additional radiocarbon dates, absolute dating and a refined chronology will need to be delayed. Instead, it is better to tentatively fit our interpretations into the existing ceramic chronology, referencing the radiocarbon dates.

The Afanasievo culture, which predates the Andronovo in northern and central Kazakhstan, is centred on pine-forest islands that jut into the steppe (Anthony 2007). This culture is identified by a collection of grave goods, circular burial kurgans, ceramic forms, and domesticated horse, cattle, and ovicaprid remains (Anthony 2007). Inhumations are laid in stone lined cists under a kurgan which is surrounded by a circle of stones. Ceramics similar to the Yamnaya style are deposited with the body. The Afanasievo is additionally characterized by copper jewellery and knives as well as the presence of wheeled vehicles in graves (Kuzmina 1994, 95).

Support for the migration theory of the origin of the Afanasievo culture in the eastern steppe is based on evidence from a kurgan called Karagash near the site of Kent in central Kazakhstan. This kurgan had the funerary traditions of the Yamnaya/Afanasievo culture and was interpreted as a waypoint for migration between the eastern and western steppes (Anthony 2007).

2.2.3 Middle Bronze Age: Sintashta

A dramatic change in settlement patterns in the steppe, particularly the trans-Ural region is associated with a cooling and drying from 2500 BCE (Anthony 2007). The Samara region had an explosion of metallurgical complexes in the Middle Bronze Age as evidenced by the development of the Sintashta culture. Radiocarbon dating, conducted by Bryan Hanks and David Anthony, has dated the Sintashta culture to approximately 2000 – 1700 BCE with the ceramic typologies suggesting a date of 1800 BCE (Popova 2009).

The Sintashta culture encompasses numerous fortified settlements with extensive evidence for metallurgical activities with the presence of smelting ovens, slag, and copper in every household (Anthony 2007, Hanks 2010). It is clear that the towns of the Sintashta culture were participating in a cottage economy of copper processing which had a transformative effect upon social organization (Anthony 2007, Kuzmina 2008).

Archaeological material culture from Sintashta sites includes grand kurgan burials that include spoked chariots, horse sacrifice, and elaborate weapons (Anthony 2007, Hanks and Doonan 2009). The drying of the climate has been interpreted as a stimulant for social unrest, warfare, and eventually movement. Evidence for warfare is rife in Sintashta, with a prevalence of weapons in burials in the later phases and even entire kurgans dedicated to those fallen in battle (Popova 2009). By the end of the Middle Bronze Age, entire families were buried with bronze objects, which may point to the development of a social hierarchy (Epimakov 2009).

The animal bone percentages from Sintashta settlements were 60% cattle, 26% ovicaprid, and 13% horse while at cemeteries it was 23% cattle, 37% ovicaprid, and 39% horse. The isotopes suggest that horse was not the primary source of protein in human diet (Anthony 2007) but that cattle formed the basis of subsistence at these sites. The higher proportion of horses in funerary contexts suggests a high-status or ritual value to horse meat.

The theories that attempted to characterize this particular society suggested that the Sintashta people were a blending of peoples who brought metal technology from the Ukraine and mixed with the local Yamnaya culture (Anthony 2007, Kuzmina 2008) Kuzmina suggests that the development of mobile pastoralism that is associated with the Bronze Age was stimulated by the need for copper deposits, which by the Early Bronze Age were depleted and abandoned in Bulgaria. She further concludes that by possessing domesticated animals, particularly cattle, and the need for metal was greater as a warrior class in need of weapons arose (Kuzmina 2008).

Metalworking need not be on a large organisational scale for it to have an impact on the local economy and on the subsistence of small groups of people. The metallurgical cultures laid the foundation for expansion of more mobile cultures of the Late Bronze Age. Chernyk asserts that by the end of the Middle Bronze Age, the development of other metallurgical centres on the steppe, such as the mines of Uspenskyi and Ulutai Hills in the central steppe met regional need and there was less contact between the trans-Ural populations and the people of the eastern and central steppe (Anthony 2007, Chernyk 2009).

2.2.4 Late Bronze Age: Andronovo

The Andronovo is a cultural horizon that encompasses the entire Central Asian steppe from the Aral Sea in the west, to the Altai Mountains in the east, and from the Tien Shan Mountains in the south, to the forest-steppe in the north. The Andronovo dates from 1900-1500 cal BCE (Gryaznov 1969 and Vadetskaya 1986 in Svyatko *et al.* 2013) with notable outliers such as Begash at 2450 cal BCE (Frachetti *et al.* 2012). Other authors suggest dates which encompass later derivative cultures, such as 1800-1200 BCE (Anthony 1997). The Andronovo is no longer considered to be a unified culture group, but rather a cultural horizon which encompasses derivative cultures such as the Alakul’ and Fedorovo (Evdokimov and Varfolomeev 2002). The Alakul' dates to 2500-900 cal BCE with peaks at three separate phases while the Fedorovo dates to 2000-1100 cal BCE (Chernyk 2009). These subcultures are delineated by differences in ceramic decoration and form as well as funerary customs (Anthony 2007, Kohl 2007, Ventresca Miller 2013). According to the traditional definition, the Andronovo cultural suite originated north of the Caspian Sea and spread across the steppe eastwards by a migration of the Andronovo ethnic group (Evdokimov and Varfolomeev 2002, Kohl 2007, Koryakova and Epimakov 2007).

The Andronovo cultural horizon marks a change in the archaeological cultures after the metallurgical developments of the Middle Bronze Age. There is an increase in the number of settlements across all parts of the steppe and a simultaneous decrease in the average size of settlements (Kuzmina 2008, Ventresca Miller 2013).

The full transition to mobility and the abandonment of urbanism in the Andronovo is explained by Kuzmina thus,

> 'The presence of fortified settlements and advanced metallurgy were necessary conditions leading up to the development of towns in the Steppe. The specific ecological situation of the vast Steppe, however, was exploited not by the economic intensification and specialisation of herding and farming, but by the expansion of pastoral activities more suitable to the Steppe. The pastoral peoples thus abandoned the process of urbanisation that had begun to take shape in the eighteenth century B.C. and instead adopted extensive livestock husbandry, which required larger areas of land. The large Timber-Graze and Andronovo communities came into existence.' (Kuzmina 2008, 59)

She goes on to note that in the 15-13th centuries BCE, there was an explosion of Timber-Grave and Andronovo sites on terraces above floodplains. She concludes that this is because the climate was warmer and drier and settlements would need to guard valuable water resources. Historical ethnography suggests alternative motivations. Winter settlements sites are often located close to watercourses to take advantage of winter grazing, shelter from the wind, as well as access to water (Spengler 2013). Additionally some settlements in the central Kazakh steppe have wells which date to this period (e.g. Atasu and Chalinka) (Evdokimov and Varfolomeev 2002). This conflicting evidence does show that water resources and attendant plant communities were favoured settlement sites.

Andronovo settlements were unfortified, with large semi-subterranean houses. The sites would have held between 40 to 50 people in total (Anthony 2007). In the forest-steppe the houses were of timber, while in the steppe they were constructed of stone and mud brick. There are copper smelting ovens in a few settlements but they are not as ubiquitous as in the MBA Sintashta culture (Anthony 2007). Grinding implements and storage pits in the forest-steppe have been taken as indirect evidence for agriculture, while the lack of these artefacts and features at steppe settlements has been taken to show a lack of agricultural practice (Kuzmina 2008). The pig was absent while Bactrian camel is ubiquitous in small numbers. In the forest steppe, typical NISP for domesticated animals are: cattle 37-52%, sheep 37-44%, while in the steppe: cattle 26-34%, sheep 50-63% (Kuzmina 2008).

Kuzmina suggests that settlements moved every 20 to 25 years due to pasture exhaustion in a radius around a settlement. Kazakh pastoralists historically practised the *jailau* method of pasturage. Animals would be pastured in a radius around the settlement, moving into and out of the small enclosures that surrounded pit houses until the local pasturage was exhausted after 25-30 years. After this short period of occupation, the residents of the settlement would move nearby to establish a new, fresh radius with a new pit house and enclosure system at the nucleus. It was calculated that it took approximately fifty years for a pasture to regenerate to its full carrying capacity, which would encourage at least three generations of movement between settlement sites, resulting in short periods of occupation, or even abandonment as old settlements were forgotten with time. This pattern of generational movement would explain why there is no evidence of long-term occupation at settlement sites and small cemeteries (Kuzmina 2008, Epimakov 2009).

This suggestion of short term settlement challenges the assumption of a population explosion in the Andronovo. Rather than a peopling of the steppe, it may be that as new sites were established every generation and the archaeological footprint of these people is greater than previous cultures. In any case, the variability of the material culture in Andronovo period sites, with admixtures of ceramic and funerary customs from the Alakul and Fedorovo as well as ambiguous social hierarchy has given rise to interpretations of the Andronovo as a less socially complex period marked by interaction, mobility, and egalitarian societies (Koryakova and Epimakov 2007, Kuzmina 2008, Popova 2009, Ventresca-Miller 2013). The uniform variability of sites in the Andronovo cultural horizon suggests that goods and traditions were traded by contact between sites that connected the steppe in a uniform manner.

2.2.5 Cultures of the Final Bronze Age in the eastern steppe

Climate change in the in the Final Bronze Age (13/12th – 9th centuries BCE) resulted in more precipitation and floodplains were inundated. Kuzmina suggests that this necessitated a different method of pastoralism: long distance pastoral circuits north –south from north of the Caspian sea to the Amu and Syr Darya or east-west circuits from the central steppe to the Aral sea (Evdokimov and Varfolomeev 2002, Kuzmina 2008). Both of these circuits would require annual round trips of 2400 kilometres. This is equidistant to a round trip from

Paris to Warsaw. Others argue that mobility was reduced with climate change and connections across cross-steppe nodal network faded (Koryakova and Epimakov 2007).

The culture-histories of the Final Bronze Age are localised continuations of Andronovo period cultures. The Alakul'/Fedorovo cultures of the northern and central steppe were 'deformed' by the influence of the Karasuk culture, which originated in the Altai Mountains to the east (Koryakova and Epimakov 2007). The Karasuk metallurgical culture in the Altai dates from 1500-900 cal BCE (Gryaznov 1969 and Vadetskaya 1986 in Svyatko *et al.* 2013). Chernyk describes the Karasuk metal material culture as a suite of metal weaponry from the Altai which was imitated or traded to China. These metal objects are largely found in funerary contexts.

The change in the Andronovo cultures of the Alakul'/Fedorovo results in the Begazy-Dandybaev culture in the central steppe. The Begazy-Dandybaev culture is characterized not only by rolled ceramic forms, but also by large settlements that include industrial and residential quarters. Small outlying villages and kurgans, some of which display social differentiation, surrounded settlements. These settlements include Kent, Myrzhik, Buguluy-1, and Shortandybulak.

Imported ceramics from Siberia and the western steppe have been interpreted as trade goods, rather than as evidence for immigration from those regions (Talanova 2007). These settlements were likely tied to the mines in the central steppe region. Technological quarters have evidence of metallurgical activity with slag and smelting ovens. The Begazy-Dandybaev culture has an abundance of decorated animal bones used for handles, bridles and other instruments (Talanova 2007). A mine near Uspenskyi in the central steppe would have supplied huge amounts of copper ore. This mine produced between 30 to 50,000 metric tons of copper during the Bronze Age (Anthony 2007). Kohl notes that in the Late and Final Bronze Age that there is evidence for greater specialization and extraction of metal ores in the central steppe (Kohl 2007).

The Semirech'ye has a slightly different culture history than the northern or central steppe. The cultural tradition of the Tien Shan is linked by ceramic forms to those of Central Kazakhstan and the foothills of the small mountain ranges that line Kazakhstan's eastern border up to the Dzhungar Mountains of Siberia.

Despite this material culture connection, the Semirech'ye in the Andronovo period was not part of the Alakul'/Fedorovo but instead part of the Kirgiz culture group (Goriachev 2004). This Karakuduk/Talas style is largely defined by the richness of the burial goods and the wide spread of settlement sites vertically from 2,800 m (e.g., the Arpa burial ground, Asi, Tsenganka 8) down to the foothills and apparently even the semi-desert around Tamgaly. Copper mines around Lake Issyk Kul (Chatkal) provided the raw metal for this branch of the Andronovo (Chernyk 2004).

Bronze Age settlement sites in the Semirech'ye are small and architecturally unimpressive. They are characterized by mud-brick houses that are partly dug into the soil surface for insulation. The much larger size of associated cemeteries, and in some cases, multiple cemeteries, gives evidence to the long term reuse of sites. The lack of size however belies what is likely a seasonal occupation by a small group of people, likely kin, which move up and down the foothills, utilizing pasturage at different times of the year. This is different than the single phase dwelling of the Alakul'/Fedorovo and the multiphase settlements of the Begazy-Dandybaev (Talanova 2007).

Bronze Age settlements on the alluvial plain are not common and instead scattered burial kurgans are located near watercourses. The petroglyph site of Tamgaly is a ritualized and sacred canyon in which animals, people and anthropomorphized shapes were carved into the rocks of a river valley on a lavish and large scale. Smaller petroglyphs are often found on exposed rock faces throughout the Semirech'ye, although at a higher altitude.

Tamgaly was the social and ritual centre of petroglyphs for the people of the Semirech'ye (Davis-Kimball *et al.* 2000, Lymer 2008). The semi-arid steppe that surrounds the site would not sustain flocks on a year-round basis. Hence local people living at sites such as Serektas likely migrated towards the southern mountains or north towards Lake Balkhash during periods of aridity. The seasonal natures of occupation around Tamgaly likely encouraged short periods of ritual use at Tamgaly.

The first site at Tamgaly (Tamgaly-1) is a cemetery which dates to 1600-1400 BCE by ceramic typology. Within the Semirech'ye this is the subculture of the Alakul'/Atasu culture. Later settlements and cemeteries (Tamgaly 2 and 4) date to the Final Bronze Age (1400-1000 BCE) (Frachetti 2009, Rogozhinskii 1999). An overlap between pastoralists from the central steppe and the Semirech'ye likely occurred at Tamgaly (Frachetti 2009).

Ceramic typologies are also used in conjunction with metalworking traditions to date sites in the Semirech'ye. Bronze artefacts from similar sites in the northern

Tien Shan foothills are grouped into the Kulsai tradition. Goriachev (2004) concludes that this tradition originated from the migration of the Fedorovo people from the southern Siberia, the Altai and eastern Kazakhstan which integrated with local people in the Bronze Age. The connection between the sites of the northern Tien Shan and the steppe to the east of the Dzhungar and Altai is evident by the similarity of ceramics and metal artefacts that form this Late and Final Bronze Age material culture.

The economy of the people of the Semirech’ye at the end of the Bronze Age is generally described as an agro-pastoral economy; largely focused on hoe cultivation of barley and millet and pastoral activity using a variety of vertical and local pasturing techniques (Chang 1999, Goriachev 2004, Rosen 2000).

2.2.6 Conclusion

Kurgans protrude from the flat landscape of the steppe. These burial mounds contain grave goods, specifically ceramics upon which Bronze Age culture histories and chronologies are based. Despite problems matching absolute radiocarbon dates to these chronologies and a lack of data from settlement sites, the change in social complexity through the Bronze Age is evident. The repeated process of proto-urban development in association with metallurgical processes took place twice- once in Samara with the Sintashta culture during the Middle Bronze Age and again in the Final Bronze Age during the Begazy-Dandybaev at Kent and surrounding sites. Culture histories that are not associated with metallurgical processes, such as those of the Andronovo culture histories, are harder to define. The presence of a variety of material culture from more than one of these culture histories at a site is usually interpreted as immigration. The association of ethnic groups with these archaeological cultures implies that groups of people repeatedly washed across the steppe, drowning the local people in these new traditions. With each new cultural ceramic form comes associated migration and repression of old styles (Evdokimov and Varfolomeev 2002). The pastoral, and hence mobile, nature of these cultures infers that repeated migrations are plausible.

Investigations of Bronze Age settlement sites have shown that the people of the Bronze Age were not exclusively pastoral and exploited a wide range of wild animal and plant resources (Lightfoot *et al.* 2014, Spengler 2013a, 2013b, Ventresca-Miller *et al.* 2014a, 2104b). Investigating admixture between flocks can challenge the inherently mobile nature of pastoralism. Furthermore, detailed zooarchaeological analysis of the exploitation of wild and domesticated animals can divulge the heterogeneity of subsistence across what has been characterised as an ecologically and culturally homogenous region. It is hoped that culture historical interpretations of ethnic migration can be abandoned in favour of models which emphasise diffusion and internal change (Evgenni 2009, Frachetti 2009 Spengler 2013, Ventresca-Miller 2013). By investigating animal exchange between disparate culture groups in the Late and Final Bronze Age, it may be possible to rule out or at least temper the migration theory of culture change.

Chapter 3: Zooarchaeological Methods and Results

3.1 Zooarchaeological Methods

The three sites of Kent, Serektas and Turgen are located in the eastern half of Kazakhstan and date to the Late to Final Bronze Age by ceramic typology (1500-900 BCE). All were excavated by hand with no sieving. Sites were excavated in box grids. Boxes at Serektas were three by three metres, with an unspecified baulk size. Box and baulk size are unspecified for Kent and Turgen. Boxes are dug in 10cm levels; artefacts and bones are bagged separately for each level within each box. Artefacts and bones that are removed from the baulks are bagged without a depth or location. Significant features recognised during excavations, such as pits, may merit separate finds bags but this is not consistent. No bones were plotted using x and y distances from the north corner, although this method is used to plot special finds, such as human bone remains or metal artefacts. Boxes are recorded by drawings at significant levels, and profiles of baulk walls are drawn at the end of the excavation season. These drawings may or may not be retained and utilised in further analyses. A matrix or interpretation of the relationships of the spit levels across boxes and between levels was not available for any of the sites under consideration here.

Hand collection is typical of excavations in Central Asia. Some excavations have included dry screening and/or sampling for flotation, including Temirkash (Outram *et al.* 2011), Taldy-Bulak 2 (Haruda 2007) and Botai (Jones *et al.* in prep). These excavations have found little fish and bird bone through both screening and sampling which was later floated and sieved. On these sites, the largest amount of fish bone reported is less than 2% NISP at Temirkash (Outram *et al*. 2011). The lack of small bone from sieved samples suggests that assemblages are unlikely to be heavily biased by hand-collection.

There was limited post excavation finds processing for the finds from these sites. Animal bone was brushed or washed after excavation and replaced into the original finds bags and archived for storage. No further contextual analysis, such as the resolution of levels into contexts or depositional layers, are applied to the animal bone remains. Often such fine stratigraphic resolution is not applied at all. Instead the ceramic remains date the site, and should there be a progression of styles through the spits, the site is considered to have a long period of occupation through these stylistic periods. Excavation reports describe the overall situation of the site, the finds from each spit and significant features. These reports are filed with the Ministry of Culture in Astana, Kazakhstan. Further analysis of the sites is reserved for publications within Russian language publications, with limited publications in English (e.g. Goriachev 2004, Outram *et al.* 2012, Lightfoot *et al.* 2014).

All bones in this study were analysed in Kazakhstan between August 2011 and June 2012 at E.A. Bukhetov Karaganda State University, Karaganda and the Margulan Institute for Archaeology, Almaty. At Karaganda State University, animal bones were compared to those already identified to species by previous zooarchaeologist Alexei Kasparov. Additionally, a small reference collection of modern material was created and archived during the analysis period for future assistance. In Almaty at the Margulan Institute of Archaeology, a formally identified zooarchaeological reference collection was not available. Bones were compared with each other within their contexts and with other known archaeological specimens. Elements were compared to bone identification manuals by Barone (1976), Hillson (1999), Gilbert (1973), and Schmid (1972). Bird bone was identified to family using Baumel (1980) and Cohen (1999). Wild specimens were identified with assistance from Bobrinskii (1965).

Unidentifiable bone was defined as shaft fragments under 5 cm in length with no muscle attachments or foramina, exfoliated cancellous bone, and viscerocranial fragments. Bones fitting this description were separated into burnt and unburnt fragments and tallied. Ribs and vertebral fragments were simply tallied and no other data was recorded for them due to their large numbers in this assemblage.

Identifiable bone was classified as bone which was longer than 5cm in length with muscle attachments or foramina present, as well as epiphyses and cranium fragments and tooth fragments. These were identified to species, element, side, and sex. The bones were analysed for age using fusion data (Reitz and Wing 1999). Butchery and fragmentation were recorded using Outram (2001, 2005) and Reitz and Wing (1999). Modifications, such as dog gnawing, and knife marks were also recorded according to Reitz and Wing (1999). Dobney and Rielly (1988) was used to record bone completeness, and Outram (2001) was used to record fracture and fragmentation information. Bone tools or artefacts that were found were re-classified with bone artefacts and are not described here.

Bone identification data were recorded in numerical form in an Excel spread sheet. Each bone specimen was assigned a row with attached contextual data. Each column recorded data for a single variable- for example a single column for species and a single column for sex. Every value was recorded in numerical form, for which there is a key available in both Russian and English. This allows the data to be accessible to a wider audience in the future.

The first two variables were bone element and species. Bones that were impossible to identify to species, were recorded into three size categories.

‘Large Mammal’ includes animals that are the same size as *Equus caballus* and *Bos taurus*. ‘Medium Mammal’ includes animals that are the same size as *Ovis aries,* and *Saiga tartarica*. ‘Small Mammal’ includes animals that are the same size as *Lepus* spp*.* and *Castor* spp. These size classes are excluded from further analysis (see below). Rodents and birds have their own category and were not recorded to species but were included in the zooarchaeological analysis. Specific rodent species, such as the marmot, are more easily identifiable and are listed separately. The elements identified to size classes form part of the total number of specimens (NSP), which include unidentifiable bone fragments, but they are excluded from the number of identifiable specimens (NISP).

The bones from *Ovis aries* and *Capra hircus* are very similar morphologically. Literature by Boessneck (1969), Payne (1985), Zeder and Lapham (2010) and Zeder and Pilaar (2010) was used to speciate these specimens. Only certain bones in the sheep or goat skeleton can be identified as either sheep or goat, for example, the astragalus, distal phalanx, pelvis and ulna can be reliably speciated (Zeder and Lapham 2010). For the remainder of the bones in the skeleton, it is difficult to distinguish between sheep and goat and they are simply recorded in a combined group as ‘Ovicaprid’.

Sex, which not only includes male and female but also castrated males, is useful in creating survivorship structures. It is difficult to find traces of sexual dimorphism in the bones (Reitz and Wing 1999). Attempts to use metrical measurements of the metapodials in cattle to sex were unconvincing (Grigson 1982). Recent research using aDNA proved that the breadth of the distal end of metapodials for cattle is useful and reliable for sexing between males and females (Davis *et al.* 2012). Unfortunately this research had not yet been published when data were gathered and these measurements were not recorded.

Aside from sexually specific bones, such as antlers in some deer species and canine teeth in horses, it is difficult to find sexually morphological traits in the field. Frequently the only bone with this information is the pelvis, which is often found broken and fragmented. While it is possible to sex fragmentary pelves (Greenfield 2006), there are still few of these elements and few total elements in this study with which to identify the sex of individuals. While data was recorded when evident, sex is not addressed specifically in further analyses here.

Age data are recorded by the stage of growth of the bone. When a mammal is born, an appendicular bone is in three pieces, the middle, the diaphysis, and the two ends, the epiphyses (Chapter 4). These three parts grow together over the course of the lifetime of the animal. We know the range of time during which the fusion of these parts will occur for each element. If the animal was killed before the fusion occurred, we can know that the individual did not live beyond the range of that fusion stage. Bones that grow intramembranously such as the skull or vertebrae (Chapter 4) cannot be aged using this method.

Combining the fusion data for all elements from a species creates a survivorship graph. This graph shows the percentage of elements that are fused from each fusion date range. By comparing the percentage of elements that are fused from all the fusion date ranges, a cull pattern for the flock or herd from the site is revealed (Reitz and Wing 1999, Payne 1973). These describe the type of products exploited, such as meat or milk (Payne 1973 and reply in Greenfield 2010). Taphonomic problems, such as the poor preservation of bones from neonatal and young animals can result in an underrepresentation of this age range in the pattern. The absence of this age range should be kept in mind during the interpretation of these graphs.

Archaeological bone is almost always fragmented. In order to record which parts of the bone are present, Dobney and Rielly (1988) was used to record bone completeness. These authors created sketches of each bone element and assigned numbers to each part of the bone. If the part of the bone is more than 50% present, then that number is recorded. This system was used for identified specimens from all three sites.

The shape of the fragmentation can reveal when the bone was broken. When the bone was fresh and damp, breaks will have a helical shape, while when it was dry and old, breaks will occur longitudinal to the midline of the bone. Helical breaks and dynamic impact scars can indicate further exploitation of the marrow inside the bone, while dry breaks can indicate that the bone sat exposed on the surface for some time, instead of being buried in a midden while still fresh (Outram 2001). Finally, modern breaks indicate the modern condition of the bone and can be used to estimate the amount of damage the assemblage sustaining in handling and storage.

Loose teeth were recorded to species. Mandibles with all teeth intact were identified to species and also evaluated for wear according to Grant (1982) and Payne (1973). As a ruminant animal ages, not only does it lose its milk teeth, but the permanent teeth also wear, creating different patterns. Intact mandibles can be compared to create an age profile of a herd, similar to what can be created from fusion data. These data cannot be collected from horses, only from ruminants such as sheep and cows.

This basic methodology was applied to each bone in the assemblage in order to record the most data from element bone efficiently. While not all of these data may be statistically significant to answer research questions about this assemblage, when the data are compared between assemblages, large patterns of economy and subsistence may begin to appear.

Analysis of each assemblage was driven by the research questions asked by the principal investigators. While all investigations focused on exploring the nature of pastoralism and subsistence economy at each site, specifics necessitated slight changes in data collection. For example, at Serektas, taphonomic questions were not a concern, and hence burning and modification data was not collected. Due to this discrepancy, modification from all sites (excepting pathologies) is not reported here.

All sites are described below in a standardised fashion. The NISP for each site as well as a more in-depth exploration of the NISP for each of the main three domesticated species are presented here. Plots of survivorship for each of the three domesticates are also presented in order to explore the cull patterns for herds. Taphonomic data collection was not uniform, as stated above. Burning data are presented for Kent and Turgen. However fragmentation data were collected at all sites, but only for NISP.

NISP is reported below for each site for the entirety of the site as NISP is ideal for comparing between species. For each of the three main domestic species (*Bos taurus, Equus caballus, Ovis aries/Capra hircus*) NISP, an MAU value and a %MAU are reported. The MAU (minimal animal units) first defined by Binford (1978) is a normed MNE (minimum number of element) value (Lyman 2008). The MAU is a derived measure that accounts for biases in fragmentation, identification, and frequencies of elements in the skeleton (Lyman 2008, Orton 2008). Both NISP and MAU are presented here to indicate these taphonomic biases in the assemblages. However, as NISP is still the most commonly used counting method in the region, further analyses are conducted using NISP (see Chapter 6).

By controlling for overrepresentation of these numerous elements, it is easier to find consumption patterns for particular parts of the carcass. Large numbers of these elements can swamp patterns in other elements.

3.2 Taphonomic Considerations

Due to the lack of stratigraphic resolution, the animal bones under consideration from these three sites are considered by site, with little stratigraphic resolution. The animal bones from each of the three sites are from the prehistoric layers of the sites and are amalgamated into a unified assemblage for each site. Dating is done via ceramic typologies. As pastoral sites largely have a limited period of occupation and a small range of ceramic typologies, the animal bone can be generally assumed to be from the small palimpsest of time relating to the prehistoric settlement period. Further post finds processing and stratigraphic analysis in the future would benefit from a refinement in stratigraphic recording and analysis.

Despite these challenges, an examination of taphonomic concerns of the three sites under consideration is worthwhile. Taphonomy describes the process any skeletal part undergoes from the biosphere to the described assemblage under study (Efremov 1940). The investigation of the taphonomic data can examine

Table 3.1: Completeness of Kent specimens, based on Morlan 1994.

Bovid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	31	152	4.9	54%
Humerus	11	16	68	4.3	39%
Radius	10	23	52	2.3	23%
Ulna	10	11	35	3.2	32%
Metacarpal	8	16	36	2.3	28%
Innominate	12	27	57	2.1	18%
Femur	11	15	24	1.6	15%
Tibia	10	32	58	1.8	18%
Calcaneum	4	30	104	3.5	87%
Astragalus	4	52	168	3.2	81%
Metatarsal	8	29	80	2.8	34%
Phalanx 1	3	84	213	2.5	85%
Phalanx 2	3	101	278	2.8	92%
Phalanx 3	2	23	41	1.8	89%

Equid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	13	56	4.3	48%
Humerus	11	8	34	4.3	39%
Radius	10	41	103	2.5	25%
Ulna	10	17	59	3.5	35%
Metacarpal	8	30	83	2.8	35%
Innominate	12	12	56	4.7	39%
Femur	11	12	17	1.4	13%
Tibia	10	27	67	2.5	25%
Calcaneum	4	20	72	3.6	90%
Astragalus	4	48	124	2.6	65%
Metatarsal	8	13	37	2.8	36%
Phalanx 1	3	55	129	2.3	78%
Phalanx 2	3	42	114	2.7	90%
Phalanx 3	2	29	51	1.8	88%

Ovicaprid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	138	636	4.6	51%
Humerus	11	166	870	5.2	48%
Radius	10	134	432	3.2	32%
Ulna	10	134	300	2.2	22%
Metacarpal	8	80	307	3.8	48%
Innominate	12	198	792	4.0	33%
Femur	11	73	131	1.8	16%
Tibia	10	143	386	2.7	27%
Calcaneum	4	110	392	3.6	89%
Astragalus	4	127	462	3.6	91%
Metatarsal	8	181	394	2.2	27%
Phalanx 1	3	221	588	2.7	89%
Phalanx 2	3	120	344	2.9	96%
Phalanx 3	2	49	94	1.9	96%

Table 3.2: Completeness of Serektas specimens, based on Morlan 1994.

Bovid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	4	11	2.8	31%
Humerus	11	5	22	4.4	40%
Radius	10	1	2	2.0	20%
Ulna	10	1	1	1.0	10%
Metacarpal	8	1	2	2.0	25%
Innominate	12	4	11	2.8	23%
Femur	11	1	3	3.0	27%
Tibia	10	9	15	1.7	17%
Calcaneum	4	2	6	3.0	75%
Astragalus	4	8	24	3.0	75%
Metatarsal	8	5	16	3.2	40%
Phalanx 1	3	17	47	2.8	92%
Phalanx 2	3	13	34	2.6	87%
Phalanx 3	2	9	17	1.9	94%

Equid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	12	43	3.6	40%
Humerus	11	14	46	3.3	30%
Radius	10	28	49	1.8	18%
Ulna	10	10	41	4.1	41%
Metacarpal	8	16	54	3.4	42%
Innominate	12	12	29	2.4	20%
Femur	11	11	20	1.8	17%
Tibia	10	14	39	2.8	28%
Calcaneum	4	6	19	3.2	79%
Astragalus	4	17	56	3.3	82%
Metatarsal	8	12	32	2.7	33%
Phalanx 1	3	33	81	2.5	82%
Phalanx 2	3	35	101	2.9	96%
Phalanx 3	2	13	22	1.7	85%

Ovicaprid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	29	140	4.8	54%
Humerus	11	30	152	5.1	46%
Radius	10	31	88	2.8	28%
Ulna	10	10	43	4.3	43%
Metacarpal	8	17	62	3.6	46%
Innominate	12	27	77	2.9	24%
Femur	11	21	53	2.5	23%
Tibia	10	27	80	3.0	30%
Calcaneum	4	12	35	2.9	73%
Astragalus	4	23	80	3.5	87%
Metatarsal	8	23	73	3.2	40%
Phalanx 1	3	59	159	2.7	90%
Phalanx 2	3	18	49	2.7	91%
Phalanx 3	2	7	12	1.7	86%

Table 3.3: Completeness of Turgen specimens, based on Morlan 1994.

Bovid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	3	15	5.0	56%
Humerus	11	3	11	3.7	33%
Radius	10	5	19	3.8	38%
Ulna	10	1	3	3.0	30%
Metacarpal	8	10	22	2.2	28%
Innominate	12	4	22	0.0	0%
Femur	11	5	25	5.0	45%
Tibia	10	6	23	3.8	38%
Calcaneum	4	4	14	3.5	88%
Astragalus	4	8	32	4.0	100%
Metatarsal	8	13	46	3.5	44%
Phalanx 1	3	16	38	2.4	79%
Phalanx 2	3	7	21	3.0	100%
Phalanx 3	2	5	9	1.8	90%

Equid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	3	10	3.3	37%
Humerus	11	4	12	3.0	27%
Radius	10	4	17	4.3	43%
Ulna	10	2	2	1.0	10%
Metacarpal	8	2	3	1.5	19%
Innominate	12	0	0	0.0	0%
Femur	11	5	10	2.0	18%
Tibia	10	2	8	4.0	40%
Calcaneum	4	3	11	3.7	92%
Astragalus	4	3	12	4.0	100%
Metatarsal	8	2	8	4.0	50%
Phalanx 1	3	11	30	2.7	91%
Phalanx 2	3	2	6	3.0	100%
Phalanx 3	2	7	13	1.9	93%

Ovicaprid	PD	NISP	PP	(PP/NISP)	%Completness
Scapula	9	11	56	5.1	57%
Humerus	11	7	53	7.6	69%
Radius	10	12	74	6.2	62%
Ulna	10	3	25	8.3	83%
Metacarpal	8	14	56	4.0	50%
Innominate	12	11	57	5.2	43%
Femur	11	10	56	5.6	51%
Tibia	10	15	64	4.3	43%
Calcaneum	4	9	33	3.7	92%
Astragalus	4	36	143	4.0	99%
Metatarsal	8	11	47	4.3	53%
Phalanx 1	3	17	41	2.4	80%
Phalanx 2	3	7	20	2.9	95%
Phalanx 3	2	4	8	2.0	100%

the human treatment of the bones after the consumption of meat and marrow, such as revealing element selection, butchery practises, and refuse disposal. These can be investigated through skeletal part abundance (e.g. Figures 3.2, 3.5, 3.10), while butchery and refuse practises can be elucidated through human modifications of the bones, such as with fragmentation type (Table 3.4, 3.9, 3.13). These are all cultural interpretations of depositional data.

Another important factor to take into account is density-mediated attrition. This describes the loss of certain skeletal elements due to their structural density (Lyman 1994). Elements with low density are more friable and less likely to survive intact. As Orton (2008, 2012) observes however, this approach suffers from equifinality. Should a site show that portions of bones with higher density are present in greater numbers than portions more likely to fragment, this does not necessarily indicate that an entire skeleton was deposited and subject to breakage. Indeed, perhaps only elements with a higher density were transported to site and deposited (Lyman 1994, Rogers 2000). Despite attempts to use more refined statistical methods to resolve equifinality (Rogers 2000), correlations between denser elements, such as those of the feet, and frequency must be interpreted with caution.

In light of this, element completeness for each of the three major domesticated species from each site was analysed to investigate bone survival. Each bone element was recorded using Dobney and Rielly (1988); these data formed the basis of the method described in Morlan (1994) and Orton (2008). The average portion present (PP) per bone (PP/NISP) for each element was divided by portions defined (PD) to find the percent completeness for each element (%Completeness) (Tables 3.1, 3.2, 3.3). Unsurprisingly, more dense elements, such as the astragalus, calcaneum, and phalanges were more likely to survive intact than long bones of the appendicular skeleton, such as the femur. This trend is true for all three sites. Bones are more likely to be more complete at Turgen, as opposed to Serektas and Kent.

The average percent completeness of specimens is broadly similar across all three sites (Tables 3.1, 3.2, 3.3). The ovicaprids upper limb elements from Turgen trend higher than the percent completeness for similar elements from horse and cow. Serektas may suffer from recovery issues, as discussed below.

More friable elements, such as the scapula, have a surprising amount of portions preserved. The thinnest scapulae in this investigation are that of the ovicaprids, which have a percent completeness of above 50% for all sites. Other elements that are denser such as the tibia have a smaller percent completeness. This may suggest a cultural interpretation for such survival especially in light of fragmentation types (Table 3.6, 3.11, 3.15). Such a difference in completeness between a more friable element (the scapula) and a denser element (the tibia) suggests that cultural interpretations may contribute towards an explanation of element presence and fragmentation and that density-mediated attrition may play a lesser role.

As other friable elements of the axial skeleton, such as the ribs and vertebrae, were not speciated and included in further analysis (see above) they were excluded from the analysis of completeness. The NISP for each site contains only elements identifiable to species, which excludes most axial elements and shaft fragments. The NISP/NSP ratio for Kent is 14%, 47% for Serektas, and 12% for Turgen (Table 3.4, 3.9, 3.13). These ratios are merely descriptive (Lyman 2008) but hint at differences in taphonomic histories between sites. A breakdown of the number of unidentified specimens (NUSP) at Kent indicates that the majority of this category is unidentifiable fragments (80%) and 60% of this category is smaller than five centimetres (Table 3.5). Seventy-one percent of the NUSP were unidentifiable fragments at Serektas, with 12% smaller than five centimetres (Table 3.10). Eighty-eight percent of the NUSP from Turgen were unidentifiable fragments while 47% were smaller than five centimetres (Table 3.14). Specimens that could only be identified to size class, for example rib fragments, were a minority of the NUSP for all sites. Serektas has a much lower percentage of fragments that were smaller than five centimetres. This is likely due to preferential recovery and storage of the bones from Serektas (Tyutkova, unpublished).

Taphonomic histories for the assemblages from Kazakhstan include complicating factors beyond socio-cultural factors. The challenging storage and excavation conditions as well as unrefined stratigraphy necessitates cautious interpretations of zooarchaeological data. More intensive zooarchaeological analysis, such as butchery patterns and intensity of marrow extraction is merely suggestive in such contexts. Comparative analyses of taxonomic abundances within and between sites as well as analyses that rely upon appendicular elements, such as mortality profiles, are likely to be undermined by such conditions, but not to the point of unreliability. Furthermore, while derived measurements for skeletal part abundance are presented here, NISPs are the standard used across the literature (Bendrey 2011a, Frachetti and Benecke 2009, Outram and Kasparov 2007) and used in regional comparisons (Chapter 6).

3.3 Kent

There were 31,143 bone fragments recovered from Excavation 11. 4335 of these were identifiable to species. Unidentified fragments were broken down into subcategories (Table 3.4). The distinctive difference between ribs and other bones makes it easy to tell them apart but it is not easy to identify species from a rib fragment, especially without a reference collection of modern animal ribs

Table 3.4: Bone analysed from Kent.

Unidentified Fragments	Identified Specimens	Total
26808	4335	31143

Table 3.5: Number of unidentified specimens (NUSP).

Type of Bone	Number of Specimens
Unidentified (smaller than 5cm)	
Unburned	11765
Burned	4215
Total	15980
Long Bone Fragments (larger than 5cm)	
Unburned	5406
Burned	616
Total	6022
Medium Mammal Ribs	1969
Large Mammal Ribs	741
Spongy Epiphyses	5
Skull Fragments	311
Calcified Cartilage	7
Vertebrate Fragment	18
Small Mammal	12
Medium Mammal	951
Large Mammal	792
Grand Total	26808

Table 3.6: Fragmentation type (NISP).

Longitudinal	Helical	Modern	Total
828 (24%)	2424 (71%)	147 (4%)	3399 (100%)

for comparison. Long bones could be separated into size classes by the shaft thickness and overall appearance, however without modern reference material for comparison it was not possible to identify these long bone shaft fragments to taxon.

Of the remaining 27,112 bones, 15,980 were smaller than five centimetres and were not identified to taxon (Table 3.5). Six thousand and twenty-two were long bone fragments larger than five centimetres which were unable to be identified to taxon. Other elements include 1969 medium mammal ribs, 741 large mammal ribs, five spongy epiphyseal fragments, 311 skull fragments, seven pieces of calcified cartilage and 18 vertebral fragments. There were also assorted bones which could not be identified to species, but were identifiable elements or identifiable to a size class of mammal. This includes 12 bones from small mammals, 951 bones from medium sized mammals, for example an ovicaprid or small deer, and 792 bones from large sized mammals, for example from horses or cattle (Table 3.5).

Burning was recorded at Kent on the small and long bone fragments and for identified specimens. Four thousand one hundred and twenty-five small fragments were burned, which is 26% of that size category. Six hundred and sixteen long bone fragments were burned, which is 10% of that size category (Table 3.5). This suggests that burning contributed to the creation of many of the small bone fragments.

Fragmentation type was recorded for identified elements. Fragmentation is dominated by helical fractures (71%), followed by longitudinal fractures (24%). Modern breakages from excavation and storage were remarkably few (4%) (Table 3.6). While elements from NISP were not burned, there is evidence for breakage while the bones were fresh, and they were perhaps broken for marrow extraction.

3.3.1 NISP

The number of identified specimens (NISP) is presented for the entire site (Table 3.7). Domesticated animals dominate the assemblage, forming 98% of the total NISP. A variety of wild animals, including both sylvan and steppic species, for example the *Cervus elaphus* and *Saiga tartarica*, respectively are present at Kent. The small eastern roe deer species, *Capreolus pygargus*, which favours any area with some type of cover (Nowak 1999) was also present at Kent. The gazelle, *Gazella subguttorsa* was a widespread gazelle species

Table 3.7: Kent NISP

Species	NISP	% of NISP
Camelus bactrianus	1	0.02%
Alces alces	3	0.07%
Bos taurus	869	20.07%
Equus caballus	627	14.46%
Equus hemionus	4	0.09%
Cervus elaphus	18	0.42%
Capreolus pygargus	10	0.23%
Saiga tartarica	9	0.21%
Ovicaprid (Sheep/Goat)	2227	51.37%
Ovis aries	377	8.70%
Capra hircus	114	2.63%
Castor sp.	1	0.02%
Marmot sp.	2	0.05%
Lepus sp.	3	0.07%
Rabbit	1	0.02%
Vulpes sp.	1	0.02%
Canis familiaris	44	1.01%
Bird	2	0.05%
Ovis ammon sp.	15	0.35%
Gazelle	4	0.09%
Sciuridae sp.	1	0.02%
Capra sibirica	1	0.02%
Total	4335	100.00%

that occurred in prehistoric times from Syria to the Mongolian plateau. The very similar *Procapra guttorosa* also roamed the Central Asian steppes. They both preferred wide-open grasslands and moved in large herds. Due to the lack of comparative material, gazelle remains have been labelled below in English as gazelle as it was not possible to differentiate between the two species. Finally, the wild goat in Central Asia is not the Chamois (*Rupicapra rupicapra)* but instead the Siberian Ibex, *Capra sibirica* which is located in mountainous regions from Uzbekistan to the Altai (Nowak 1999). This wide variety of hunted animals shows the range of ecological niches available around the vicinity of Kent.

A wide variety of domesticated animals, including *Equus hemionus* and *Camelus bactrianus* contribute to the overall domestic animal assemblage, however the majority of domesticated animal remains are from *Ovis aries*,

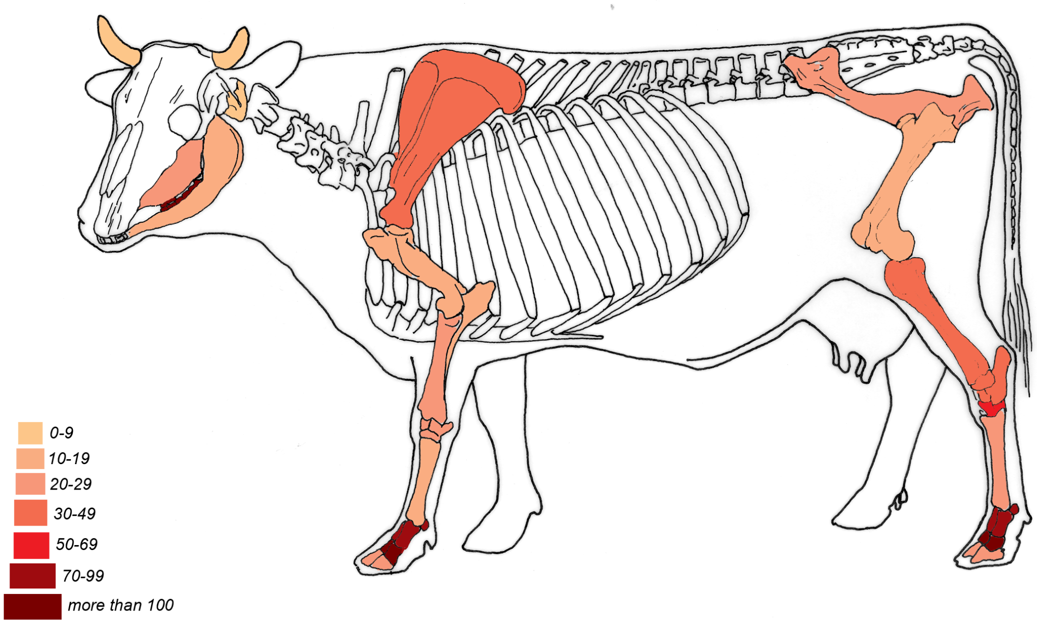


Figure 3.1: *Bos taurus* elements from Kent, NISP.

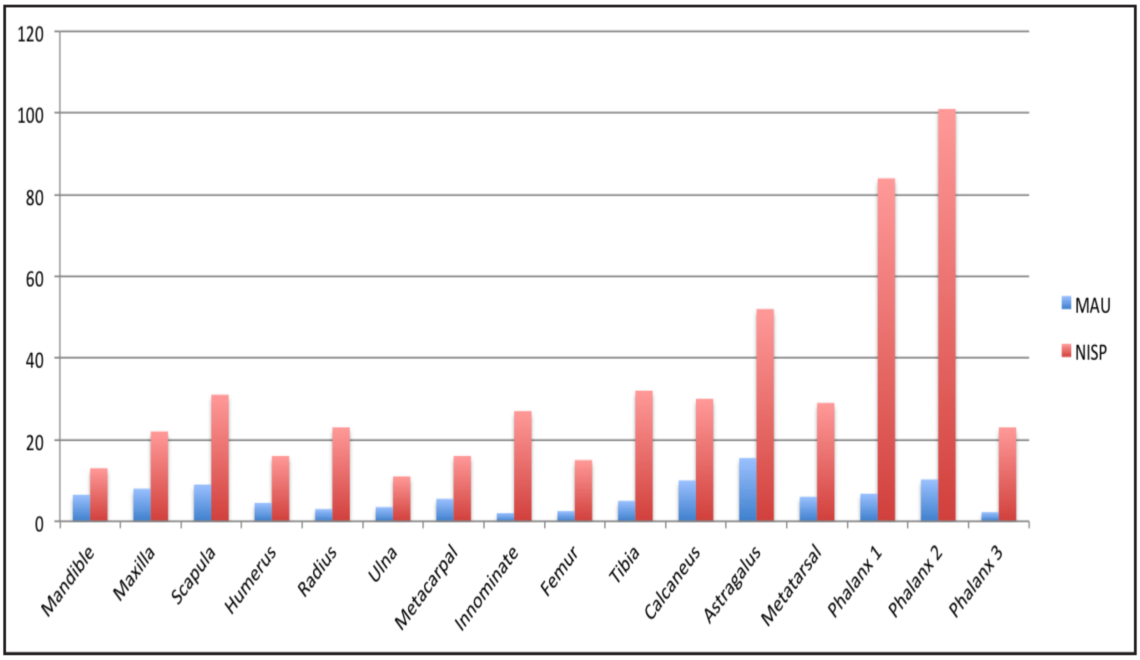
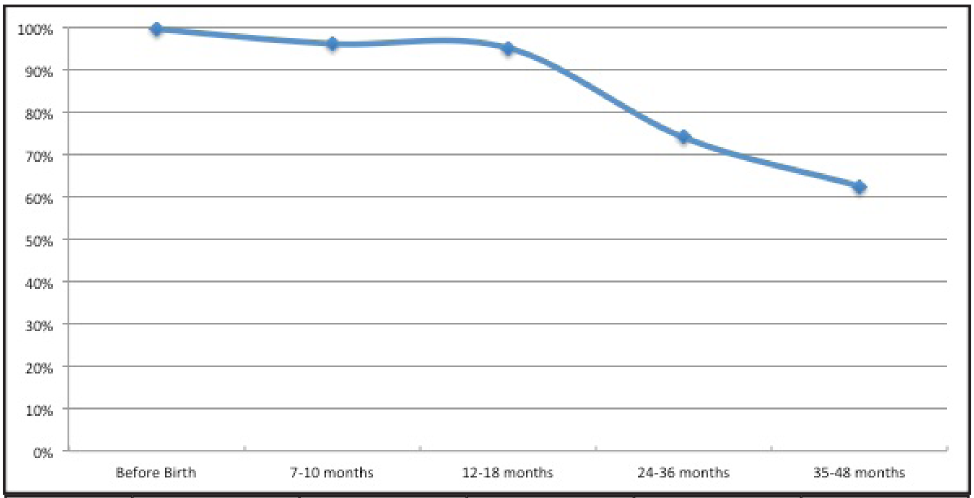


Figure 3.2: *Bos taurus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	7-10 Months	12-18 months	24-36 months	35-48 months
Fused	204	50	177	20	35
Unfused	1	2	9	7	21
Total	205	52	186	27	56

Figure 3.3: *Bos taurus* survivorship at Kent as a percentage in five fusion stages with number of specimens for each fusion stage.

Capra hircus, and the ovicaprid category (73% of total NISP). *Canis familiaris* contributes just over 1% to the assemblage, and was likely domesticated and used to assist in herding and guarding. Many of the rodent species are likely taphonomically intrusive, such as *Sciuridae* spp*. Marmot marmot* is a known delicacy and *Castor* spp. has provided bone material for worked artefacts so potentially these rodent species are not intrusive but instead part of consumed assemblage.

3.3.2 *Bos taurus*

Loose teeth and bones from the feet dominated the NISP of *Bos taurus* (Figure 3.1, 3.2). Ribs were not identified to taxon and instead identified to size class (Table 3.5). Hence a lack of axial bones, such as vertebrae and ribs does not indicate a transportation bias for limbs and skulls. Figure 3.1 displays the NISP, colour-coded to body region. The bones that form the girdles, the scapula and the pelvis, are well represented. The pelvis is covered in the most tender and greasiest meat of the rump, while the scapula has more tough muscle tissue cover. The limb bones are nearly as numerous as the girdle bones. In Figure 3.2, the MAU values have controlled for the overrepresentation of the foot bones, yet they still comprise a large proportion of cattle bones from Kent. Eighty-four percent of the first phalanges display exotosis on the proximal posterior articular surface, while thirteen specimens exhibit moderate to severe caudal lipping (Johannsen 2002). Five second phalanges also display exostosis at the proximal articulation. There is a multi-casual aetiology of this particular pathology which may originate from age, weight, or repetitive strain (Groot 2002, Thomas 2008). This exotosis cannot be interpreted as evidence of repetitive strain induced by traction without the presence of other pathologies on other elements of the skeleton, such as pathologies on the acetabulum and distal metatarsals which are not present in this assemblage (Bartosiewicz 2013, Groot 2002).

A figure of survivorship percentages based on bone fusion indicates that a good proportion of the population survived past four years of age (Figure 3.3). While it appears that there are no neonatal remains, this is a common problem (Halstead 1989) and is likely related to taphonomy. There is a drop off in survival between 18 months and 24 months of about 20%, indicating that some animals were slaughtered at this time. Most of the cattle present in this assemblage were over four years of age at death and it is likely that cattle were exploited for secondary products. Investigations into the animal bones from previous excavations at Kent suggest that the cattle herd is largely female to maximise secondary product output such as dairy (Outram *et al.* 2012, see chapter 6). Cultural interpretations for the presence of older animals, such as a signifier of wealth, are unlikely as horses are the animal that has associated cultural significance and is found in funerary and ritual contexts (Outram et al.

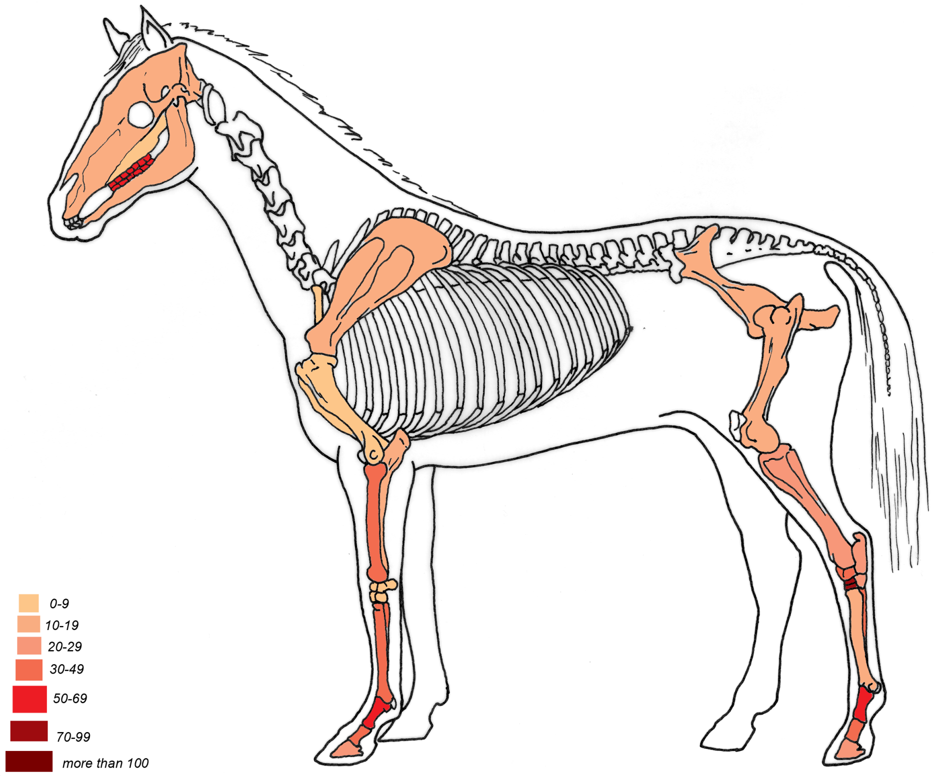


Figure 3.4: *Equus caballus* elements from Kent, NISP.

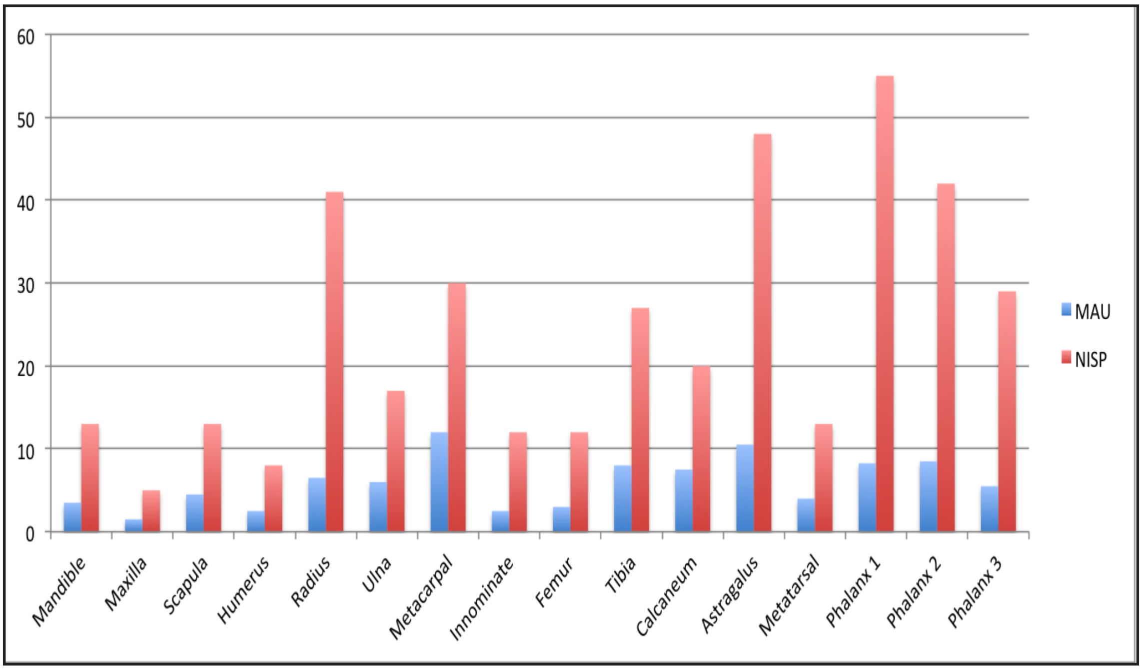
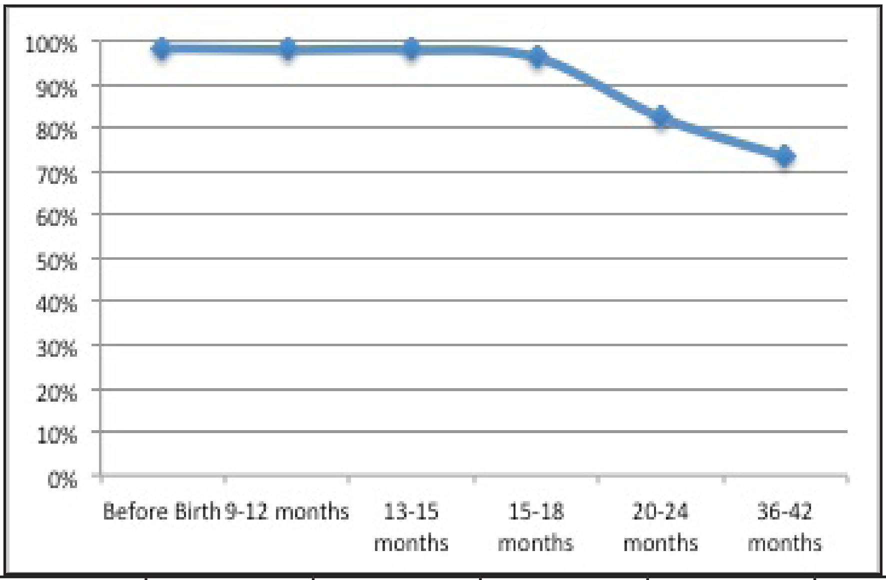


Figure 3.5: *Equus caballus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	9-12 Months	13-15 months	15-18 months	20-24months	36-42 months
Fused	117	47	47	25	28	41
Unfused	2	1	1	1	6	15
Total	119	48	48	26	34	56

Figure 3.6: *Equus caballus* survivorship at Kent as a percentage in six fusion stages with number of specimens for each fusion stage.

2011). Cattle have no presence in these contexts.

3.3.3 *Equus caballus*

Bones from the feet and loose teeth also dominate the NISP of *Equus caballus*, although to a lesser degree than cattle (Figure 3.4). There are more lower limb bones such as the radius than bones from the girdles or upper limb (Figure 3.5).

The survivorship percentages indicate that most horses were slaughtered after three and a half years (Figure 3.6). Like cattle, horses were likely exploited largely for secondary products, such as for transportation. There is a small dip in survivorship between 18 months and 20 months, indicating that some young individuals were slaughtered, but the majority of the population survived to adulthood.

3.3.4 Ovicaprids

Ovis aries and *Capra hircus* specimens are numerous enough at Kent to be displayed alongside the combined ovicaprid category. At Kent, the sheep and goat are displayed along with the ovicaprid NISP in Table 3.9. Elements which have features which allow for speciation, such as the third phalanx, have fewer bones in the 'ovicaprid' category. In contrast, the first phalanx can be difficult to speciate, and hence most of the first phalanx elements are recorded as ovicaprid, rather than as *Ovis aries* or *Capra hircus*. Figures 3.7 and 3.8 further show the discrepancy between elements which can be speciated (Figure 3.8) as opposed to those which can not (Figure 3.7).

In Figure 3.10, all sheep, goat and ovicaprid elements are combined and are shown as NISP and MAU. There are many scapulae and humeri, which are relatively meaty areas (Figure 3.10). There are numerous mandibles and maxillae, suggesting a large number of deposited skulls. The high amounts of foot bones are moderated in the MAU values and further emphasise the meaty elements.

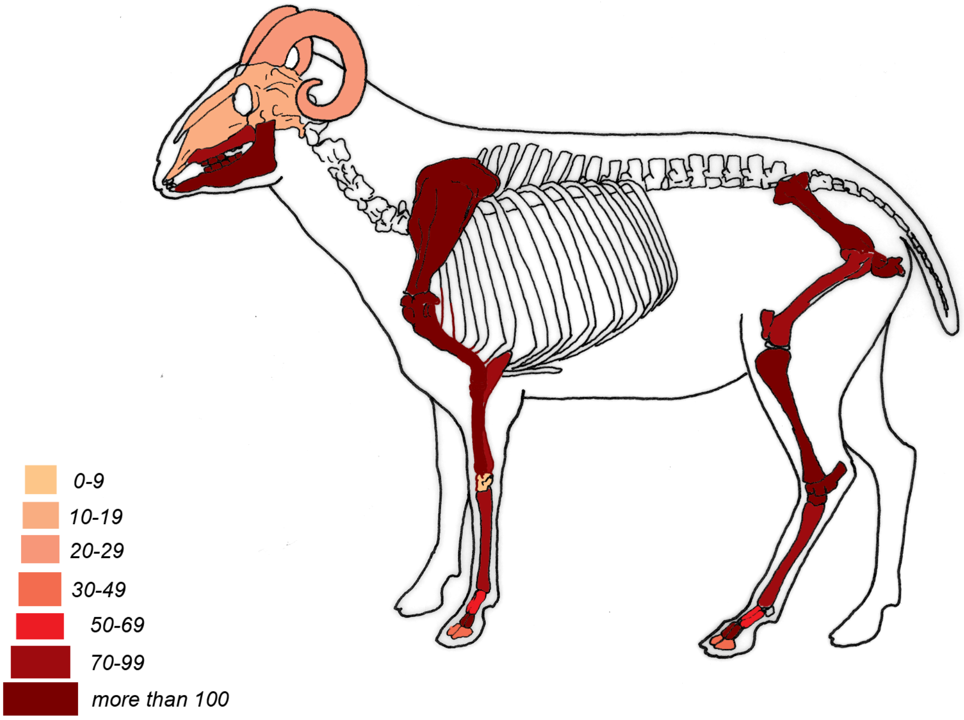


Figure 3.7: Ovicaprid Elements from Kent, NISP.

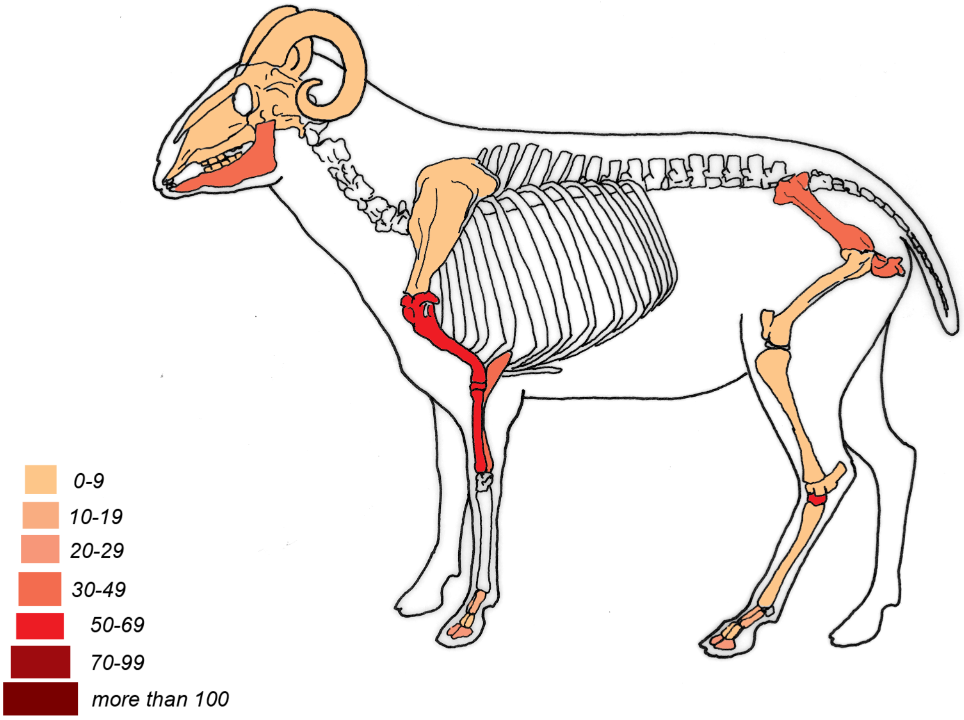


Figure 3.8: *Ovis aries* elements from Kent, NISP.

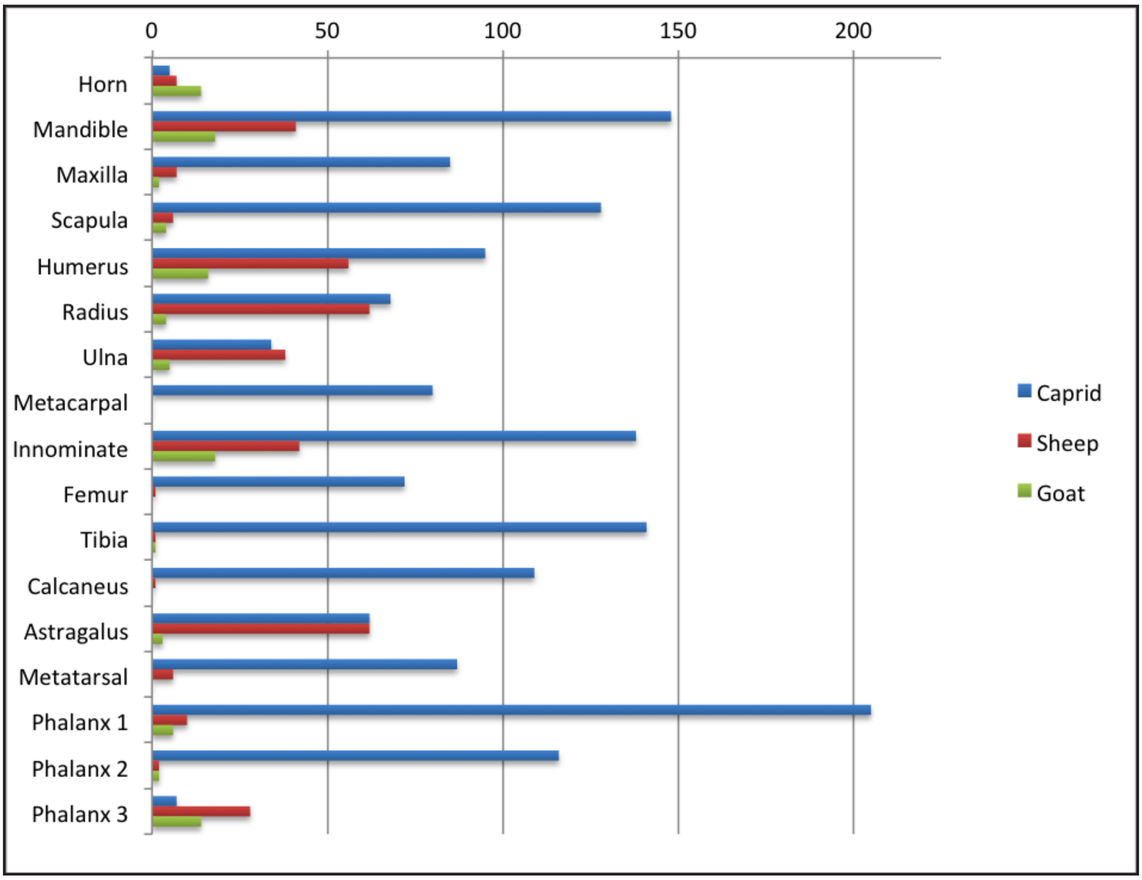


Figure 3.9: Ovicaprid Elements from Kent, NISP. Goats are green, sheep red, and caprids are blue.

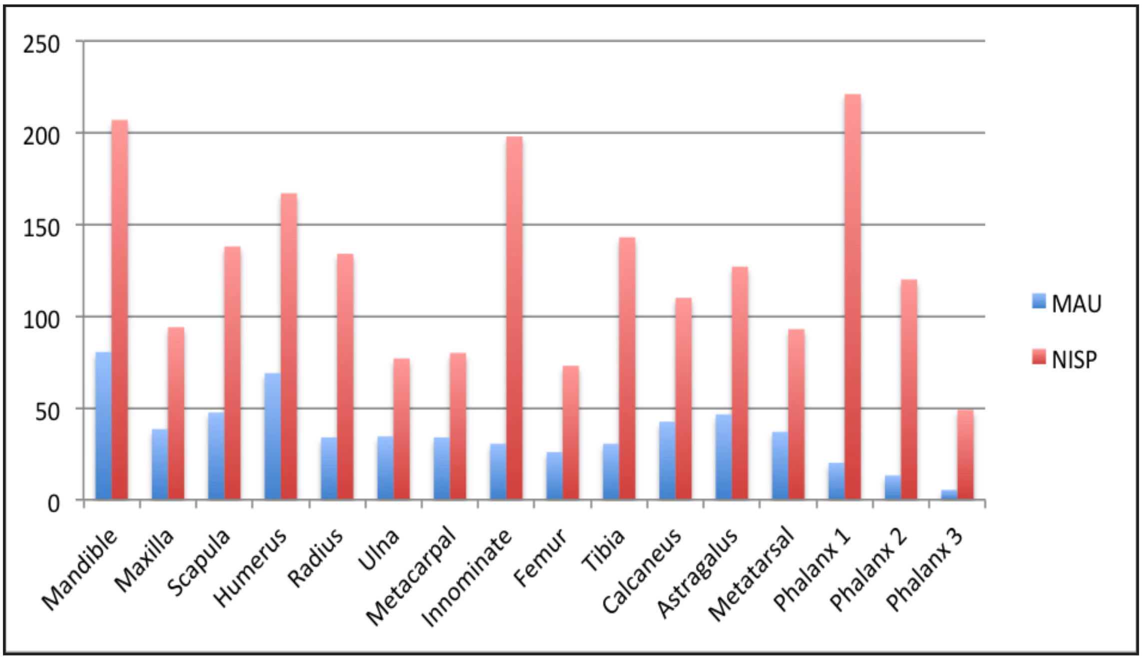
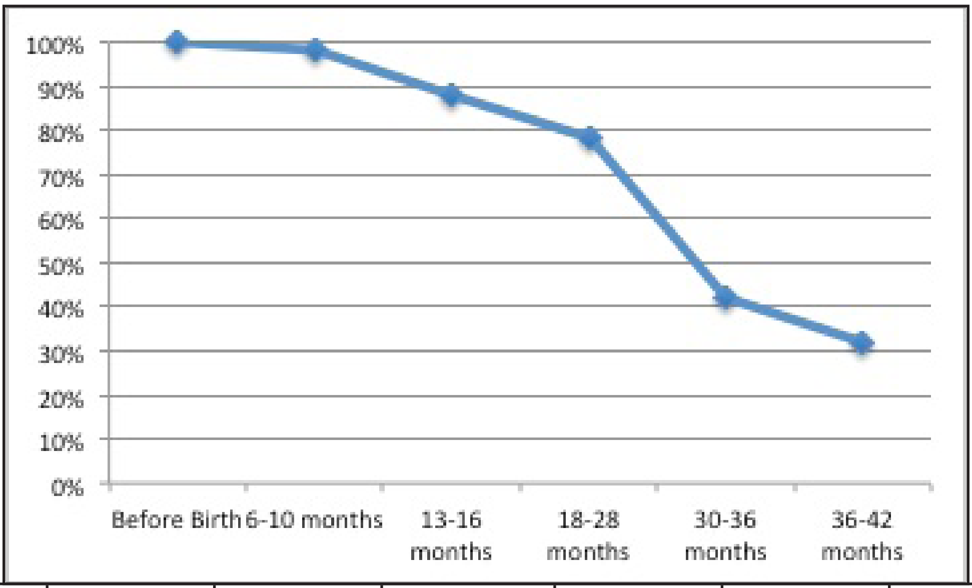


Figure 3.10: Ovicaprid skeletal part abundance, presented as NISP and MAU.



	Before Birth	6-10 Months	13-16 months	18-28 months	30-36 months	36-42 months
Fused	481	513	259	115	93	11
Unfused	2	11	35	32	131	23
Total	483	524	294	147	224	34

Figure 3.11: Combined ovicaprid survivorship at Kent as a percentage in six fusion stages with number of specimens shown for fusion stage.

Figure 3.12: Ovicaprid kill-off pattern based on mandible ageing data.

The figure that depicts the percentages of survivorship stages which combines ovicaprids, sheep, and goats (Figure 3.11) indicates that most individuals did not survive past three and a half years. Only 30% of the deposit displayed bone fusion past that age. Instead, most of the assemblage comprises individuals younger than 28 months, or two years of age. This would indicate that ovicaprids were not exploited for secondary products, such as wool, but instead were consumed for meat.

The ovicaprids from Kent was the only species category that was numerous enough to merit analysis of ageing by tooth wear. Mandible wear data (Table 3.8) would support an interpretation of primary product exploitation. Plotted against Payne's (1973) plots for primary and secondary exploitation, it is clear that Kent mimics the slope of the meat cull pattern (Figure 3.12).

A plot of the three main domesticates for Kent display the skeletal part abundances, presented at %MAU (Figure 3.13). The ovicaprid category has a predominance of mandibles and humeri, as well as a high proportion of bony feet elements. In comparison with Table 3.1, the elements from the feet are more complete than more meaty appendicular elements- in particular the innominate, which is on average 33% complete, while the femur is only 16% complete. Yet other friable appendicular elements, such as the scapula, are 48% complete. A high proportion of helical fragmentation at Kent (71%) suggests that appendicular bones may have been exploited for marrow consumption. This is supported by a low average completeness for metatarsals (27%), which are not meaty elements.

Horse and cattle skeletal part abundance as presented in Figure 3.13 are

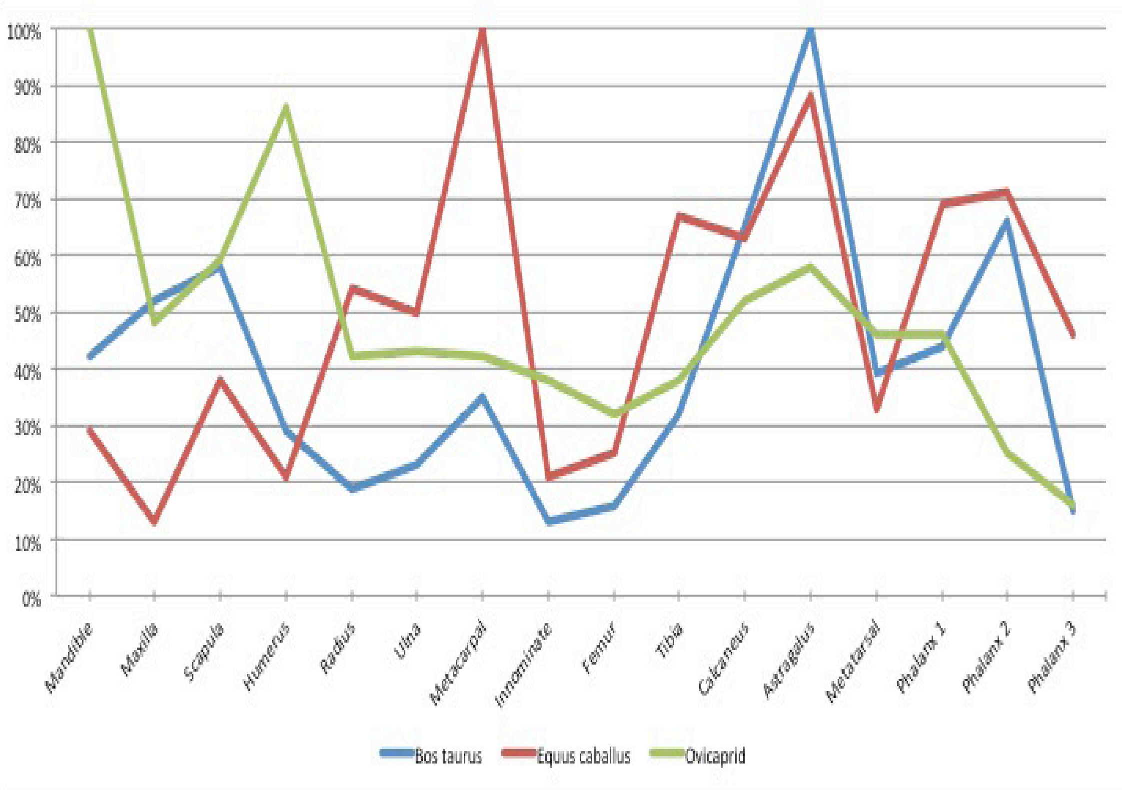


Figure 3.13: Comparision of three main domesticates as %MAU.

dominated by bony foot elements, such as metacarpals and astragalus. In comparison with Table 3.1, the small dense elements of the feet, such as the astragalus and phalanx 1, are nearly complete, and their abundance in the %MAU plots are explained. However, the dominance of elements such as the metacarpal, which is only 28% complete for horse, and the metatarsals at 34% and 36% complete for horse and cattle respectively, contrasts with their abundance in the %MAU. This abundance is clearly not taphonomic, and with the evidence for similar low completeness rates for other appendicular elements and high helical fragmentation, indicates that marrow exploitation is likely. Such an observation must be tempered with an acknowledgement of the taphonomic considerations; a higher %MAU may still be caused by a high rate of fragmentation, despite the use of this derived measurement to control for such fragmentation.

Table 3.8: Mandible wear stages for *Ovis aries*, *Capra hircus*, and ovicaprids according to Payne (1985).

Wear Stage	Number
A	0
B	2
C	4
D	9
E	4
F	9
G	15
H	1
I	1

3.4 Serektas

There were 2772 bones analysed from the site of Serektas. One thousand thirty-eight bones could be identified to element (Table 3.9). The unidentified fragments totalled 1234 and were recorded as long bone fragments, rib fragments, or very small fragments (Table 3.10). There are 145 fragments smaller than five centimetres, 728 long bone fragments larger than five centimetres, 86 medium mammal ribs, and 36 large mammal ribs. There are 134 fragments that are identifiable to element, but could not be identified to

Table 3.9: Bone analysed from Serektas.

Unidentified Fragments	Identified Specimens	Total
1234	1038	2272

Table 3.10: Number of specimens

Type of Bone	Number of Specimens
Unidentified (smaller than 5cm)	
Unburned	N/A
Burned	N/A
Total	145
Long Bone Fragments (larger than 5cm)	
Unburned	N/A
Burned	N/A
Total	728
Medium Mammal Ribs	86
Large Mammal Ribs	36
Spongy Epiphyses	0
Skull Fragments	0
Calcified Cartilage	0
Vertebrate Fragment	0
Small Mammal	0
Medium Mammal	134
Large Mammal	105
Grand Total	1234

Table 3.11 Types of fragmentation (NISP)

Longitudinal	Helical	Modern	Total
270 (34%)	457 (47%)	72 (9%)	799 (100%)

species, and instead are identified to medium mammal size class. There are 105 elements that were identified to large mammal size class.

Fifty percent of fragments could not be identified to taxon or size class. This is not a very large percentage and suggests two possibilities- that the animal bones which were recovered were largely from untrampelled deposits, for example middens and pits, or that the majority of the bone fragments were too small to be recovered by hand, and were not recovered from the site.

Fifty-seven percent of elements identified to species (NISP) with fractures had helical breaks, or breaks which occurred when the bone was fresh, while 34% had dry breaks- or breaks which occurred after the bone had been dried out (Table 3.11). Only 9% of the bones had modern breaks from excavation and handling. The high percentage of helical breaks indicates that people were actively breaking the bones, most likely to extract the bone marrow.

3.4.1 NISP

Serektas is a very unusual site as there is a large percentage of horse remains (Table 3.12). Thirty-two percent of the NISP is *Equus caballus,* which is a very high percentage in comparison with other Bronze Age sites in Eastern and Central Kazakhstan. Interestingly, there is 6% *Equus hemionus* at Serektas. Once again, because of a lack of reference material, it was impossible to tell if these smaller equids were wild, but it was clear that they were a different

Table 3.12: Serektas NISP

Species	NISP	% of NISP
Bos taurus	113	10.9%
Equus caballus	328	31.6%
Equus hemionus	62	6%
Cervus elaphus	6	0.6%
Capreolus pygargus	14	1.3%
Ovicaprid (sheep/goat)	446	43%
Ovis aries	46	4.4%
Capra hircus	2	0.2%
Marmot sp.	2	0.2%
Canis familiaris	3	0.3%
Rodent	16	1.5%
Total	1038	100%

species from domesticated horse.

The ovicaprid (sheep and goat), *Ovis aries*, and *Capra hircus* combine to 47% NISP, which is a typical percentage for Bronze Age sites in Kazakhstan (Table 3.12, Haruda 2007, Outram *et al.* 2011). *Cervus elaphus* (1%) likely represents the occasional consumption of meat from wild animals, and the less than 1% of *Marmot marmot* also likely indicates occasional consumption. There are very few remains of *Canis familiaris* (>1%) and the 2% of rodent bones are most likely intrusive or lived on the site as commensals rather than being consumed.

3.4.2 *Bos taurus*

There are few cattle bones at Serektas. The NISP (Figure 3.14, 3.15) show a high number of meaty girdle elements, such as the scapula and innominate with a typically high amount of foot bones. However, the MAU values indicate that the skeletal parts which are most abundant are the tibia, astragalus, and metatarsals.

The cattle at Serektas show a cull from the 18-month to 24-month range (Figure

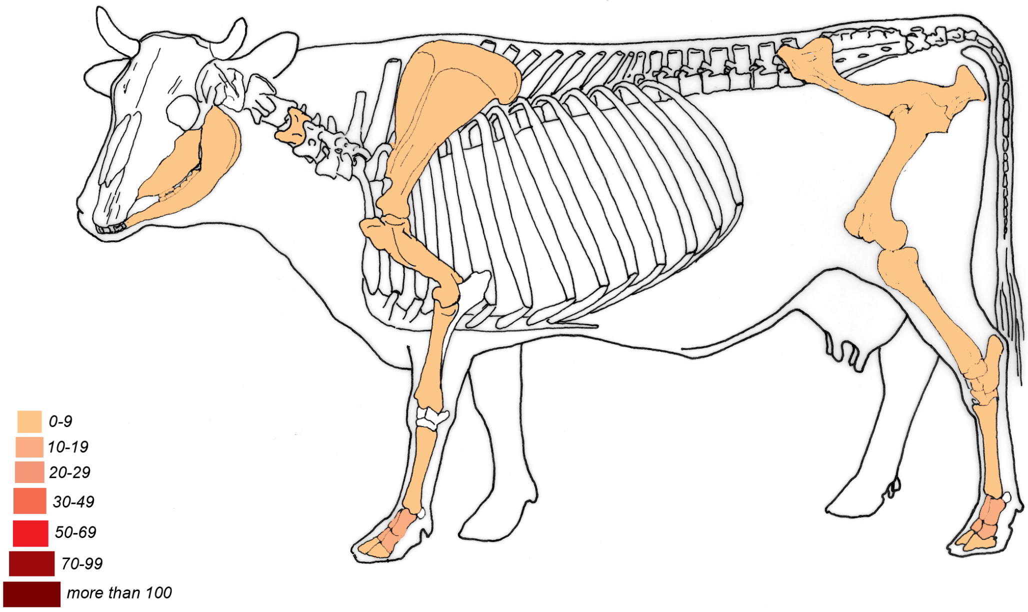


Figure 3.14: *Bos taurus* elements from Serektas, NISP.

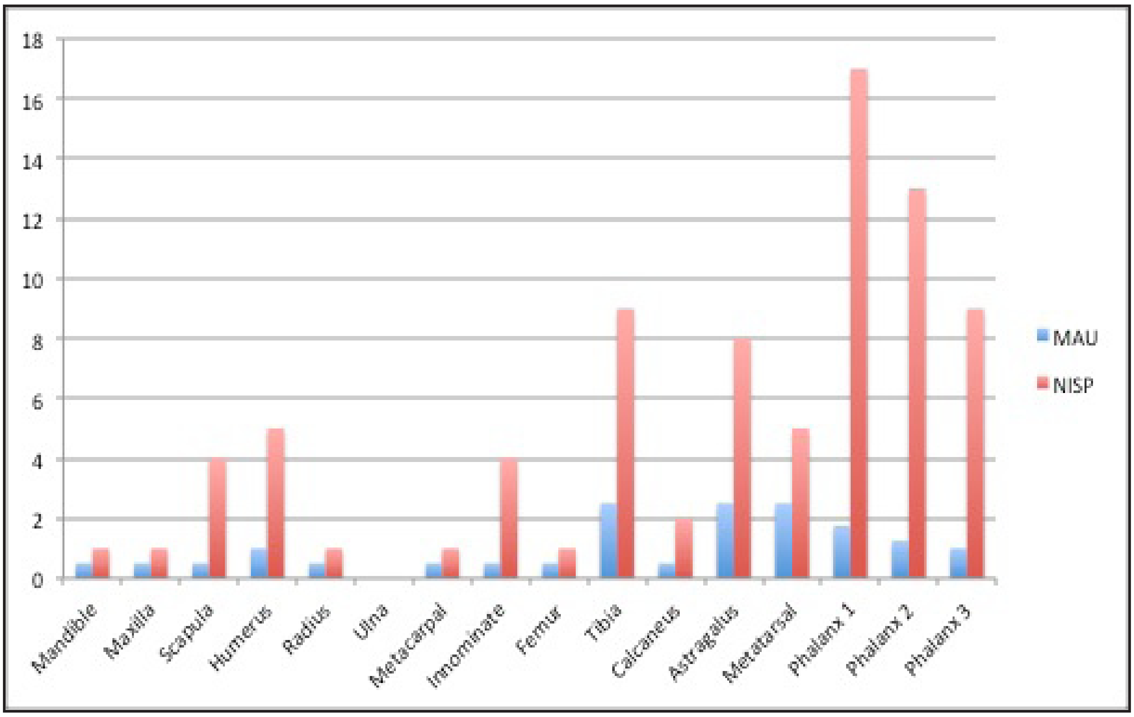
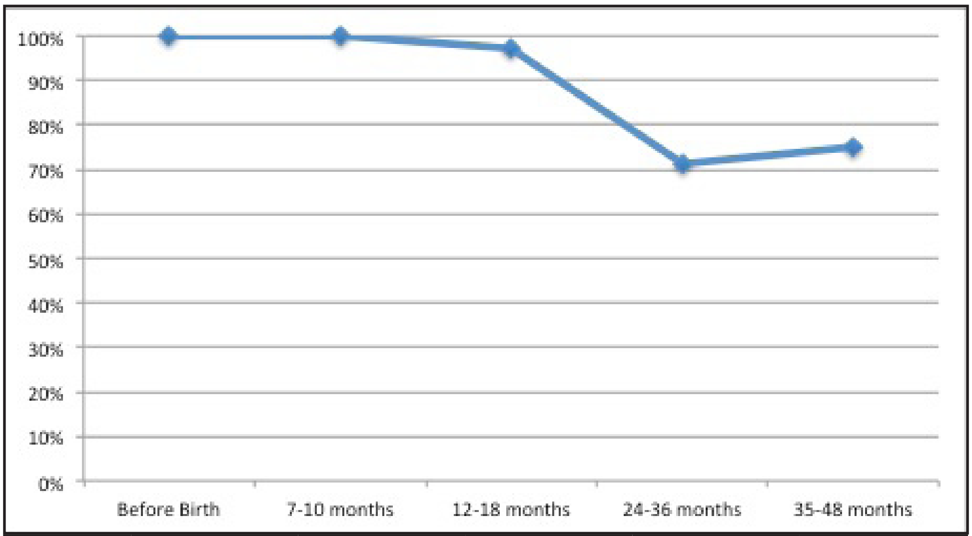


Figure 3.15: *Bos taurus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	7-10 Months	12-18 months	24-36 months	35-48 months
Fused	35	4	29	15	3
Unfused	0	0	1	6	1
Total	35	4	30	21	4

Figure 3.16: *Bos taurus* survivorship at Serektas as a percentage in five fusion stages with number of specimens for each fusion stage.

3.16). This could represent early culling for meat or a cull of surplus male calves. However, 75% of the cattle at Serektas survived beyond 48 months of age before they were slaughtered. This later slaughter pattern indicates that cattle were not being bred for meat. While it is clear that some cattle were killed while young, the majority of the population survived. This survival indicates that cattle were being exploited for secondary products, such as milk, which can be produced throughout the animal's lifetime.

3.4.3 *Equus caballus*

Bones from *Equus caballus* were much more numerous than nearly every other species on site, excepting the ubiquitous ovicaprid category. Included with this section are data from the *Equus hemionus*, which was numerous enough to merit analysis.

The NISP of the *Equus caballus* presents a profusion of radii and phalanges (Figure 3.17, 3.18). Yet the MAU values, which are adjusted to control for fragmentation and skeletal part frequency, indicate an even spread of elements across the skeleton. The NISP and MAU values for *Equus hemionus* indicate a preponderance of bony foot elements, as well as the presence of a few meaty elements, such as the humerus and femur (Figure 3.20).

While there is a large amount of equid bone on the site, the survivorship graphs do not show any distinct signs of culling for meat. If a population of animals were being bred for meat, there would be a distinct drop in survivorship. Figure 3.19 illustrates that 80% of horses survived beyond 20 months when they were killed. There is a drop between 20 months and 42 months and the percentage of animals that survived dropped to 64%. Nearly all of the horses at Serektas were consumed after all of their long bones had finished growing at 42 months of

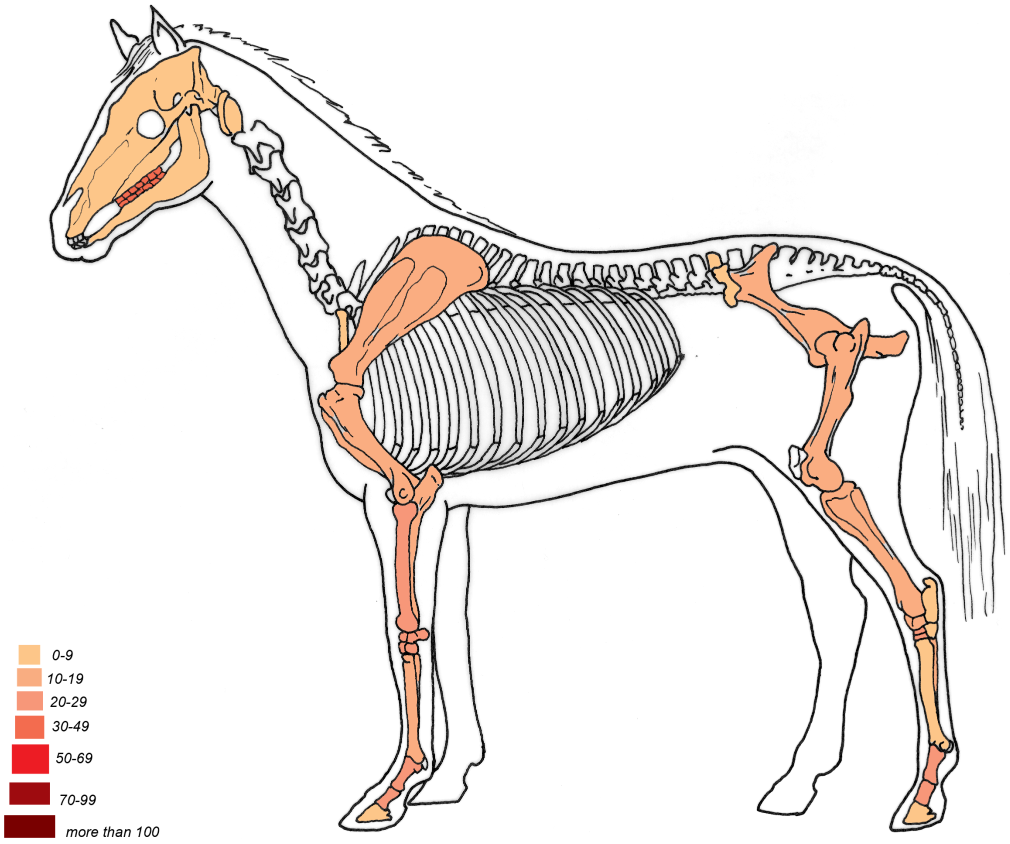


Figure 3.17: *Equus caballus* elements from Serektas, NISP.

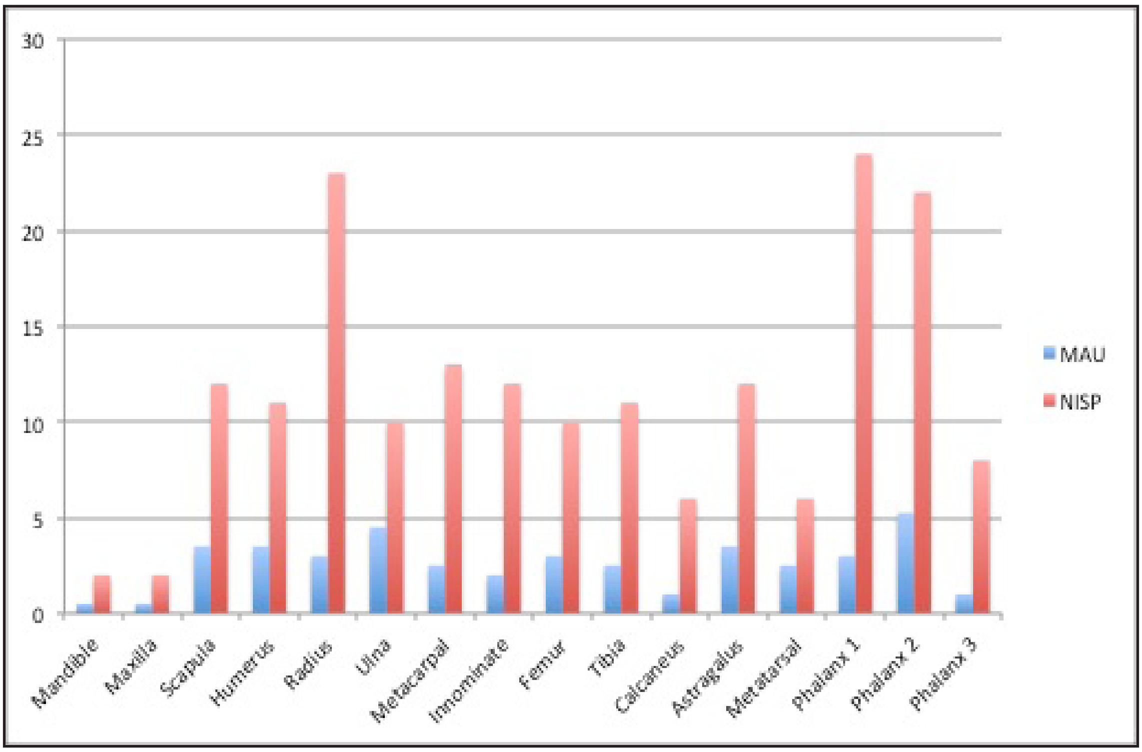
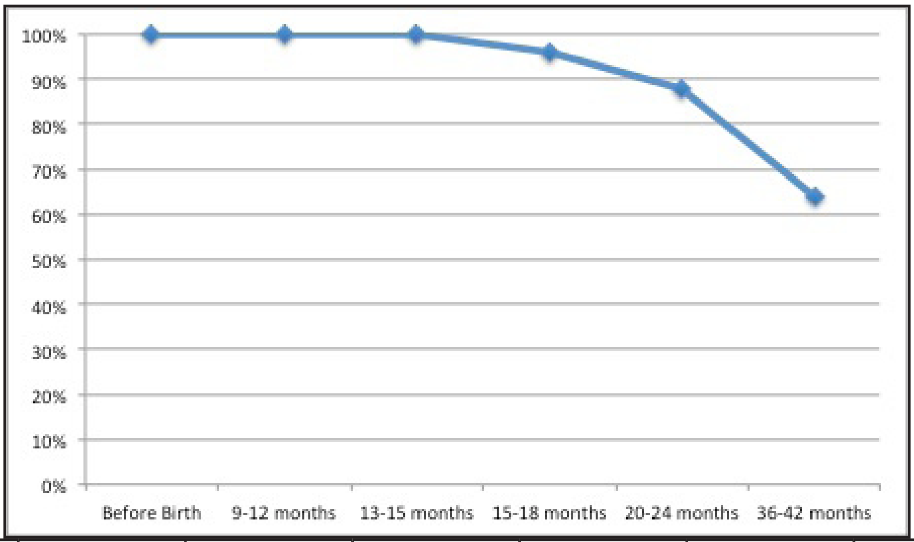


Figure 3.18: *Equus caballus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	9-12 Months	13-15 months	15-18 months	20-24months	36-42 months
Fused	52	30	15	46	15	23
Unfused	0	0	0	2	2	13
Total	52	30	15	48	17	36

Figure 3.19: *Equus caballus* survivorship at Serektas as a percentage in six fusion stages with number of specimens for each fusion stage.

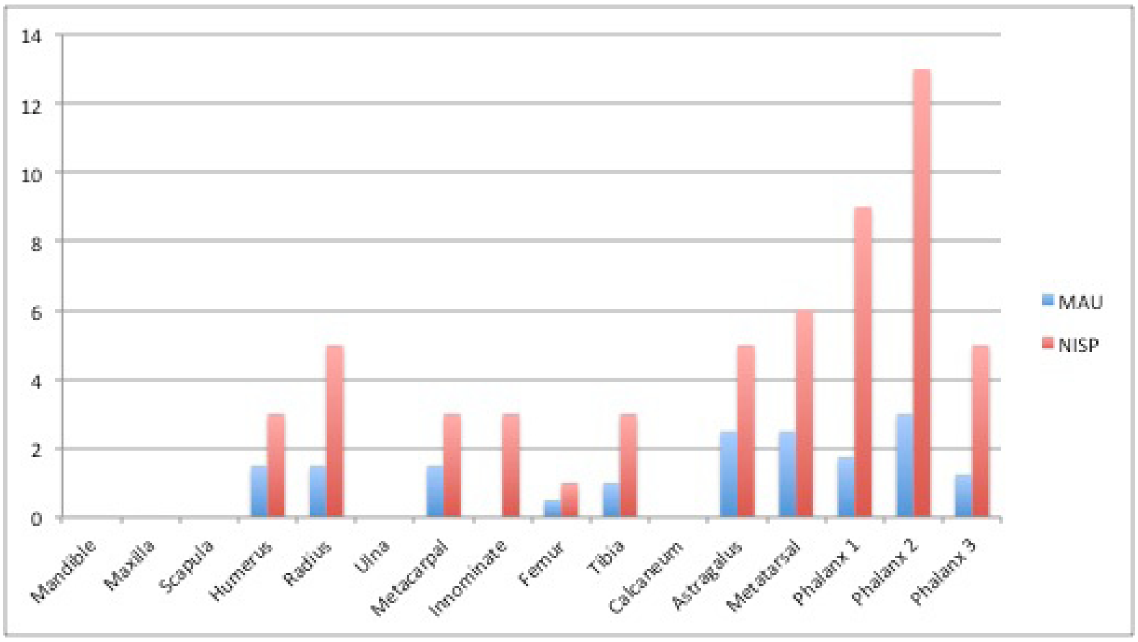
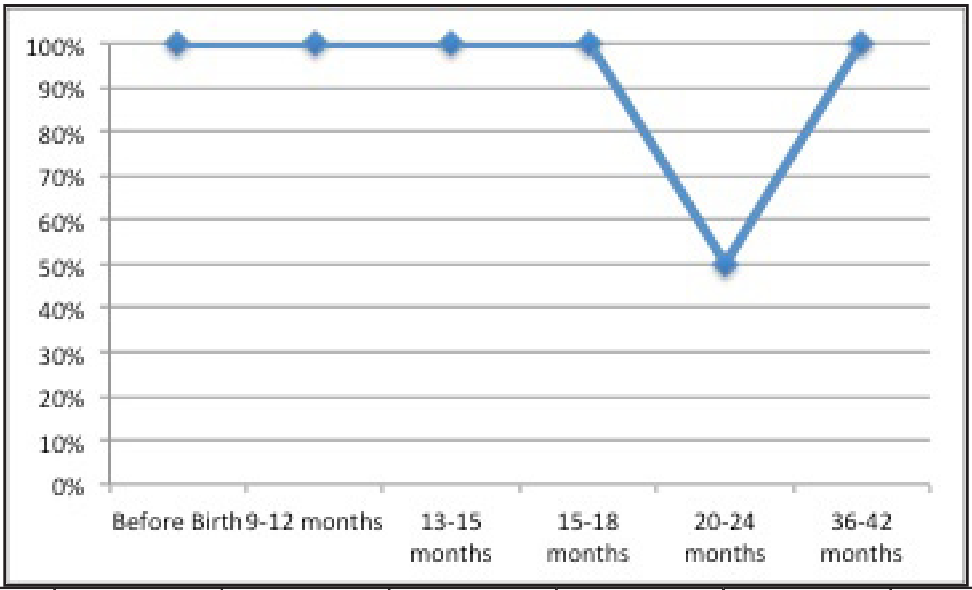


Figure 3.20: *Equus hemionus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	9-12 Months	13-15 months	15-18 months	20-24months	36-42 months
Fused	23	13	7	15	1	5
Unfused	0	0	0	0	1	0
Total	23	13	7	15	2	5

Figure 3.21: *Equus hemionus* survivorship at Serektas as a percentage in four stages.

age. This type of consumption pattern indicates that horses were likely exploited for secondary products, such as milk, before they were consumed.

The percentage of *Equus hemionus* at Serektas is unusually high and is largely from quadrants 2A, 3A and 3A*. The data from these bones shows that only one animal was killed before it reached 20 months of age- the rest of the bones show that all of the these individuals were killed after 42 months of age (Figure 3.21). Once again, this seems to suggest that these animals were being exploited for secondary products. As it is unclear from the bone morphology whether these were domesticated or wild, it is important to remember that donkeys were most likely domesticated in this area by this time. There is evidence that donkey was domesticated by at least the third millennium BC in Persia and Syria and much earlier (5th millennium BC) in Egypt (Rossel et al. 2008). While it is not certain, this exploitation pattern may suggest that presence of domesticated donkeys, rather than wild kulan (Chapter 6).

3.4.4 Ovicaprids

All of the elements from *Ovis aries, Capra hircus,* and ovicaprid categories are combined in this analysis. The number of specimens identified to taxon was so small as to make analysis of each species untenable. Instead, they have been combined into an overall ovicaprid category for analysis.

Unlike other species at Serektas, foot bones do not dominate the elements from ovicaprids. The phalanges are relatively few, and the profusion of first phalanges is modified in the MAU value (Figure 3.22, 3.23). There is a smaller proportion of *Canis familiaris* at Serektas than at any other site in this study (less than 1%), which suggests that the loss of these elements was not due to carnivore gnawing and digestion. The mandibles, the girdles and the limb bones

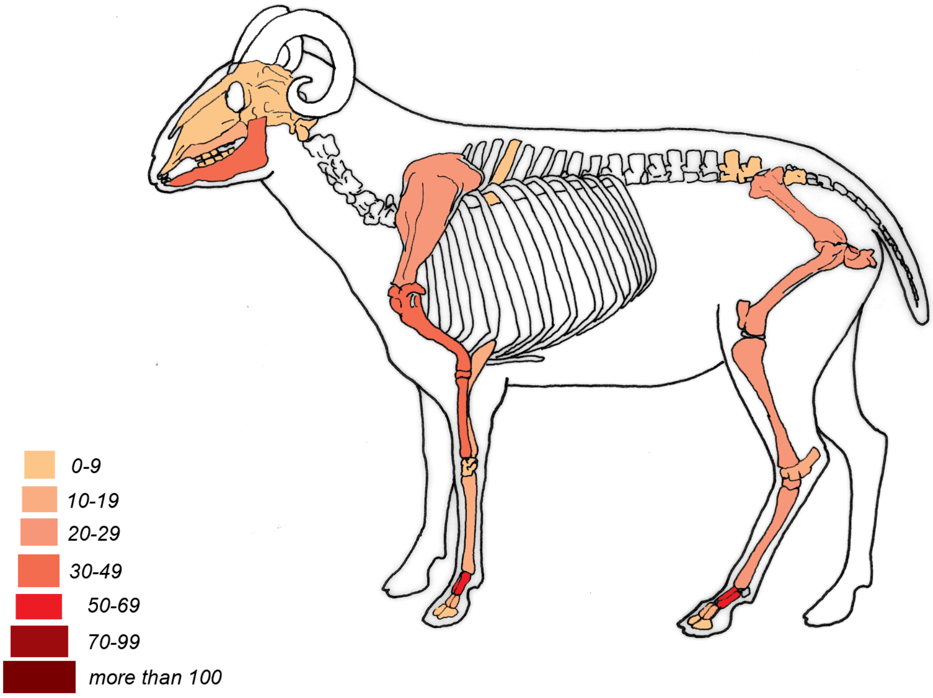


Figure 3.22: Ovicaprid Elements from Serektas, NISP

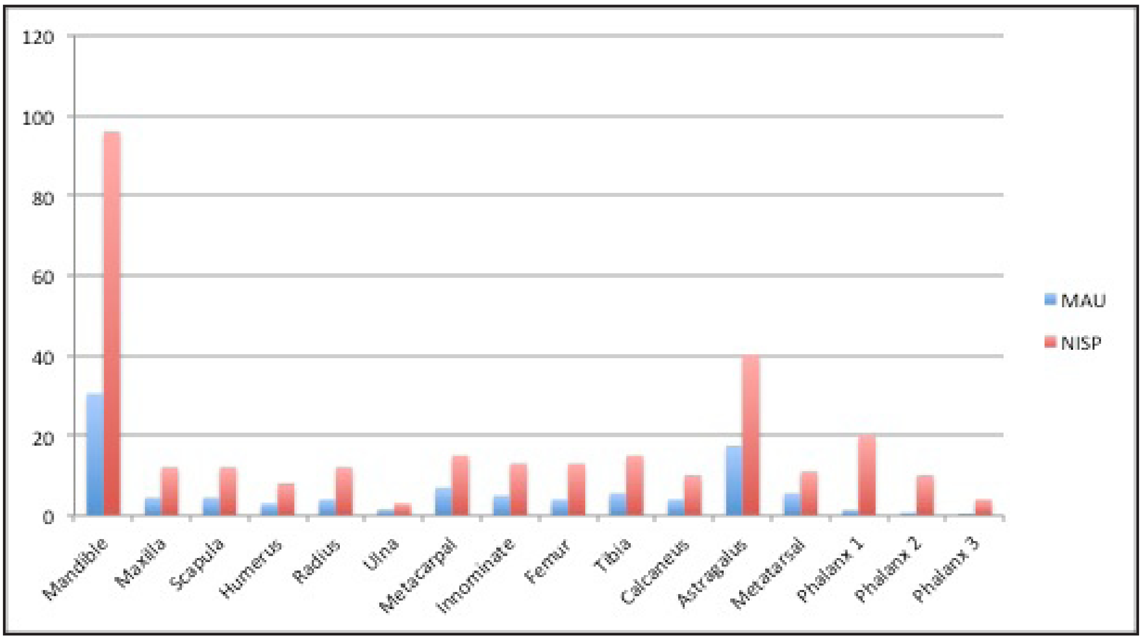


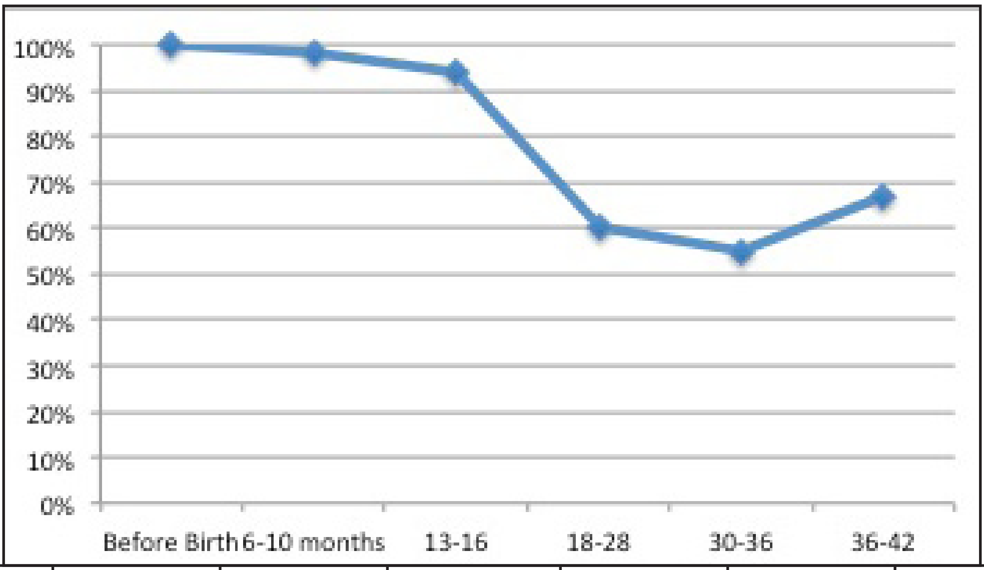
Figure 3.23: Ovicaprid skeletal part abundance, presented as NISP and MAU.

are the most numerous skeletal elements.

The survivorship graph from all the ovicaprids from Serektas includes all *Ovis aries, Capra hircus*, and ovicaprid specimens. The survivorship graph shows that the population slowly decreased, with few animals killed before 15 months of age. After the 13-16 month age range, 30% of the animals were killed, leaving 60% of the population alive. More animals were killed after 18-28 month range, leaving only 55% of the population alive. Approximately half of the animals survived past 42 months.

A large drop in the population of caprines is typical for a meat cull. After 13-18 months, animals reach optimum size for slaughter; economically it is not profitable to continue feeding animals which will not put on much more carcass weight after this age. However, in herds which are raised largely for meat, most animals will be killed before the 36-42 months range. In this population however, nearly half of the population survived past four years before they were consumed. This could indicate exploitation of the herd not just for meat, but also secondary products such as wool.

A plot of the three main domesticates from Serektas, excluding *Equus hemionus*, display skeletal part abundances as %MAU (Figure 3.25). The skeletal part abundances of ovicaprids are similar to those from Kent. There is a predominance of mandibles and scapulae, as well as tibiae. In comparison with Table 3.2, the feet bones again have a high percent completeness, while the other appendicular bones are less than half complete, with the exception of the scapulae which are on average 54% complete. There is a much lower percentage of helical fractures at Serektas than at Kent (47%, Table 3.1). Horse and cattle skeletal part abundance are also similar to those at Kent. The tibiae, astragali and metacarpals are the most numerous for cattle, while the second



	Before Birth	6-10 Months	13-16 months	18-28 months	30-36 months	36-42 months
Fused	109	82	65	44	22	10
Unfused	0	2	4	29	18	4
Total	109	84	69	73	40	14

Figure 3.24: Ovicaprid survivorship at Serektas as a percentage in six fusion stages with number of specimens for each fusion stage.

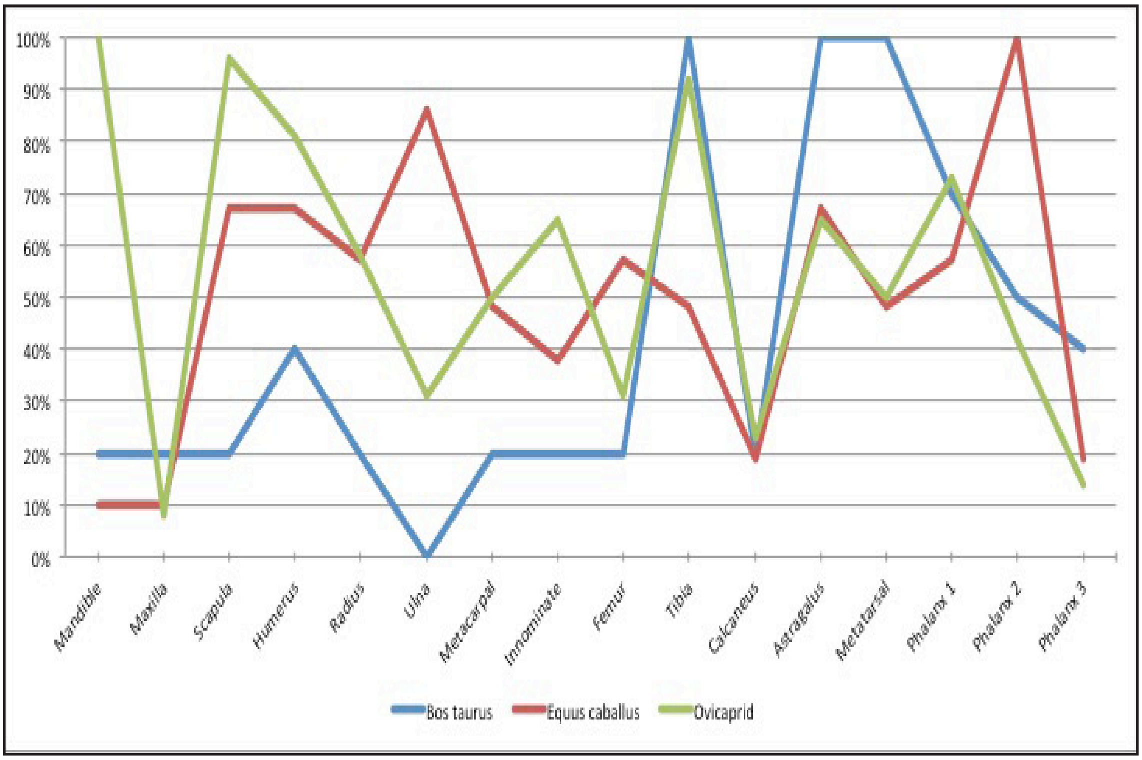


Figure 3.25: Comparision of three main domesticates as %MAU.

phalanges and ulna are the most numerous for horses. While the phalanges, calcanei and astragali are the most complete elements (Table 3.2), the tibiae from *Bos taurus* are the most fragmented. This is in contrast to the %MAU value that indicates that cattle tibiae are the most abundant element. In combination with a lower percentage of helical fracturing, this abundance of tibia may be due to depositional factors. Earlier discussion regarding the breakdown of the NUSP category at Serektas above indicates that taphonomic factors may cloud cultural interpretations of the animal remains at this site.

3.5 Turgen

There were 6787 animal bones recovered from the site of Turgen (Table 3.13). Unidentifiable fragments totalled 5964. There were 2826 fragments smaller than five centimetres, 2436 fragments of long bone that were larger than five centimetres, 196 medium sized mammal ribs and 113 large sized mammal ribs (Table 3.14). There were 393 fragments which could be identified to element, but not to species. Twenty-three fragments were from small mammals, 219 from medium sized mammals, and 141 fragments from large sized mammals.

Table 3.13: Bone analysed from Turgen

Unidentified Fragments	Identified Specimens	Total
5954	833	6787

Table 3.14: Number of specimens.

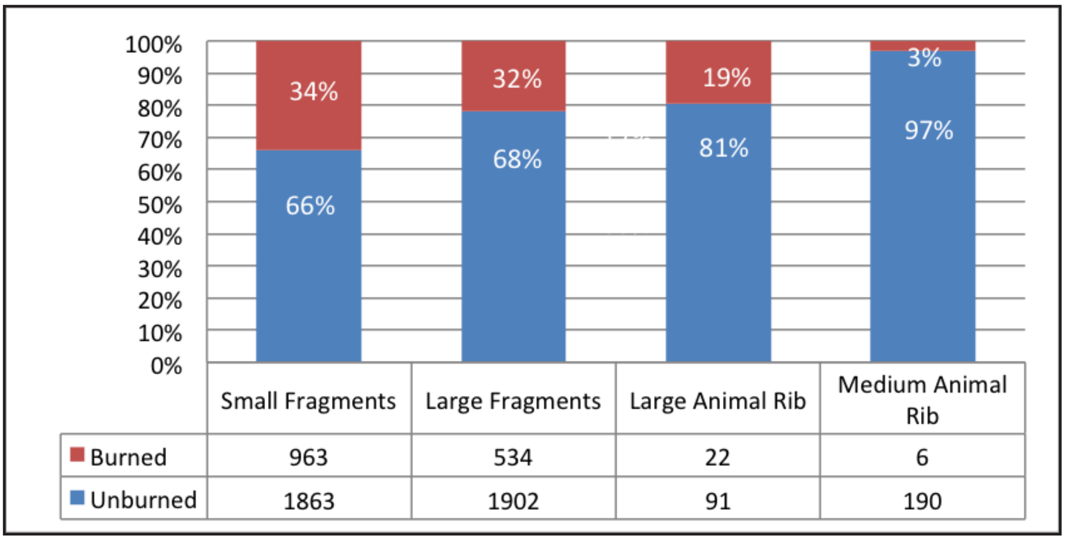
Type of Bone	Number of Specimens
Unidentified (smaller than 5cm)	
Unburned	1863
Burned	963
Total	2826
Long Bone Fragments (larger than 5cm)	
Unburned	1902
Burned	534
Total	2436
Medium Mammal Ribs	196
Large Mammal Ribs	113
Spongy Epiphyses	0
Skull Fragments	0
Calcified Cartilage	0
Vertebrate Fragment	0
Small Mammal	23
Medium Mammal	219
Large Mammal	141
Grand Total	5954

Table 3.15 Types of fragmentation from NISP at Turgen

Longitudinal	Helical	Modern	Total
356 (30%)	651 (24%)	9 (1%)	651 (100%)

The total percentage of the unidentified fragments as compared to NISP and bones that were classified to size class is 88%. This is a typical percentage of NISP from prehistoric sites in Kazakhstan (Haruda 2007). Around a quarter of the unidentified animal bone from Turgen was burned. Burning accounts for 34% of small unidentified fragments at Turgen, while 32% of long bone fragments are burned (Figure 3.26).

This is most likely not due to a difference in disposal for different animal remains, but instead related to bone destruction. Medium-size animals have thinner bone shafts, and are most likely to fracture into smaller unidentifiable pieces during and after burning than large animal long bone shafts (Reitz and Wing 1998). The rib category has a much lower burned percentage, especially for the medium-sized animal category. However, once again, medium-sized animal ribs are much less robust than ribs from large-sized animals. Any burned ribs were more likely to be reduced to small unidentifiable fragments than large-sized animal ribs. Yet in general the ribs are burned less than long bone fragments



	Small Fragments	Large Fragments	Large Animal Rib	Medium Animal Rib
🟥 Burned	963	534	22	6
🟦 Unburned	1863	1902	91	190

Figure 3.26: Turgen Unidentified Fragments and Burning

At Turgen, most of the bone did not have any fragmentation recorded (45%), most likely because small bones, such as carpals and tarsals, rarely fragment, and due to their high number in each animal, can make up a significant portion of the NISP. Helical breaks (24%), which occurred when the bone was wet and had just been butchered, accounted for a quarter of the assemblage, while longitudinal breaks, which occur when the bone is old and dry, accounted for a third (30%) (Table 3.15). This pattern indicates some bone breakage, perhaps for marrow exploitation or in the course of food preparation, but not as great as the percentages of helical fracturing at Kent or Serektas. It is likely that the bones were not exploited systematically for the marrow located inside the bones and instead were discarded without further processing.

3.5.1 NISP

In total there were 833 bones that could be identified to element and taxon. The assemblage was 53% *Ovis aries*, *Capra hircus*, and ovicaprid (combined), 14% *Equus caballus,* and 26% *Bos taurus* (Table 3.16). There is a larger than expected wild animal component at Turgen. It is clear that even though the

Table 3.16: Turgen NISP

Species	NISP	% of NISP
Camelus bactrianus	3	0.4%
Bos taurus	218	26.2%
Equus caballus	117	14%
Equus hemionus	2	0.2%
Cervus elaphus	37	4.4%
Sus scrofa	5	0.6%
Ovicaprid (Sheep/ Goat)	380	45.6%
Ovis aries	55	6.6%
Capra hircus	6	0.7%
Marmot sp.	1	0.1%
Canis familiaris	8	1%
Rodent	1	0.1%
Total	833	100%

percentage of *Cervus elaphus* is small (4%), it is significant enough to show exploitation of wild animal resources in the area. Rodent bones are likely intrusive, however *Marmot marmot* is a delicacy (see Chapter 6). Domesticated dog is present, although not in great numbers, just 1%. Interestingly, *Sus scrofa* is present at Turgen. This species is not commonly found in Central Asian sites, and likely is a wild specimen. The shade sylvan ecology and availability of year round access to water likely made an ideal environment for wild boar or pig.

3.5.2 *Bos taurus*

The elements from *Bos taurus* indicate an even consumption of all body parts on site, with no preferential transportation of body parts. Bones from the feet dominate the assemblage even within the MAU values (Figure 3.27, 3.28). Both meaty and non meaty elements are represented in this assemblage.

All of the cattle bones that could be aged were from individuals that lived until at least 12 months of age (Figure 3.29). There is a small drop in survivorship between 18 to 24 months and again from 36 to 48 months. The majority of cattle slaughtered at Turgen survived past 48 months. Seventy-five percent of the cattle consumed and deposited on the site were older than 4 years of age. The pattern presented here is suggestive of secondary product exploitation. The signature of a secondary production exploitation is evidence for a cull after the male calves had weaned, which would show in a survivorship graph as a large dip in the surviving population from 12 months onwards (Payne 1973).

However, if the population of animals or people is mobile as may be the case at Turgen, it is highly likely the most of the cattle at were slaughtered in different locations, and the herd could have been exploited for a variety of primary and secondary products. The cattle bones from Turgen most likely represent old individuals which no longer had any secondary value and hence were culled. As

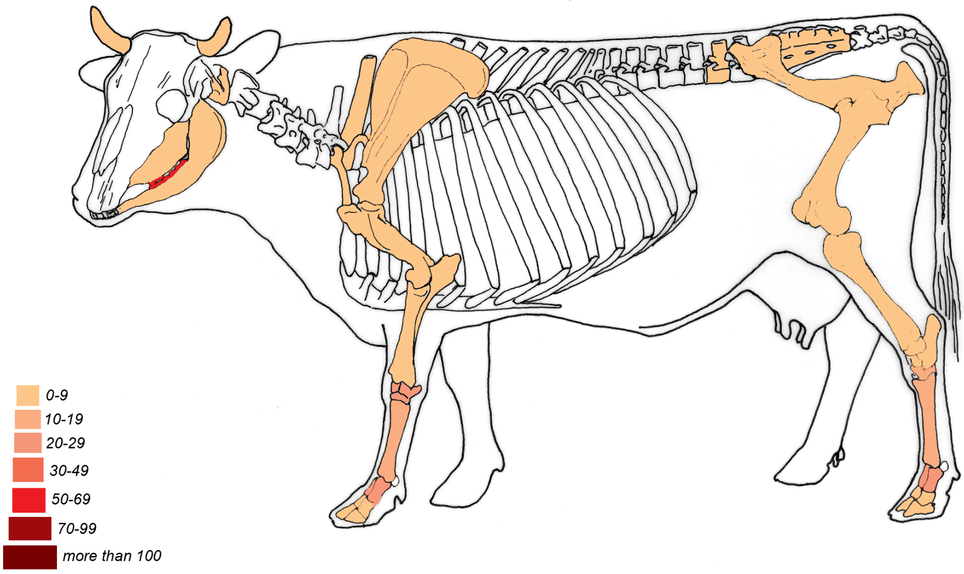


Figure 3.27: *Bos taurus* elements from Turgen, NISP.

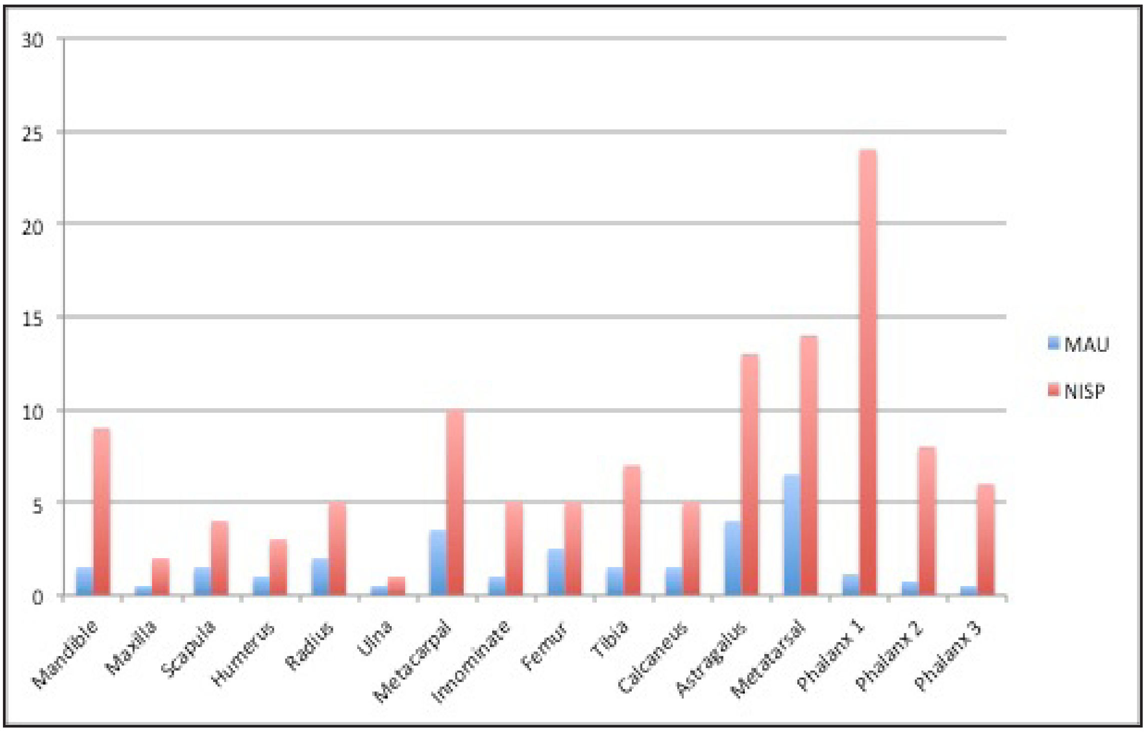
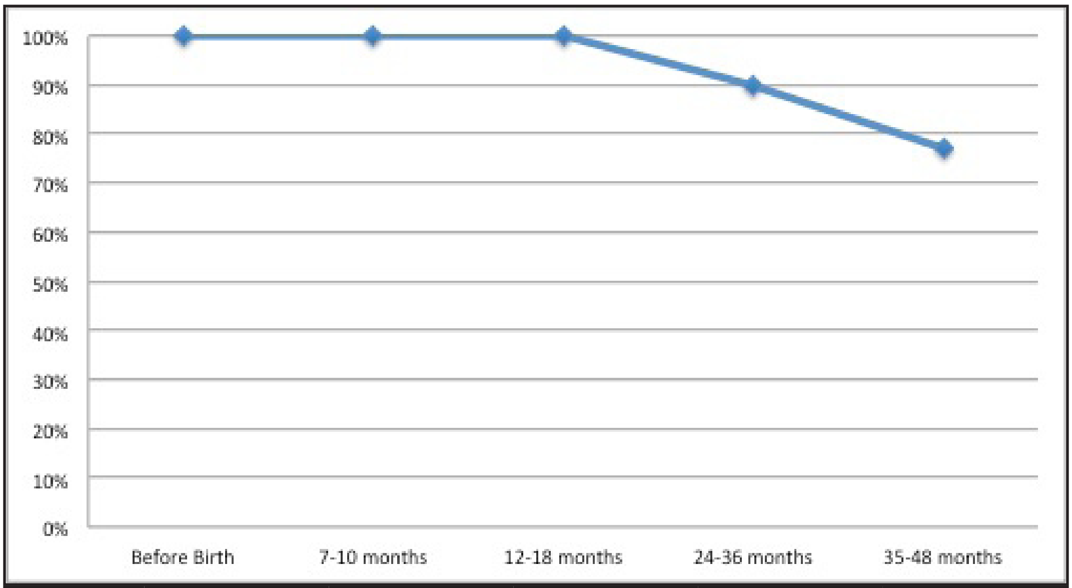


Figure 3.28: *Bos taurus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	7-10 Months	12-18 months	24-36 months	35-48 months
Fused	55	11	34	18	17
Unfused	0	0	0	2	5
Total	55	11	34	20	22

Figure 3.29: *Bos taurus* survivorship at Turgen as a percentage in five fusion stages with number of specimens for each fusion stage..

at Kent, there is no known ritual or cultural value associated with cattle. There are few finds of cattle in funerary and ritual contexts (Outram et al. 2011).

3.5.3 *Equus caballus*

The most numerous *Equus caballus* elements from Turgen are the first and third phalanges in the raw NISP (Figure 3.30, 3.31). The MAU values reduce the abundance of those foot bones and reveal a more balanced presence of nearly all skeletal elements. There are no innominate bones, and few scapulae.

The horse survivorship graph is very similar to that of the cattle (Figure 3.32). Nearly all of the population lived beyond 42 months (70%). This type of exploitation pattern, as stated above for the cattle, may be indicative of secondary product exploitation. For horses, it is likely that in addition to milk, transportation was also a valuable secondary product. Horses are also carry value culturally, as evidenced by the presence of their bones preferentially in funerary contexts (Outram *et al.* 2011). Juvenile horses may not have been consumed at this site if the human population was practicing vertical transhumance. Hence, the deposition of bones from older individuals at Turgen may have a multi-causal aetiology.

3.5.4 Ovicaprids

There is a clear pattern of economic exploitation for the sheep, goats and ovicaprid category. Ovicaprids, *Ovis aries*, and *Capra hircus* specimens were combined for this analysis.

There were many astragali found at Turgen (40 specimens), many more than nearly every other element, except mandibles (Figure 3.33, 3.34). As astragali are used as playing pieces in the game of *shagan*, this might be due to

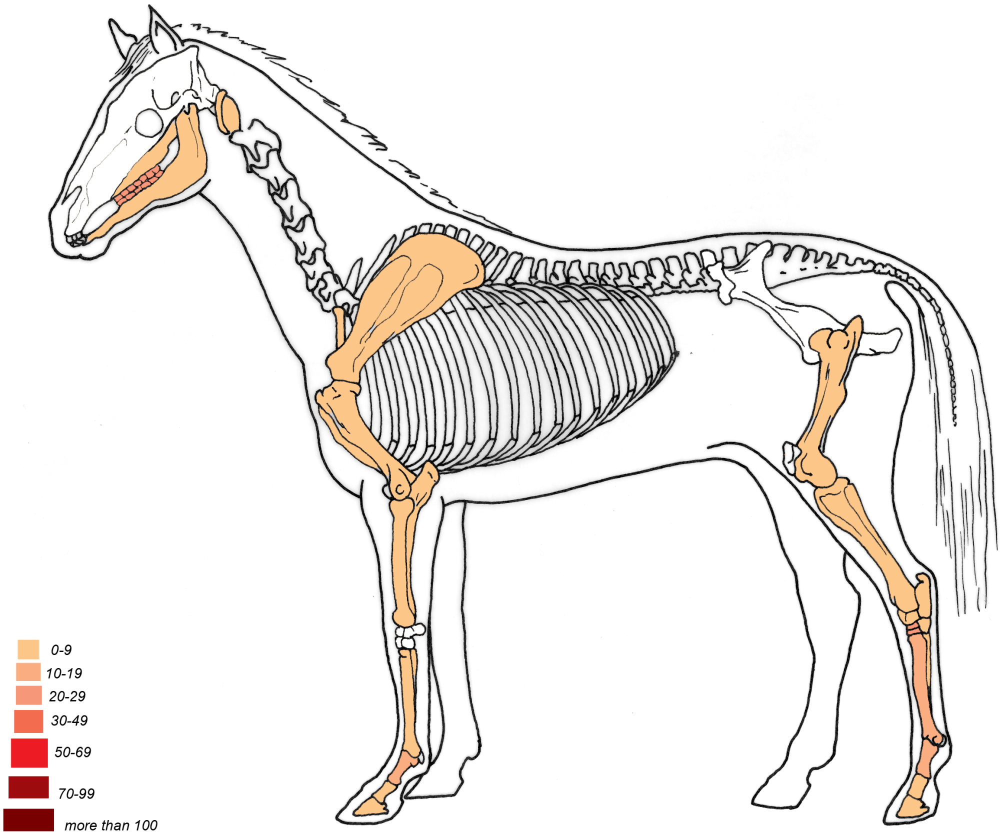


Figure 3.30: *Equus caballus* elements from Turgen, NISP.

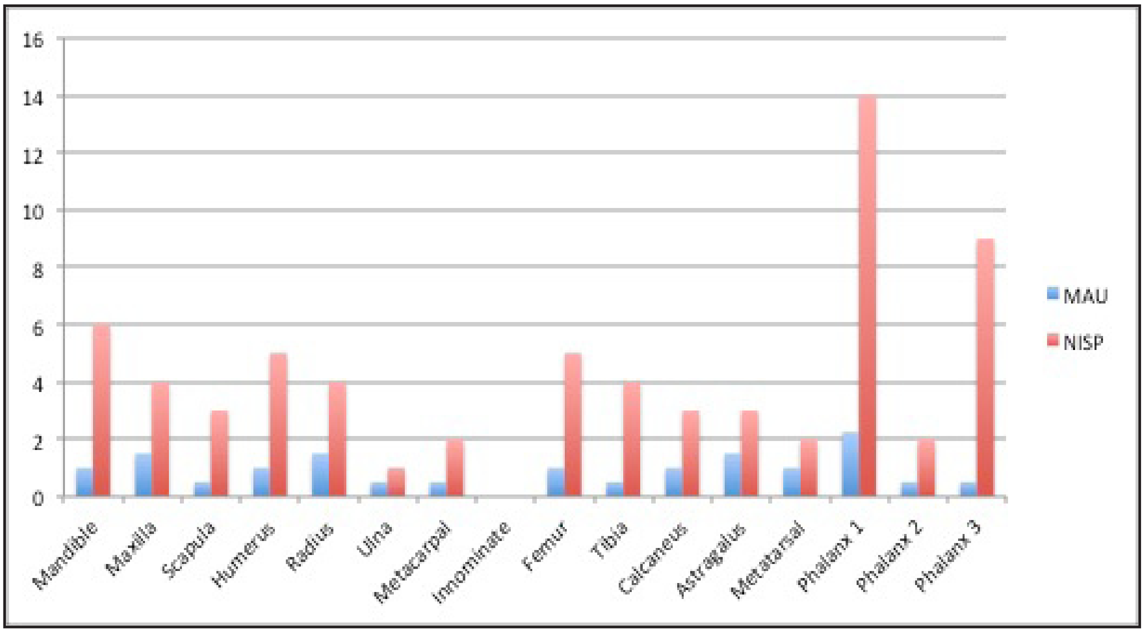
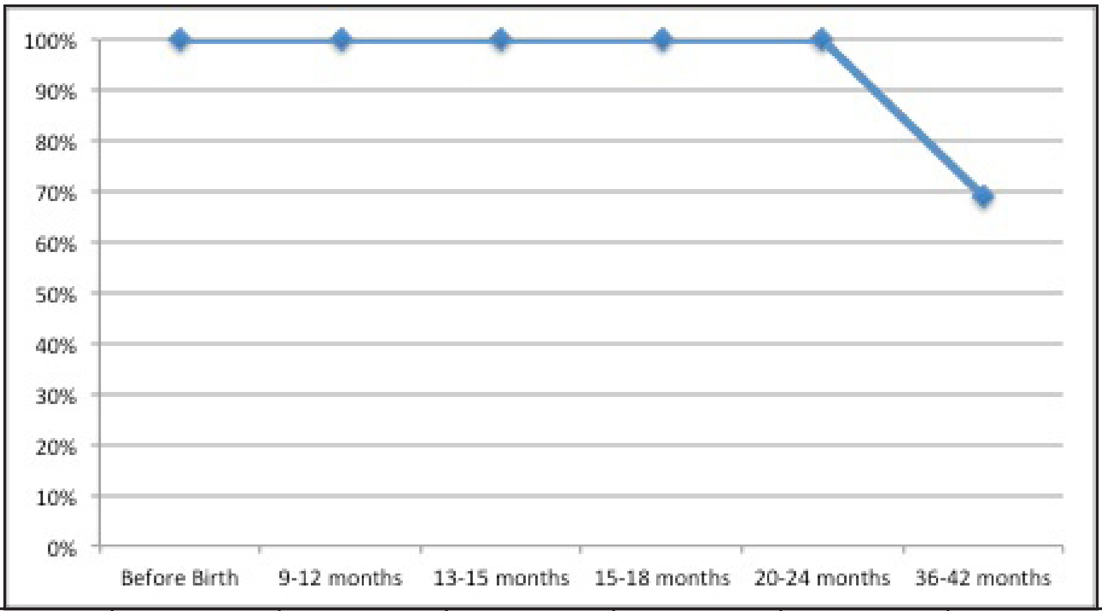


Figure 3.31: *Equus caballus* skeletal part abundance, presented as NISP and MAU.



	Before Birth	9-12 Months	13-15 months	15-18 months	20-24months	36-42 months
Fused	15	3	13	4	3	9
Unfused	0	0	0	0	0	4
Total	15	3	13	4	3	13

Figure 3.32: *Equus caballus* survivorship at Turgen as a percentage in six fusion stages with specimens listed for each fusion stage.

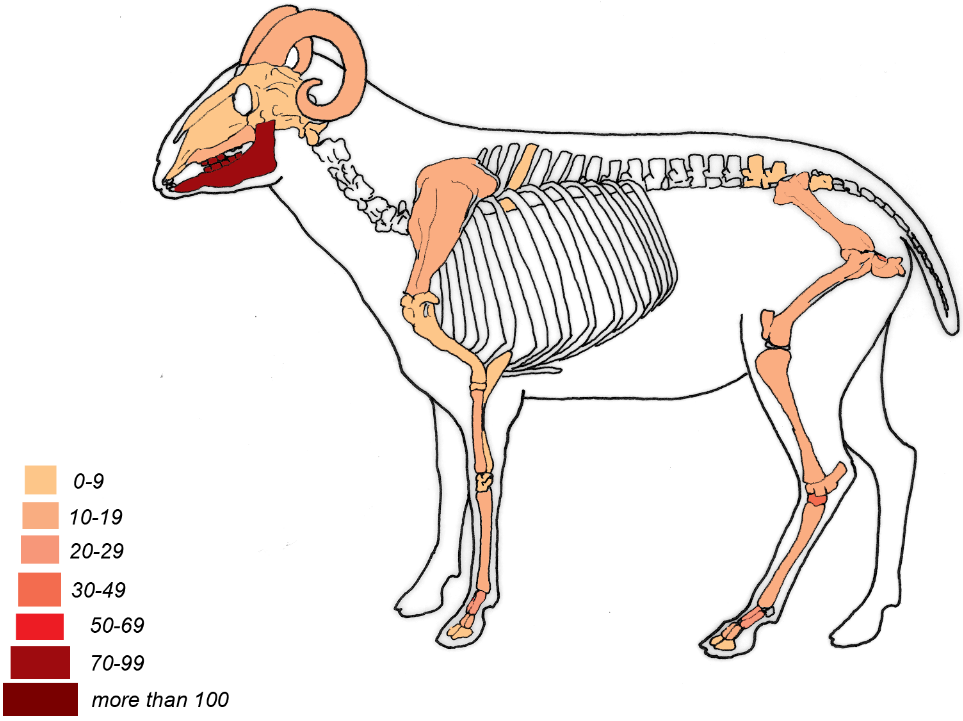


Figure 3.33: Ovicaprid Elements from Turgen NISP

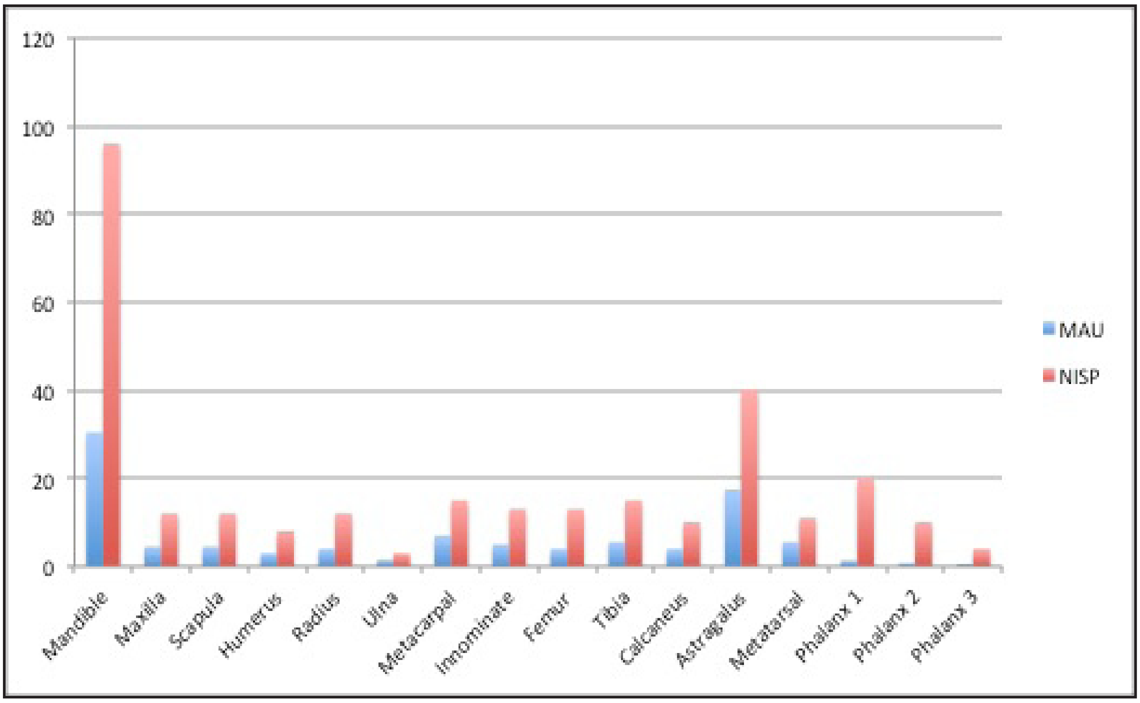
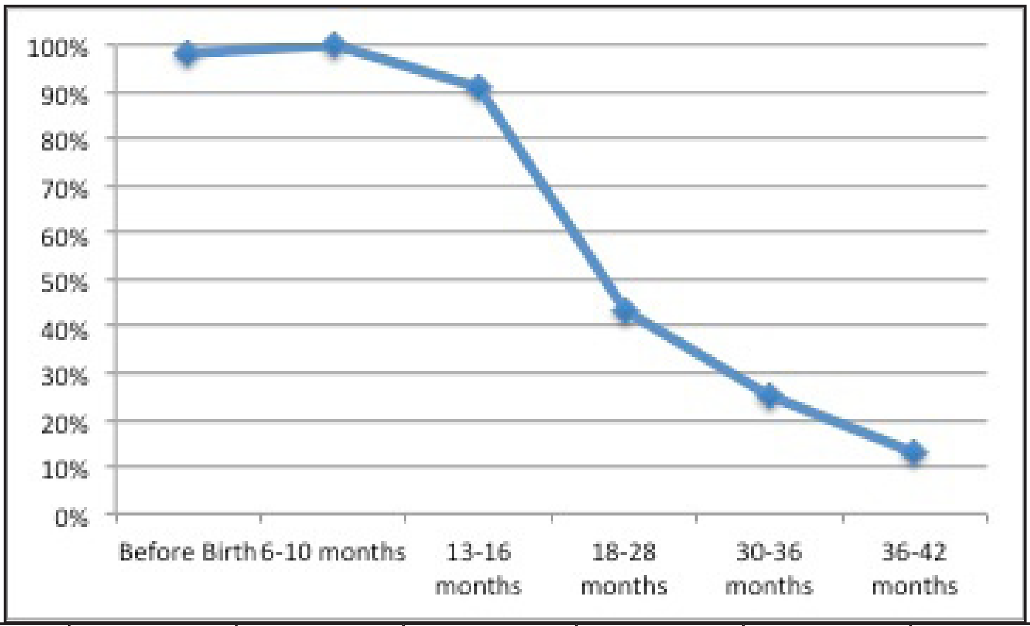


Figure 3.34: Ovicaprid skeletal part abundance, presented as NISP and MAU.

preferential collection by the people of Turgen. The MAU values reveal a similar skeletal abundance pattern. The calcaneus is tightly bound to the astragalus by a sheath of ligaments and connective tissue; to separate the astragalus and calcaneus without damage to the surface of the astragalus is no easy task. The relative scarcity of calcanei as compared to astragali MAU values is an indication that the taphonomic history of the astragali may have followed a different path that was more culturally driven than that of the calcanei.

There is a large drop in survivorship between 16 and 18 months from 90% to just over 40% (Figure 3.35). There is a further drop from 28 to 30 months of age, with only 25% of animals surviving past 36 months and 10% surviving past 42 months of age. This graph is consistent with a meat economy that slaughters animals as soon as they reach full size for consumption (Payne 1973). In



	Before Birth	6-10 Months	13-16 months	18-28 months	30-36 months	36-42 months
Fused	56	31	21	12	8	2
Unfused	1	0	2	16	24	13
Total	57	31	23	28	32	15

Figure 3.35: Ovicaprid survivorship at Turgen in six fusion stages with number of specimens for each fusion stage.

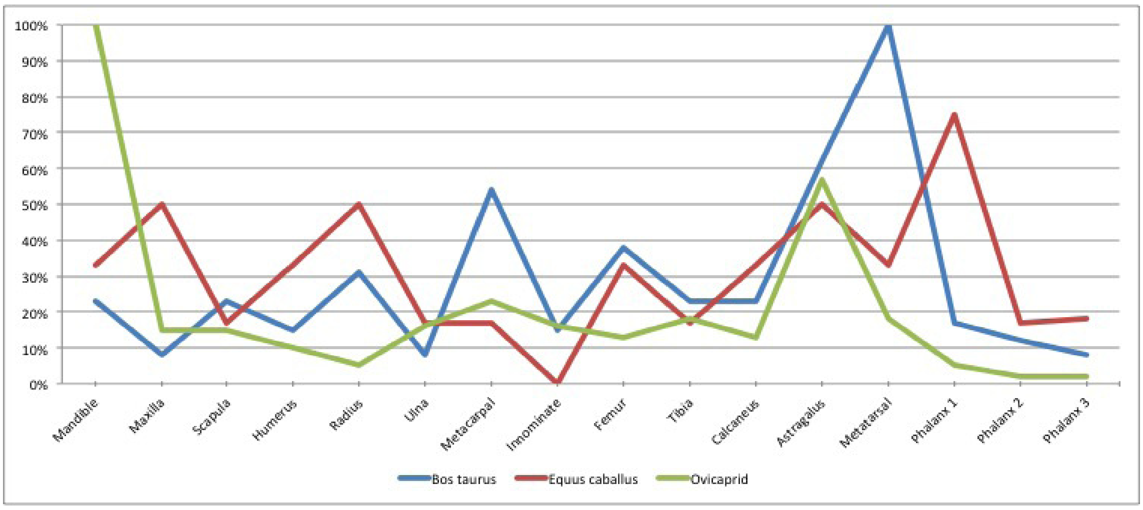


Figure 3.36: Comparision of three main domesticates as %MAU.

comparison, a milk model would show a cull much earlier as male lambs were slaughtered before the winter, while a wool model would have a largely intact population that reached full adulthood.

A plot of the three main domesticates from Turgen display skeletal part abundances as %MAU (Figure 3.36). The ovicaprids at Turgen are poorly represented by appendicular elements- instead dominated by mandibles and astragali. The astragalus and most of the bones of the feet are unsurprisingly the most intact of all the skeletal elements from the ovicaprids (Table 3.3). The appendicular elements from Turgen are less fragmented than those from Kent and Serektas, and indeed less fragmented overall. The low percentage of helical fracturing (Table 3.15) would support an interpretation of ovicaprids which were consumed and quickly deposited with little processing for marrow. Horse and cattle skeletal part abundances are similar to those at Kent and Serektas; the most numerous skeletal elements are those from the feet. The percent completeness for these specimens follows what appears to be a clear pattern. The denser bones of the feet are nearly intact, while other appendicular elements vary more widely. These remaining appendicular elements all are less than half complete (Table 3.3).

3.6 Conclusion

The zooarchaeological analyses of these three sites reveal that three main domesticated animals formed the foundation of the subsistence economy in Late and Final Bronze Age Kazakhstan. Ovicaprids, cattle, and horses contributed to over 80% of the NISP at each site. It would appear from these numbers that these sites were similar and hence all utilised this standard pastoral suite of animals in similar ways. Further exploration of these results (Chapter 6) reveals that the variations in the proportions of these three main domesticates, as well as the other animal remains, were specific to each site and each ecozone.

Taphonomic issues which arise from differing excavation and archival practises have an impact on the interpretation of these remains. The lack of small fragments at Serektas and the small sample size, as demonstrated in the ovicaprid survivorship graph (Figure 3.21) illustrates that excavation and post-excavation practices may affect zooarchaeological analyses. The use of the MAU values and %MAU as a derived value has sought to negate some of the fragmentation and duplication which can occur in highly fragmented assemblages such as these (see Tables 3.4, 3.9, 3.13). A suggestion of marrow extraction at Kent was revealed by a combination of an assessment of fragmentation type and completeness and is an example of the value of taphonomic queries.

These zooarchaeological analyses should only serve as a preliminary assessment of the value of these assemblages. Stratigraphic refinement could answer questions about seasonality while a more detailed examination of animal pathologies could further examine the possibility that cattle were exploited for traction at Kent. Further detailed analyses such as these would clarify the taphonomy and the nature of human/animal interaction. Yet the

NISP values are helpful in comparison of these sites and reveal broad trends in subsistence patterns.

Chapter 4: Measurement Methods and Biological Variables

4.1 Introduction to Geometric Morphometric Methods

Dennis Slice (2005, 5) defines geometric morphometrics in his canonical text as, ‘A suite of methods for the acquisition, processing, and analysis of shape variables that retain all of the geometric information contained within the data.’

This succinct quote veils the complexity of geometric morphometric methods (GMM). The field brings together biometry and multivariate statistics to investigate the shapes of biological objects. The term geometric morphometrics was first coined in the late 1970s (Bookstein 1978) yet currently used techniques have originated in the last twenty years of research, spurred by an increase in computing power (Bookstein 2005, Boyko *et al. 2010,* Curran 2012, Goodall 1991, Klingenberg 1996, 1998, Otsuki *et al.* 2005, Richtsmeir *et al.* 1993, 2005, Singleton 2005, Taylor and Slice 2003, Volkman *et al.* 2003, von Cramon-Taubel *et al.* 2007, Zelditch *et al.* 2012).

There are two major components to GMM. Shape variables are defined primarily through data acquisition, which is performed with a variety of techniques and methods in multiple dimensions. This is followed by a suite of geometric and multivariate statistical methods that can be used to extract geometric information and process in the most appropriate manner according to the research question.

The power of GMM lies in the ability to detect small but significant changes in shape within and between individual specimens in a data set. These significant differences are often lost in traditional quantitative and qualitative measurement methods whilst retaining the element of shape information related to size

(Curran 2012, Zelditch *et al.* 2012). This makes GMM ideal for investigating the variability of landraces of ovicaprids from a variety of ecozones.

4.1.1 Data Acquisition

The geometry of an object is most easily captured in a coordinate system, which is defined in GMM as a morphospace (Zelditch *et al.* 2012). Specimens can be easily recorded by defining relevant points known as landmarks. Landmarks contain shape data by defining edges, biologically consistent features, and other distinctive characteristics. The relationships between these points in morphospace describe the relative shape of the object in reality and form the basis of the data set for geometric morphometric multivariate statistical methods.

*T*here are various methods to record geometric shape data using landmarks. The simplest employs digital photographs of the object taken with a digital camera or through a microscope. Landmarks are plotted from the photo into a digital morphospace (e.g. Rando 2011, Savriama 2008). This method benefits from the relative simplicity of the equipment and the ease of acquiring digital data but introduces additional variables and lens distortion must be taken into account. Objects must be positioned at exactly the same distance from the lens and in the same location in the frame as every other object from the data set. If these conditions are not met, the parallax effect can cause distortion of the object, particularly at the edge of the frame. Special arrangements may be needed to ensure a flat and non-distorted object surface is presented to the lens (Mullin and Taylor 2002).

The two dimensional nature of digital photographs introduces additional issues. Many landmarks, such as edges, will be duplicated on different views. Hence, it is often easier to restrict analysis to only one view rather than combine the data from multiple views into one dataset. Landmarks can be placed on photographs using a variety of software programs such as tpsDig (Rohlf and Burridge 2012). The two dimensional nature of the data predetermines further multivariate statistical methods and precludes the potential for analysis of the entire specimen.

A three-dimensional stylus tool on an articulated arm, such as a Microscribe, acquires shape data that imports directly into a digital three-dimensional morphospace. This device is a precisely calibrated mechanical arm. A user locates landmarks on the object that is then translated into coordinates by a computer (e.g. Curran 2012). This is a direct way of recording landmarks without the middle step of creating a digital copy. The Microscribe is very precise, and hence, subject to small recording errors introduced by different users or improper alignment. The landmarks recorded by the Microscribe are not editable. To add more data to a landmark configuration, the physical specimen must be recorded again.

A three-dimensional laser scanner records a complete digital copy of an object, including surface textures and colours. These scanners utilise the triangulation of a laser beam: they shoot a laser at an object and use a camera to capture location information when the laser hits the surface of an object and is bounced back to a receiver. Some scanners use an array of lasers and cameras, while others may rely on only a few.

The processing of the raw data from the scanners is accomplished automatically with software that is packaged with the hardware. As a scan is taken from only one point, there is a data shadow where the laser does not reach. To overcome this, scans need to be taken either from multiple locations or the object turned and multiple scans taken. The human operator is required to stitch these scans together, although some scanners are equipped with software which can do this automatically, reducing processing time. Software packages may also offer additional processing, such as surface smoothing, texture matching, and layering of colour data onto the model (e.g. Scan Studio HD, Next Engine Inc., Santa Monica, CA, USA).

The accuracy of the model is dependant not just upon the precision of the recording lasers and camera but also upon the software algorithm which align the individual laser scans into a digital model as well as the skill of the operator to stitch the scans together. The digital copy of the object can be exported as a mesh or a point cloud into other model manipulation software for further refinement.

For objects with complex shapes, it is clear that using three-dimensional recording method is best. Using a two dimensional method on objects that do not present a flat surface to a camera lens can be challenging to align consistently and accurately. Additionally, three dimensional scanning offers the benefit of storing a digital copy of an object. In archaeology, a digital copy of a fragile bone specimen or artefact reduces handling and increases accessibility for other researchers.

4.1.2 Landmarks

The simplest way to capture and describe the shape of a specimen is by using landmarks. Klingenberg defines landmarks as points that can be located precisely on each specimen under study and clearly correspond in a one-to-one manner from specimen to specimen (Klingenberg 2008).

Landmarks should produce a representation of the specimen in the morphospace and be taken in a set sequence around a specimen. Landmark coordinates are a simplified representation of the specimen and provide data with which to conduct further analysis. The configuration of landmarks forms the shape datum; individual landmarks are not datum points (Zelditch *et al. 2*012,).

Geometric morphometric methods can be used to investigate any type of shape variation within a population of individual specimens, but it is most frequently utilised in zoological studies *(*e.g. Burgio *et al.* 2004, Seetah *et al.* 2014, Volkmann *et al.* 2003). Hence, the types of landmarks are driven by biological underpinnings of cell and tissue formation that drive biological morphological variation.

There are three general types of landmarks (Bookstein 1991). Type I landmarks are located on the intersection of different tissues or the meetings or edges of fissures, such as foramen or at suture joints. Type II landmarks define the maxima and minima of curvatures, such as processes or dips on bones. Type III landmarks are located at the ends of an object that can be defined in relation to the object axes. These are similar to Type II landmarks but refer to the entire object such as the end of a bone, rather than a local feature. Type III landmarks closely match traditional metrical measurements which utilise callipers and measuring boxes.

Landmarks should be chosen to define the shape of an object as well as for suitability and consistent presence across the data set. Landmarks absolutely must be homologous across all of the specimens in a data set. Landmarks that are inconsistently present imperil the integrity of the data set and the resulting analysis. They should be reliably and easily found with clear visual markers as to their location (Zelditch *et al.* 2012).

Landmarks should reflect research questions and be led by an attempt to evaluate desired variables. A thorough background of the phylogenetic and ontogenetic biological variables that can affect bone shape should be considered in order to select a configuration of landmarks that measure the desired biological variables.

4.1.3 Generalised Procrustes Analysis

In order to extract the shape information from a configuration of landmarks for a specimen, the position, orientation and scale must be removed from the data set in a Cartesian plane (Rohlf and Slice 1990, Zelditch *et al.* 2012). This can be accomplished by rescaling configurations to a standard size, shifting them to a uniform position and rotating them into a consistent orientation (Rohlf and Slice 1990, Zelditch *et al.* 2012). This collection of mathematical procedures is called a Procrustes superimposition, the first step in a generalised Procrustes analysis.

Scaling is done via the computation of a centroid size among a data set of landmark configurations. The centroid is the mean position of all coordinates, while the centroid size is, 'the square root of the summed square distances of each landmark from the centroid' (Zelditch *et al.* 2012, 60). To scale a configuration for a best fit to centroid size of 1.0, each coordinate is divided by the centroid size of that configuration (Rohlf and Slice 1990, Zelditch *et al.* 2012). The benefit of using centroid size is that size is now independent of shape. All other size variables are now uncorrelated with shape after scaling to centroid size (Rohlf and Slice 1990, Zelditch *et al.* 2012). Scaling is followed by a translation that shifts the centroid of the configurations to the coordinates

(0,0) that is followed by rotation around the centroid until a best fit is achieved (Rohlf and Slice 1990, Zelditch *et al.* 2012).

An ordinary Procrustes fit aligns one configuration against another configuration, which acts as a fit model (Rohlf and Slice 1990). This method is used for situations in which there are only two configurations to be compared against each other. For situations in which multiple configurations need to be compared against each other, a generalised Procrustes fit is a better method (Gower 1975, Rohlf and Slice 1990). This compares each configuration to a consensus configuration. An average configuration is computed using an average of the landmark coordinates. The Procrustes superimposition is repeated but this time on the consensus configuration and a new average consensus configuration is computed. This is repeated until the consensus configuration does not vary despite repeated cycles of comparison (Rohlf and Slice 1990). The coordinates of the configurations after a completed fit (ordinary or generalised) are now called Procrustes coordinates and present exclusively shape variation.

The way to quantify shape difference between two landmark configurations is to use a Procrustes distance. The Procrustean distance between two shapes is the square root of the sum of squared distances between corresponding landmarks (Zelditch *et al.* 2012). The Procrustes process treats whole landmark configurations as data points. Shape variation is spread out across all of the landmarks, rather than localized at specific points. The influence of any one landmark on shape variation is minimised (Chapman 1990). There are other methods of using a Procrustes fit that address this issue, such as the resistant-fit Procrustes superimposition (Rohlf and Slice 1990) but as this method relies on median measurements, rather than centroids, and there is a lack of mathematical theory to use the resulting data in further analyses (Bookstein

1996).

It is important to note that when using Procrustes methods that individual landmarks no longer act as individual data points. Instead, they are only part of a datum, which is the landmark configuration. Therefore, variation is between configurations, rather than between individual landmarks in different configurations. This method is a holistic approach to shape analysis, and as such, there are limitations. The lack of quantification of the importance of individual landmarks is a serious loss, but one that is made in order to compare large amounts of data.

4.1.4 Digitisation and Measurement Error

Measurement error is common in all forms of metric and morphometric analysis. Variations between investigators, equipment, and preservation can lead to measurement error. Systematic error affects all specimens in the same direction and can be caused by an uncalibrated recording device. For example, three-dimensional objects that are recorded with lenses can be affected by optic distortion. Due to the parallax effect, parts of the specimen that were recorded at the edge of the lens may be distorted. Systematic error can affect studies of directional asymmetry (Klingenberg *et al.* 2002). This can be controlled with a simple and uniform recording procedure for photographs and a careful calibration of recording devices such as callipers, digitisation arms, and scanners.

Measurements or landmarks that are difficult to take repeatedly and consistently generate random error. This type of error can be detected, measured and controlled for through a pilot study. Repeatedly recording and measuring a single specimen can detect random error (Figure 5.1). Significant random error can be detected by applying a Procrustes ANOVA to a pilot study with replications of specimens as described above. If the imaging and digitising error is less than the smallest level of biological variation, then random error is not a concern, and the recording method does not have significant error. Should the measurement error be less than two times the smallest level of biological error, then methods for digitisation and recording should be modified to reduce error or repeat measurements of the same specimen should be taken to average out error (Klingenberg and McIntyre 1998, Klingenberg *et al.* 2002).

Unreliability in particular landmarks can be detected through the addition of exploratory multivariate statistical methods such as a principal component analysis. The variation described by the first few principal components could suggest a large amount of unreliability in measuring of particular landmarks (Klingenberg and McIntyre 1998, von Cramon-Taubel *et al.* 2007). Should a large amount of variation be associated with specific landmarks, it may be worthwhile in these instances to refine the definition or location of such a landmark or omit it from the study altogether. If adjustment of the location of these landmarks does not significantly change the results, the landmarks are likely reliably located and the variation is biological.

Traditional morphometric systems and geometric morphometric methods both have inherent error in their recording systems. Systematic and random error can be detected, quantified and controlled. Pilot studies should be conducted to test for error and to ensure the reliability of defined metrics and landmarks. Should there be any problems in recording, it should be caught at this stage. Any outliers that exist after a pilot study would indicate a landmark swap or a specimen that has been misclassified and lies outside of a group of specimens.

4.1.5 Conclusion

GMM investigates small changes in shape and therefore careful control for error through the application of a pilot study is critical. Additionally, careful research design is needed to ensure that only relevant biological variables are measured. Biological factors that affect bone shape are complex and thorough background knowledge of bone formation is a necessary precursor to element and landmark selection. For this study, phylogenetic variation rather than an exploration of adaptive remodeling is the focus. Adaptive remodeling may affect the attrition rates of flocks and influence the persistence of phylogenetic traits. The focus of this study is the variation between inherited phylogenies.

4.2 Specimen Selection: Biological Variables

Bone shape is the final result of a complex process that involves multiple variables. Bone shape is set by inherited traits, but influenced by developmental variables. These variables do not uniformly influence bone shape; long bones tend to be more susceptible to change before fusion, while small compact bones are less susceptible to change.

4.2.1 Phylogeny

DNA drives the overall shape and organisation of biological anatomy. In a population, a mix of inherited genes determines the morphology of an individual. Any significant inherited changes in shape will be due to genetic mutation. Increased evolutionary pressure on the expression of this mutation will result in higher reproductive success, and this mutation will increase in frequency within the total population (Hildebrand and Goslow 2001).

The morphology and designation of the regions of the body are determined by the *Hox* genes, which are present not only in all vertebrates, but also in invertebrates, such as arthropods (Burke *et al.* 1995, Popadic *et al.* 1998). This set of genes is known to be responsible for the orientation, location, and shape of the limb buds. It is not yet fully understood which genes determine specific bone shape. Recent research has suggested that bone shape is controlled by a variety of genes whose relationships to each other are not yet fully understood and epigenesis is not simply a journey from code to shape (Boyko *et al.* 2010, Burgio *et al.* 2009, Otsuki *et al.* 2007, Volkman *et al.* 2003).

The size and shape of an organism can develop along a variable range, the limits of which are determined genetically. A vertebrate’s size can never grow disproportionally outside of a certain range (Hildebrand and Goslow 2001, Searle *et al.* 1989a, 1989b). Variations in health, food, and environment will not cause disproportionate growth outside that range (Klingenberg 2002, Searle *et al.* 1989a, 1989b).

Form follows function, and bone is no exception (Sullivan 1896). Bone shape has been optimized through natural selection for the type of movement utilised by the animal. Bone articulations are located at optimal leverage points to optimize the amount of output force (F0) needed for a specific type of movement (Hildebrand and Goslow 2001). Vertebrates are characterised by their types of locomotion. Vertebrates that move by running, such as cheetahs or antelope, are called cursors; those that jump, such as kangaroos, are saltors; those that burrow are fossors; those that climb are scoursors; those that fly are volors; and finally those that swim are aquatic (Hildebrand and Goslow 2001).

Each of these unique types of movements requires different lever points at bone articulations, as well as different densities and shapes in the diaphyses and epiphyses. By moving the lever point at, for example, the joint of the upper and lower front limb, the force exerted can be increased if the articulation is moved further away from the ends of the ulna. If the lever is moved in the opposite direction, the length of the bone can be enlarged, increasing stride, but decreasing force (Hildebrand and Goslow 2001).

Stride length is critical for cursors, which rely on running for survival. Evolutionarily speaking, cursors have optimised their stride length, and therefore their speed, by standing on the very ends of their digits. In comparison, plantigrade animals stand on large flat feet and have shorter strides. Additionally, cursors have longer distal limb segments, the metapodia, that further increase stride length. Cursors also have reduced rotation in their limbs, which decreases the amount of muscle effort that is needed to keep the limbs extended while in motion. By fusing sets of bones that are designed for rotation, such as the ulna to the radius and the fibula to the tibia, cursors are able to reduce the weight of abductor and adductor muscles. Finally, cursors have articulations that function as one-way hinges with the increase in size of ridges and grooves at articulation points (Hildebrand and Goslow 2001).

Ovicaprids can largely be classified as cursors, and they share the Bovidae family with antelopes. Ovicaprids have elongated distal limbs, specifically long metapodia. They do not have fibulae, and their ulnae are fused to the radius mid-diaphysis. The wild ancestor to the domesticated sheep, the mouflon (Ovis orientalis), not only runs, but also climbs (Mason *et al.* 2002). Other wild ovicaprid species are known for their climbing ability, and use their shorter metacarpals and splayed hooves, which can act to support force independently of each other, to climb much easier than a long-limbed gazelle or antelope (Reading *et al.* 2003).

The astragalus is a key bone for the gait of the hind limb of ovicaprids. The angle of the movement is affected by the angle of the ankle joint (Kim and Breur 2008). The distal tibia interacts with this joint on the proximal articular surface and plantar articular surface of the astragalus. The calcaneum holds the astragalus steady as a pivot point. The astragalus articulates distally in a complex joint with the tarsals. The joint in encased in a tight sheath of tendons and connective tissue. The astragalus is at the centre of this joint, determining the range and angle of motion.

4.2.1.i Sheep Breeds

Sheep and goats have been consciously and unconsciously bred by humans since domestication. Human control over domesticated sheep and goat have changed breeding patterns and changed grazing ranges. These types of changes influence inheritance of favourable traits which may be consciously selected for or generated by local conditions. Traits can be inherited, such as for high quality wool from Merino sheep, or for a longer tail from a fat-tailed Karakul sheep (Mason *et al.* 2002). The breed standards for modern animals are well defined and list particular coat colour, head shape, wither heights, or other such descriptors for a variety of domesticates such as dogs, horses, cattle and sheep (Mason *et al.* 2002).

However, the term ‘breed’ is not a biologically recognized word. In fact, the closest biological term in the same sense as breed is ‘subspecies’ which is a group or population of animals that have distinct characteristics that are different from a larger global population of a species largely due to geographic isolation. Individuals from different populations may mate and produce viable offspring when they encounter each other but this is rare in the wild (Reitz and Wing 1999). The term ‘landrace’ is most applicable in this context; this term describes a regional morphotype of a species.

Some domesticated animals, such as horse (*Equus caballus*) and cattle (*Bos taurus*) were originally considered to be separate species from their wild relatives and prehistoric ancestors. Genetic research has confused the issue and made it clear that modern domestic animals are not separate species as they can often interbreed with their wild cousins and produce viable offspring and have done so throughout their histories (Hiendleder *et al.* 1998, Jansen *et al.* 2002).

While it has long been assumed that there was a Middle Eastern origin for sheep domestication (Meadow 1993), mtDNA shows that there are at least four different lineages of female sheep, and most likely at least three domestication events which is blurred by breeding of female domesticated stock to wild male rams (Tapio *et al.* 2006, Zeder 2006). It is not yet clear whether Central Asian sheep in prehistory were descended from the Middle Eastern stock, or whether they were domesticated in a different event from the wild sheep populations of *Ovis ammon nigrimontana* (Argali) which are native to Central Asia (Nowak 1999).

Despite a firm line between domesticated and wild animals in modern genetic and taxonomic research, the identification of domesticated sheep has long been deliberated in zooarchaeological literature. There are morphological differences between domesticated animal bone and the bones of wild predecessors but it is difficult to see a significant and quantitative difference in the field (Zeder 2006). For example, domestication of caprines in the Near East 10,000 years ago was first investigated through shape and size change but was superseded by tracking differences in population mortality (e.g. Zeder and Hesse 2000). Kill-off patterns showed a distinct change in human exploitation of ovicaprid populations and from this, it was inferred that domestication had taken place (Zeder 2006).

In Central Asia and Western China, Kazakh breeds of cattle and sheep are distinguished by their ability to fatten quickly and survive long periods of poor feed and famine. Kazakh sheep are one of a group of fat-tailed sheep. These sheep from Central and Western Asia possess fat tails or rumps that can store large amounts of fat for times of food scarcity (Cheng 1984). The males are horned and weigh up to 60 kg while the females are polled and weigh up to 40 kg (Mason *et al.* 2002; Xinjiang Department of Agriculture, 2014). These types of fat-rumped sheep were developed to supply a cultural preference for fatty meat prior to Russian colonisation in the 18th century C.E. (Cheng 1984).

Kazakh sheep are today considered to have low quality wool (Mason *et al.* 2002). They produce little wool every year- it has been recorded as 1 kg per year, a low yield compared to modern improved Merino varieties (Cheng 1984). Some of the earliest finds of bioarchaeological remains in this region are wool fibres from a sheep fleece from the Pazryk burials in the Altai Mountains dating to about 400 B.C. (Davis-Kimball 2000, Rudenko 1970). These fibres indicate that the fleece was not yet continuously growing and hence they were a different phenotype than modern Kazakh sheep (Ryder 2007).

Central Asian sheep were described before the advent of Soviet improvement of the local stock with imported Merino sheep. Youatt (1885) wrote that the flocks of the Central Asian Tartar hordes were nearly uniform across the steppe, but his reference to small differences suggests that different breeds existed. He stated that with a weight of 91kg the Tartary sheep was the largest unimproved type. Of this, 14 kg came from the rump, which was so large that it hindered walking. His description and illustration of a horned ram showed two large hemispheres of fat, and an almost vestigial tail. Youatt described the Kirghiz sheep as having a rounded nose, pendulous ears, coarse wool and sometimes four to six horns. The Kalmukian sheep had a less-curved nose, shorter ears, less hairy wool, and were seldom horned (Ryder 2007).

Modern heritage breeds still found in Central Asia include the Telegenit or Altai sheep which is another fat-rumped breed. Native to the Ili river valley in southeastern Kazakhstan and the steppes of Western China, the Altai is a sheep bred for meat with coarse wool. It is white with a black or browns head and shoulder. The males and females are both polled, with the male weighing up to 100 kg and the female 65 kg. This sheep is described as having good resistance to heat and cold, and able to tolerate long journeys and poor pasturage (Xingjiang Department of Agriculture, 2014).

'Improved' wool and meat sheep predominate today. The Xinjiang fine wool is a cross between the Kazakh sheep and the Novocaucasian Merino variety. The males can weigh up to 143 kg and are horned, while the females can weigh up to 94kg and are polled (Mason *et al.* 2002). Other modern hybrids include the Kazakh Arkhar-Merino, a native Arkhar sheep crossed with a Merino, and the Kazakh Corriedale, a Border Leicester/ Romney Marsh cross that is then crossed with a Kazakh sheep (Mason *et al.* 2002). The Altai sheep was developed at the Rubtsovek state farm between 1935 and 1949. This sheep is bred from a cross between an American Rambouillet, a Caucasian Merino, and a Siberian Merino in successive generations (Mason *et al.* 2002).

From these descriptions, it is clear that the Central Asian sheep breeds were very different to Mediterranean and European sheep breeds, at least in recent history. The fat-tailed sheep is a clearly different breed of sheep than those found further west, and today are found only in remote regions of Central Asia. There have been no descriptions of the metrics or morphology of breeds of sheep from Central Asia in published academic literature.

4.2.2 Ontogeny

Bone is a complex organ that forms the support structure for vertebrates. It undergoes constant remodeling throughout the lifespan of the organism, and rather than acting as a static framework from which muscle is strung, bone is a dynamic tissue that changes with the organism throughout its lifespan. A number of variables can influence final bone size and shape before bones are deposited in the archaeological record.

4.2.2.i Bone Formation

Skeletogenesis in vertebrates begins in the earliest days of embryonic development. Both the axial and appendicular skeletons are formed from the mesoderm, one of the three original tissue layers. These germ layers differentiate when the embryo has undergone significant cell division and is developing beyond a hollow sphere of single cells into a gastrula (Hildebrand and Goslow 2001).

The ectoderm, mesoderm, and endoderm are composed of stem cells that

Figure 4.1: A problem with the expression of the *Hox* gene has resulted in a split tail in a newborn lamb. Photo by Hannah Stone, reprinted with permission.

are able to differentiate into various types of specialised cells. The mesoderm stem cells will later propagate the musculo-skeletal, circulatory and urogenital organ systems. In the embryo, the mesoderm acts as a filling tissue between the ectoderm and endoderm, and replicates quickly as the gastrula continues to develop. The majority of the axial skeletal system is formed from a group of cells called the sclerotome, while the appendicular skeleton is formed from a group of cells, the somatic layer, which originates from the mesoderm (Hildebrand and Goslow 2001).

The axial and appendicular skeletons continue their development on divergent paths. The axial skeleton is formed largely via intramembranous development. The stem cells from the sclerotome inhabit a dense mass of cells in the embryo called the mesenchyme. These cells condense and differentiate directly into osteoblasts that mineralise the matrix and encourage vascularisation (Klein-Nulend and Bonewald 2008). The morphology and designation of the regions of the vertebrae are determined by the *Hox* genes (Burke *et al.* 1995, Popadic *et al.*1998).

The Hox suite of genes directs the orientation and placement of the limb buds, which are created by the growth of the mesenchyme and capped by a layer of epithelium (Karaplis 2008). Errors in cell division and organisation at this stage can result in birth defects, such as split tails (Figure 4.1). The appendicular skeleton is formed via endochrondral ossification, in which hyaline cartilage model of long bones are first formed in utero. The stem cells in the somatic layer differentiate into chondroblasts as the limb bud elongates away from the body wall. The chondroblasts multiply rapidly as they grow interstitially to form one long hyaline cartilage model that runs the length of the limb bud. The first signs of joint formation appear in a gathering of cells that runs perpendicular to the length of the limb bud, forming an ‘interzone’ which is thick and compact

(Karapalis 2008). The interzone gives rise to the articular cartilage, synovial lining, and joint tissues of the articular ends.

Once a preliminary hyaline cartilage model of the limb bones is defined and the interzone has been formed, ossification begins near the centre of the diaphysis. The chondrocytes secrete collagen X, which encourages differentiation of nearby stem cells into osteoblasts (Karaplis 2008). These new osteoblasts follow a prescribed pattern of ossification. First they replicate and proliferate throughout the matrix followed by extracellular matrix development through vascularisation and maturation of the osteoblasts. Finally the process is completed with the mineralisation of the matrix (Aubin 2008). The osteoblasts are embedded in the matrix into spaces called the lacunae. In these spaces, they transform into a mature osteon. An osteon reaches through small channels in the matrix called canaliculi to connect with other osteons, blood vessels and nerves, and even the exterior and internal surfaces of the bone (Klein-Nuland and Bonewald 2008). If the osteoblasts do not mature into osteons, they may either undergo apoptosis, programmed cell death, or become a lining cell (Klein-Nuland and Bonewald 2008).

Ossification of the hyaline model of the appendicular skeleton begins in the middle of individual bone. This diaphyseal ossification centre is also known as the primary ossification centre. At this first site of ossification, a ‘bony collar’ of cortical bone is formed around the incipient diaphysis (Karapalis 2008). Ossification progresses outwards along the diaphysis towards both the epiphyses of the long bone. However, in mammals ossification does not continue uninterrupted to the articulations. Instead, a layer of cartilage, known as a growth plate, or secondary ossification centre, remains postnatally between the articular ends and the diaphysis. This growth plate is where further long bone growth occurs postnatally as ossification continues to move towards this plate from both the articular and diaphyseal sides (Young 1988). Diameter growth occurs through the mechanism of intracartilaginous ossification on the exterior surface of the diaphysis (Hall 2005).

The bone structure of the long bones of the appendicular skeleton is complex, and composed of different varieties of bone. Cancellous bone is found at the epiphyses of mature bone, and is characterised by a light bone lattice that is largely vascularised. Compact bone, which forms the diaphysis, is largely formed of longitudinal columns of Haversian canals. These circular structures contain a central canal that runs longitudinally through the bone and is surrounded by osteons that are arranged in concentric rings around the central canal (Klein-Nuland and Bonewald 2008). Thin lamellar sheets of bone line external and internal surfaces. Long bones such as femora often contain a hollow internal cavity.

4.2.2.ii Nutrition

From birth the nutrition of an individual ruminant is dependent upon external sources. The neonate is no longer connected to the mother via the umbilical cord and hence the input of nutrients and calories are no longer constantly supplied by the mother’s bloodstream. The ewe supplies milk for the first few weeks of life in the form of nutrient and calorie-rich milk. However, this period quickly ends when weaning occurs between 30 and 90 days (Ryder 1964) when a lamb must forage. For ruminants, this generally entails consumption of plant matter, which can either be growing wild or supplied by human handlers.

Between parturition and the completion of bone growth it is critical that the individual has a good and consistent supply of high protein plant material (Ryder 1964, Sykes 1994, Young 1988). Without a constant supply, the animal may suffer from irregular ontogenesis that will change its proportions for the rest of its life.

Experimental research by Young (1988) investigated the reduction of nutritional intake on young lambs. Between weaning at 56 days old and 860 days old, Young kept two groups of female sheep- a control group that was allowed to graze freely, and another group that had a 57-day restricted feeding period. The femur length and smallest diameter of the femoral diaphysis was plotted against the weight of muscles and overall live weight of the animals. In the group that had restricted calorie and nutrient intake, muscle weight could recover upon resumption of feeding and reach nearly the same volume and weight as the control group. However, the femoral weight and measurements were not able to attain the same maximum as the control group. Furthermore, the ratio of femur length against mid-length diameter in feed restricted animals showed distinct growth reduction, as the bones never grew as long as those in the control group (Young 1988).

4.2.2.iii Disease

A wide variety of pathological conditions can affect bone development. Metabolic bone diseases such as scappie, osteomalacia, and rickets are caused by imbalances of calcium and phosphorous or deficiencies of vitamin D respectively. These diseases cause bones to become brittle and distorted and affect an entire flock, rather than individuals (Henderson 1990). Bone morphology changes are not just due to these direct deficiencies, but also due to the complex metabolic systems that regulate bone development.

Bone development is affected through similar metabolic pathways by much more common and widespread type of infection- parasite infestations. Parasitic organisms that infect sheep are invasive and unwanted external (ectoparasites) or internal (endoparasites) species and are actively repelled by the host organisms (Henderson 1990). Parasitic relationships extend far beyond the host and the parasite (Reinhard 1992). The rate of parasitic infestation is dependent upon the surrounding environment, and may also be reliant upon intermediary hosts, or even upon specific forms of behavioural patterns (Reinhard 1992).

The nematodes *Ostertagia* spp. and *Trichostrongylus* spp. are covered here as an example of endoparasites for which sheep are the definitive host; there are however hundreds of ecto- and endoparasites with direct and indirect lifecycles that plague sheep worldwide. The relationship between sheep and these two nematode species have undergone the most research in veterinary and parasitological fields due to the market value of the animals and the simplicity of transmission and reproduction of the parasites across a wide variety of environments (e.g. Kaplan and Vidyashankar 2012, Sykes 2008, Wilson *et al.* 2004).

Ostertagia spp. and *Trichostrongylus* spp. inhabit the gastrointestinal (GI) tract of ruminant vertebrates. These two parasite genera work their own way out of faecal deposits as larvae, and climb onto nearby foliage for entry into a new host. The GI tract is well situated to provide entry and exit, and additionally provides a continuous nutrient supply. The parasites enter the GI tract along with the fodder in a larval stage. They take up residence in the abomasum or the rumen, attaching themselves in the folds of the epithelium (Sykes and Poppi 1982).

The robusticity of these species outside the host is dependent upon the environmental conditions, such as temperature, humidity and the availability of fodder which to cling to. In the right conditions, larvae can survive for months, even over winter in mild climates. There is a strong increase in parasite load and correlated pasturage population of larvae in the early spring.

Periparturient ewes often have a period of high parasite load, especially during the lactation period, in which their immune system is compromised (Brunsdon and Vlassoff 1982). The young lambs then pick up many parasites as they begin to graze at the end of the first and beginning of the second month of life. They are exposed to a high level of larvae, mainly from the mother's faeces, and unless removed to different pastures at this time, will become heavily infested. Fluctuations in parasite abundance have been tracked for lambs throughout their first summer of life, peaking sharply between six and eight months, at which point their immune system is able to reject the parasite infestation. As the temperature and humidity drops in the autumn and the young lambs increase immune response, most young animals are able to expel heavy parasite loads before their first winter (Brunsdon and Vlassoff 1982, Sykes 1994, Vlassoff 1982). Pastoral choices about pasturage locations in specific weather conditions and at particular ages for lambs can have a significant impact on the amount of parasite load.

The host response to an infestation of parasites can vary greatly and it is most significant to final skeletal morphology when the host is still growing. Parasite infestation of the GI tract can lead to severe malnutrition. This is not due to parasites consumption of the GI tract contents, but rather due to a group of host responses to infestation that can severely impact nutrition and metabolism (Sykes 1994, Van Houtert and Sykes 1996). The host may not show signs of disease, but simply a loss in productivity (Sykes 1997).

Host response can range from the production of GI tract secretions to an increased immune response with a heavy production of T helper cells to assist in phagocytosis. Sykes' extensive research into the subject has revealed that when a host is infected with a heavy parasite load, it severely reduces the amount of protein available for protein metabolism and growth (Sykes 1983, 1994, 1997, 2008, Sykes and Poppi 1982).

Goblets cells that line the GI tract increase mucus secretions, which aid worm expulsion (Fairweather 1997). 'The mucus secreted onto the surface of the intestine forms a physical barrier to invading parasites, engulfing and entrapping them. In this way, their attachment to the surface is prevented and their expulsion by peristalsis facilitated' (Fairweather 1997, 117). Protein from the GI tract is still absorbed at a nearly normal rate, but the increasing loss of endogenous proteins from blood, mucous and sloughed epithelium in turn raises the demand for metabolisable protein, which remains either constant or even reduces slightly with infection (Sykes 1994, Van Houtert and Sykes 1996).

In addition to heavy mucosal secretions and high immune response, parasite infestation can induce anorexia in animals. Heavy parasite infestation can reduce intake of food by between 10% and 30%, which further aggravates nutritional deficiencies (Sykes 1994, Van Houtert and Sykes 1996). Such parasite induced anorexia is not well understood at present, but thought to be related to abdominal pain and inflammation, changes in pH of the gut, changes in the flow rate of digesting material, changes in protein to energy ratio of absorbed nutrients and change in the secretions of gut hormones (Fairweather 1997, Sykes and Poppi 1982, Van Houtert and Sykes 1996).

Parasites are not the only infection to affect growth. Any of a variety of infections will lead to a deviation from normal bone growth.

> ‘Bone growth is reduced in infection and prolonged infection can result in osteoporosis. A general effect is a matrix osteoporosis probably as a consequence of diversion of amino acids away from bone and muscle to the alimentary tract. In addition, however, absorption of phosphorus is impaired in infection of the proximal small intestine, resulting in hypophosphatemia and bone mineral osteoporosis, and as a consequence slower skeletal growth’ (Sykes 1997, 87).

Osteoporosis, or as it is known colloquially in sheep, osteomalacia, therefore results in bone lesions and reduction in growth of the external dimensions of bones by

> ‘Reduced activity of bone forming cells (osteoblasts) and reductions in the degree of mineralization of bone matrix, the latter being particularly the case in intestinal parasitism…reduced bone growth could result from a reduced availability of bone matrix- forming substance (matrix osteoporosis) as occurs in protein and energy deficiencies, induced calcium or phosphorus deficiencies (mineral osteoporosis) and change in the endocrine environment (viz. increased corticosteroid secretion) which may reduce osteoblastic activity’ (Sykes and Poppi 1982, 29).

The ties between metabolic bone disease and parasite infestation are therefore complex and interlinked.

The most susceptible time for ruminants to infestation and associated disease is in the first eight months of life. Infestation leads to a drop in body weight, and a proportional decrease in bone growth. Protein reduction through any means, such as infection and poor pasturage will affect bone growth. Reductions in protein intake affect growth at the growth plate in long bones most significantly. Lack of protein leads to lack of longitudinal growth (Sykes 1982). Change in the width of long bones operates at a different rate using a different mechanism and is not as affected by a reduction in protein intake, particularly in the early months of life. The small bones of the carpals and tarsals do not have growth plates and grow only by intercartilaginous formation around the bone, similar to the mechanism for long bone width growth. Hence, small bones and those that are formed via intercartilaginous formation are not as susceptible to protein reduction.

4.2.2.iv Hormones

Many hormones affect bone development. During growth, growth hormone drives bone growth but the effects of other hormones, particularly testosterone, modify this. Testosterone present in neonatal lambs encourages sexual dimorphism. There is a clear difference in the morphology of crania and pelves of ovicaprids (Boessneck 1969). Testosterone increases bone size, and male bones are not only longer than female bones, but they are also more robust. Castrates and females have more fatty carcasses, and grow at a slower rate than leaner males (O’Riordan 1992).

Castration is frequently practiced in human managed flocks, and bones from castrates overlap female and male bone morphology (Popkin *et al.* 2012). In a thorough investigation of the effect of sex and castration on bone size, Popkin *et al.* (2012) concluded that differences between sexes have a stronger effect on bone shape and size than castration. Males and castrates have a larger variability in shape and size than the more constant females. Castrates exhibit delayed long bone ossification in growth plates and hence have longer bones despite a reduction in testosterone levels (Davis 2000, Ho 1989, Popkin *et al.* 2012, Searle 1989). Castration plays a large part in changing the shape of long bones, particularly the SD measurement (smallest diameter of the diaphysis) in the distal limbs such as the radius, tibia and metapodials (von den Driesch 1976). Only a few dimensions, such as the length of distal leg bones, provide clear distinction between males, females, and castrates (Popkin *et al.* 2012). Plots of long bone length versus shaft widths do show some shape differences between the three sexes, with ewes being short and slender, rams being short and robust, and castrates being long and slender (Davis, 2000).

Metric measurements on sheep flocks from different nutritional planes were used to evaluate skeletal growth and morphometric variation (Popkin *et al.* 2012). Simple measurements laid out in von den Driesch (1976), Davis (1996) and Greenfield (2006) were subjected to statistical tests, such as correlation analysis and discriminant functional analysis to evaluate the variation between sex and flock groups.

Nutritional deficiencies were more likely to affect the overall greatest length of long bones in females, while castrates and males were less affected. Females with a high level of nutrition have longer limb bones than females on a lower level of nutrition, but low nutrition does not affect castrate bone length, and only affects the male distal limb elements (Popkin *et al.* 2012). In an archaeological palimpsest variation in nutrition should likely be taken as a given, and it is recommended that only the tibia should be used for recognising castrates (Popkin *et al.* 2012).

Popkin found that the astragalus continues to grow after birth along the medio-lateral axis (Davis 2000, Popkin *et al.* 2012). This growth in breadth does exhibit some differentiation by sex, but is largely unsuitable for sexing sheep (Boessneck 1969, Ruscillo 2003). The astragalus does not grow on the proximal-distal axis (the GLl measurement), and this is the only measurement in the entire sheep skeleton that is age independent (Popkin *et al.* 2012). Additionally, the astragalus is the only element in which males do not have a significantly larger distal breadth measurement relative to castrates (Popkin *et al.* 2012). This would suggest a phenotypic reliant element; a bone that is not affected by variables such as nutrition and sex. In comparison, the distal tibia is the most responsive location to sex- castrates shows the most extensive growth and delayed fusion at the distal epiphyseal plate on the tibia (Popkin *et al.* 2012).

Davis (2000) used ratios and plotted the age independent GLl as the basis of a ratio to investigate sex difference in a flock of Shetland sheep of males, females, and castrates. There was no clear bimodality or trimodality between sexes, despite evidence for medio-lateral growth after birth. Payne suggests that cursorial mammals experience early and rapid bone development around the distal metapodials and astragalus (Davis 2000). This early growth would account for nearly all of the age dependent growth of the astragalus except in breadth and by sexual maturity would likely be complete. Davis suggested the astragalus would be the most useful element for, ‘comparing sheep from different periods/ sites in order to investigate sheep size variation through time or between different geographical areas’ (Davis 2000, 387).

Bones which fuse early and have post-fusion growth, such as the scapula and astragalus are poor estimators of sex (Davis 2000, Popkin *et al.* 2012). Yet female and castrate sheep have been found to have a swelling in the dorsal-plantar in descriptive studies (Ruscillo 2003). The post-fusion growth of the astragalus is along the breadth (Bd) measure, which corresponds to the sex driven swelling on the medial plane found by some investigators, while the length (GLl and Dl) is age independent (Davis 2000). This would suggest that while the astragalus displays the influence of hormone driven changes, it is limited along one axis only.

4.2.2.v Adaptive Remodeling

Changes in bone thickness and structure post-fusion are driven by mechanical stress. Most often, changes in bone caused by stress in animals are also related to pathologies. For example, exostosis on the proximal end of the first phalange of cattle have been linked to repetitive stress, but are also classified as pathologies due to the severe nature of the bone modification (Bartosiewicz and Gál 2013, Groot 2002, Johannsen 2002, Thomas 2008).

Wolff's law of bone remodeling states that bone under a strain will change internal structure and external form to better support that strain (Wolff 1986). This law, while simple enough, has been disputed in practice. Research suggests that mechanical strain is detected through the displacement of fluid in Haversian canals (Burr *et al.* 2002) and the development of microfractures in bone structure (Ruff *et al.* 2006). Compact and trabecular bone in long limb bones have been shown to adapt to dynamic loading, e.g. exercise, in a variety of ways. Human bones have shown this clearly, such as the development of robust arm bones for archers (Rhodes and Knüsel 2005) or changes to the elbow in tennis players (Bertram and Schwartz 1991, Lieberman *et al.* 2001, Pearson and Lieberman 2004, Ruff *et al.* 1994, Ruff *et al.* 2006).

This law has been explored experimentally in sheep (Kim and Breur 2008, Liebermann *et al.* 2001). Sheep exercised on a slope developed a clear and significant change in the organisation of the trabecular architecture of the distal tibia that was aligned to the new orientation of the tarsal joint (Barak *et al.* 2011, Lieberman *et al.* 2004). While the authors noted a slight visual change in the external shape in the distal tibia, this change was not quantified and unclear in significance. Additionally, other investigations into the articular surfaces of postcranial bones under a variety of strains (Lieberman *et al.* 2001) did not show any significant change in shape. Instead, it appears that consistent application of strain during exercise results in a demonstrable change in the thickness of the diaphysis and the organisation of trabecular bone, but the shape of the epiphyses of long bones are not shown to change significantly. This change in internal structure is particularly clear in juvenile sheep. Adult sheep do not show the same degree of bone remodeling and replacement, even at the same levels of exercise (Lieberman *et al.* 1998 in Pearson and Lieberman 2004). Additionally, there is currently no evidence to indicate that stress and strain change the external surfaces of small compact bones in the tarsal and carpal joints, although research to investigate this is currently in preparation (Barak, pers. comm. 2014).

4.2.3 Conclusion

Breed characteristics, from wool type to head shape, are all inherited characteristics; genes also control bone morphology. Inherited characteristics are tied to human breeding decisions and evolutionary selection driven by attrition in an environment. Birth defects do not arise consistently in a population over time, and hence appear in the palimpsest as outliers and can be discounted.

Lost bone growth from poor nutrition and pathologies in juvenile sheep can never be recovered. The effects of poor nutrition and pathologies on bone growth largely affect the long bones, particularly those that fuse after the young animal is weaned and picks up its first parasite load. Bones that are fused before this time or before birth are not as affected by these variables, which includes the small bones of the carpals and tarsals.

Post-fusion growth in these small bones is largely driven by age and use, with the occasional influence of hormones. However, the influences of these factors, particularly for the astragalus, are shown to be small. Only hormone driven sex differentiation may modify the astragalus, and even then, only along the Bd measurement (Boessneck *et al.* 1964, Ruscillo 2003). Functional use on different slopes may change in the internal structure of bones in the ankle joint but this plasticity has not been shown to extend to external morphology.

Cursors depend upon the efficiency of movement in particular environments, and the morphology of the bones in the ankle joint is critical to determining attrition in specific environments. For animals moving long distances, stiff and non-rotational ankle joints will use less energy and hence be more favourable to survival. Conversely, flexible ankle joints are better for manoeuvring slopes. As the astragalus is not subject to many of the ontogenetic variables described above, it is the ideal element to measure inherited phenotypes of regional landraces.

4.3 Landmark Selection

Landmarks for the geometric morphometric investigation of the appendicular bones of *Ovis aries* and *Capra hircus* are not currently published in the academic canon. Currently few studies that have focused upon the appendicular morphology of Cervidae but none on ovicaprids (Curran 2012, Curran 2013, Sykes *et al.* 2013, Thompson and Curran 2013). Therefore, it is necessary to evaluate studies that use traditional biometry in order to direct the selection of landmarks. These studies rely on measurements defined by von den Driesch (1976), Plummer and Bishop (1985 in Klein *et al.* 2010), and measurements defined by individual investigators. Often these measurements are similar, but they do not always overlap. Additionally, these studies utilise different analytical techniques, ranging from ratios to logarithm deviation techniques.

4.3.1 Quantitative Background

Ovis aries bones have been quantitatively described in the archaeological literature according to the standard for appendicular and non-appendicular bones laid out in the metrical guide written by Angela von den Driesch (1976). This manual is the standard for the analysis and publication of zooarchaeological metrical material. This manual describes the measurements, such as Greatest Length (GL) and Distal Breadth (Bd) for all bones (Figure 4.2).

Metrical measurements and the comparison of elements and individuals have found that size accounts for the largest amount of variation (Klein et al. 2010). In some cases, such as the use of pig scapula width, this size measurement is a useful archaeological for detecting seasonality (Albarella and Payne 2005, Rowley-Conwy 2001). Biometric research on fallow deer astragali ratios (GLl v. Bd) reveals clear groupings of astragali in different geographical locations

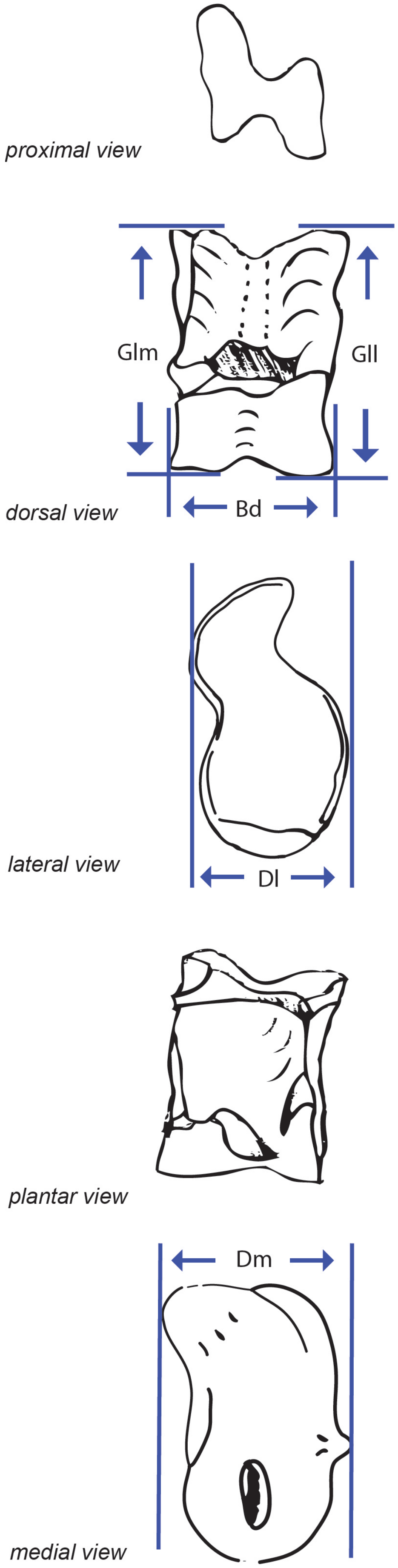


Figure 4.2: von den Driesch's (1976) suggested measurements for astragali.

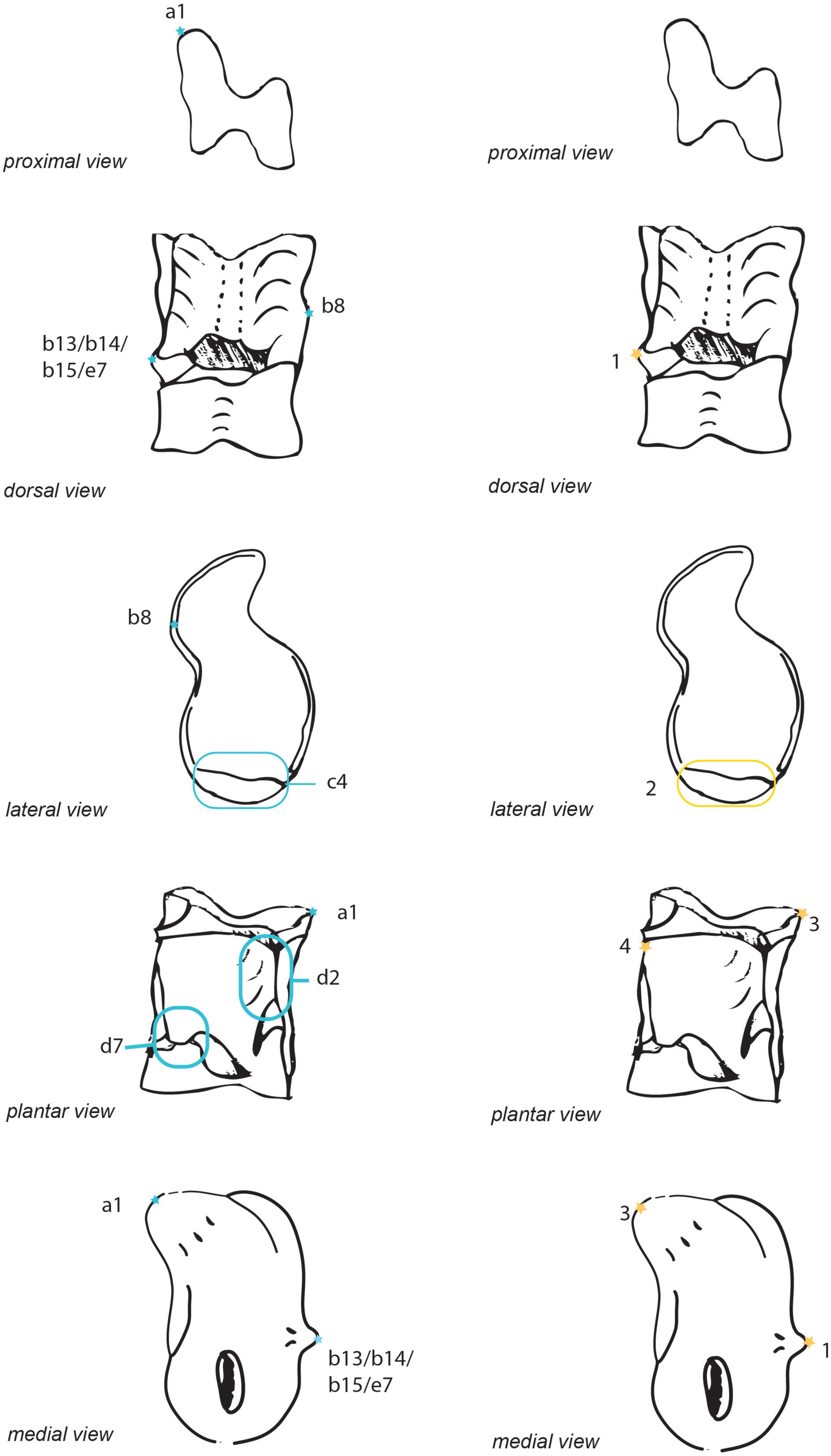
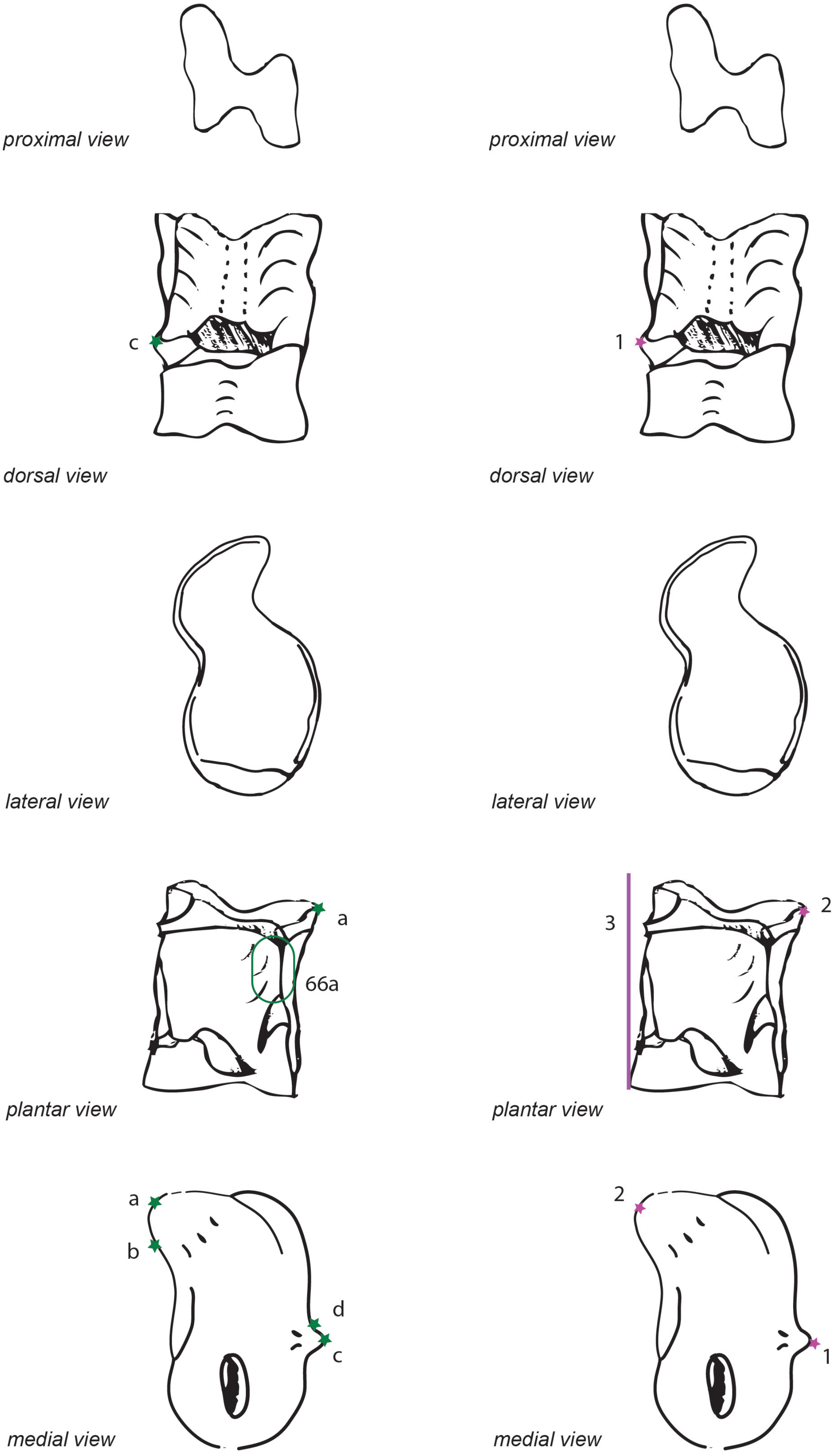


Figure 4.3: Fernandez (2001) left, and Zeder and Lapham (2010) right, qualitative characteristics for species separation, labelled by respective systems.



Figre 4.4: Boessneck (1969) left, and Prummel and Frisch (1988) right, qualitative characteristics for species differentiation, labelled by respective systems.

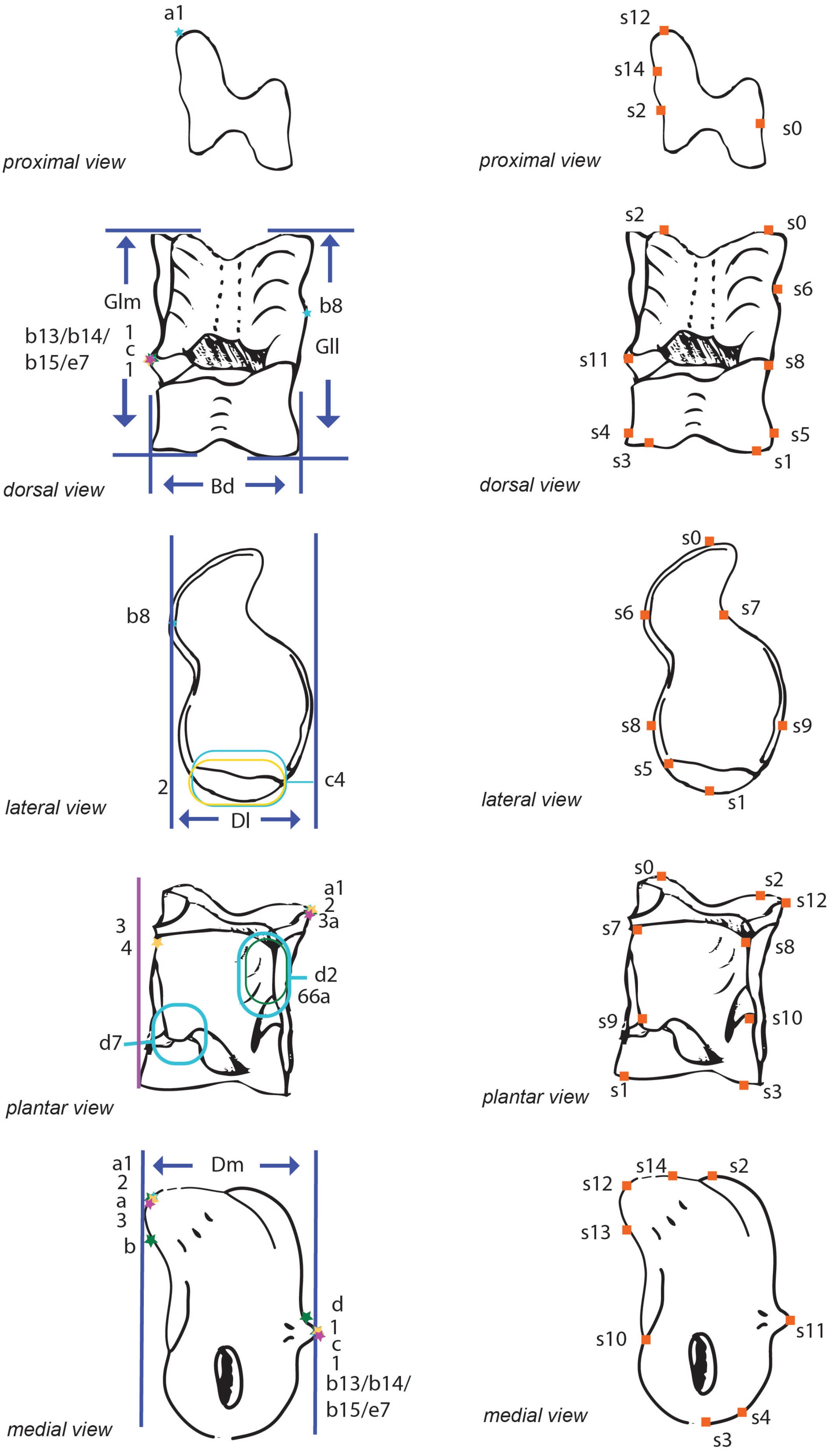


Figure 4.5: Left, all quantitative and qualitative characteristics overlaid in comparison with landmarks chosen, right.

(Sykes et al. 2013). This suggests inherited shapes in geographical regions despite the potential for admixture.

Biometry with the addition of Simpson's log-ratio method (Simpson *et al*. 1960 in Johnstone 2004) allows bone measurements from different elements and sizes to be compared relative to a determined standard. The equation for this analysis would be:

$$\log_{10} \text{(archaeological measurement/standard measurement) (Johnstone 2004)}$$

This technique is used to detect changes in size through time (e.g. Albarella 1997, Russell 2010, Thomas 2005, Zeder 2001). This technique was applied to two medieval populations of sheep at Owslebury and Launceston Castle (Davis 1996). Based on measurements from a Shetland sheep, the two populations were smaller than this primitive breed, although the Owslebury population had more variation between element sizes whereas at Launceston Castle, the population was uniformly smaller than the Shetland standard.

While this technique is useful for detecting size difference between populations, it does have limitations. The average measurement for each type of element in a population is subjected to the log-ratio technique, which can compress a variety of breeds present at a site through time. Log-ratio works best when the measurements are compared along a uniform axis, e.g. the proximo-lateral axis, as measurements from the same axis tend to correlate best across populations (Davis 2000). Finally, log-ratios may be affected by variables that can change long bone growth, such as castration and reduced protein intake. Log-ratio methods are best used as a whole site approach to investigate relative change of all elements from a species through a broad range of time (e.g. Thomas *et al.* 2014).

Wolff's law describes the morphological changes that occurs to healthy bone under loads and suggests that this change can be reliably predicted mathematically (Wolff 1986). The application of this theory to animal bone has been discussed extensively, particularly in regards to predicting bone development in the diaphysis of long bones (Barak *et al.* 2011, Bertram and Schwartz 1991, Burr *et al.* 2002, Davies *et al.* 2012, Frost 1990a, Frost 1990b, Lieberman *et al.* 2001, Pierson and Lieberman 2004, Ruff *et al.* 2006). These studies sought to define significant changes in bone, particularly those that were caused by a variation in ecology that would affect the strain on distal limb bones in movement. While these studies were not conclusive, they did suggest that the combination of Wolff's law, a law that applies to individuals, in addition to evolutionary selection, could together suggest a coevolutionary trend to specific morphology in environments.

DeGusta (2003a) utilised ratios and raw metrical measurements of Bovidae astragali to develop discriminant functions that predicted species habitats based on morphology. He found that while size was an influencing factor, it only affected the accuracy of his equations to predict habitat by 13% when size was removed from the discriminant function. The astragalus proved to be robust in predicting the palaeohabitat of multiple species that inhabited a variety of open and closed habitats, which were arranged along a gradient of structural complexity, from fully open (grassland) to fully closed (forest).

Plummer *et al.* (2008) also used raw measurements and ratio of the astragalus to refine this method. Use of the astragalus has been shown to be more useful than that of metapodia (DeGusta 2003a, Plummer *et al.* 2008) and nearly as useful as femoral models in determining palaeohabitat (Kappleman *et al.* 1997). DeGusta (2003a) suggests that the most useful size exclusive ratio for palaeohabitat determination is the ratio of intermediate length to intermediate width. This ratio roughly correlates to von den Driesch's (1976) measurements of GLI and DL. These two measurements are more specifically defined as landmarks s0 to s1 (GLI or intermediate length) and s2 to s3 (roughly DL or intermediate width, see below for details).

Klein *et al.* (2010) addressed these ecomophological investigations into discriminant functions of post-cranial Bovidae elements. Using metapodials, he concluded that size was the determining factor that overwhelmed any morphology that would describe an environmental niche. This is most clearly seen when the geometric mean (the average logarithm for each specimen) was plotted against an individual log-length, which clearly grouped each species into clear clusters without significant overlap (Klein *et al.* 2010). Klein relied on principal component analysis to estimate the effect of size on clusters of taxa and concluded that taxa grouping overrode palaeohabitat clusters. The size variation accounted for over 96% of variation, which separated the species clusters, while the shape component was only weakly controlling for palaeohabitat. Yet DeGusta's findings are compelling and suggest biometric change, similar to the geographically specific biometry of pre-Roman deer populations (Sykes *et al.* 2013).

4.3.2 Qualitative Background

Qualitative characteristics of bone morphology are assessed by eye, usually describing the stages of development of a characteristic (Johannsen 2002) or utilising figures to differentiate between closely related species, such as *Ovis aries* and *Capra hircus* (Boessneck 1969, Prummel and Frisch 1986, Zeder and Lapham 2010).

The qualitative characteristics of *Ovis aries* astragali are described in comparison to other closely related species, such as goat (*Capra hircus),* wild European relatives such as Chamois sheep (*R. rupicapra*) and very similar morphological species, such as the roe deer (*C. capreolus*). The most comprehensive analysis of all published qualitative material (Boessneck 1969, Prummel and Frisch 1986, Zeder and Lapham 2010) is a doctoral dissertation from Elena Fernandez, from the University of Geneva (2001, Figure 4.3). This dissertation covered all of the key qualitative references for these morphological similar species.

Fernandez (2001) thoroughly evaluates the efficacy of each characteristic in distinguishing between domesticated sheep, goat, wild goat, ibex and roe deer. Some of the characteristics are more useful for wild/domestic distinction, others for ovicaprid/cervid distinction, and yet others, for sheep/goat distinction.

The tuberculum talus, which is located on proximal plantar medial edge of the astragalus, and a trochlea on the dorsal-lateral corner are extremely effective distinguishing characters for domesticated sheep (Fernandez 2001). The distal articulation on the lateral side is effective in distinguishing between sheep and goats. In sheep this is elongated along the distal end, while in goats it is an isolated, nearly circular flat pad. Prummel and Frisch (1986, Figure 4.4) suggest that on the lateral side goats have nearly flat articulations, while sheep do not, resulting in a table test in which goat specimens will lie flat while sheep bones fall over.

The amount of variation for each qualitative characteristic within this group of morphological similar species was critical to selecting landmarks which not only would represent the space of the bone in morphospace, but would also capture significant amounts of shape variation.

4.3.3 Astragalus Landmarks

Landmarks were selected based on upon a combination of metrical measurements suggested by von den Driesch (1976, Figure 4.2) and characteristics separating sheep, goats, and deer (Fernandez 2001, Boessneck 1969, Prummel and Frisch 1986, Zeder and Lapham 2010, Figure 4.3, 4.4, 4.5) Additional characteristics were suggested by material from Curran (Curran 2013).

Landmarks are described based on their label given consecutively and automatically by Landmark software (IDAV, University of California, Davis) and begin numbering at s0. They are described by their location on the astragalus, any previous documentation or use in the zooarchaeological or ecomorphological literature, and how they are defined in the Landmark program on a three dimensional model. All of the landmarks are Type II and Type III (Bookstein 1991). There are no Type I landmarks selected in this scheme as these landmarks, are not consistently found in all specimens, and hence are not suitable for GMM.

The landmark s0 is the first landmark and is the most proximal point of the lateral proximal trochlea. This Type III landmark lies near the proximal-distal axis. This is one of a pair of landmarks based on traditional biometric measurements of the greatest length of the lateral side (GLl) (Figure 4.2, von den Driesch 1976). s1 is the maximum of the lateral distal articulation. This Type III landmark also lies close to the proximal-distal axis and completes the traditional GLl measurement. These landmarks are most clearly seen in the plantar

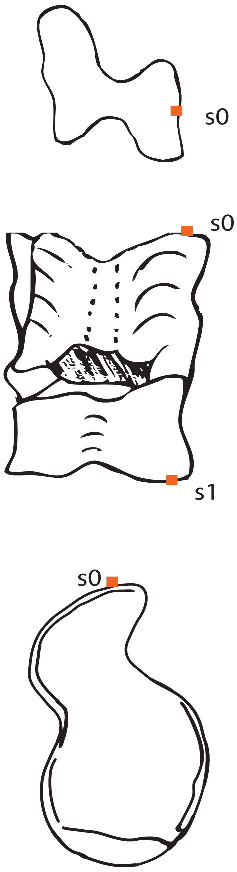


Figure 4.6: The proximal, dorsal, and lateral views of landmarks s0 and s1.

and dorsal views of Figure 4.6.

The landmark s2 is a type III landmark and located at the most proximally oriented point of the medial proximal trochlea. However, the most proximally oriented point of the medial proximal end of the astragalus can vary, depending upon the morphology of the tuberculum talus. s2 was chosen to be one of a pair of landmarks to define the greatest length of the medial side (GLm) (Figure 4.2, 4.7, von den Driesch 1976). Caliper measurements would measure either s2 or s12 on a physical model, as the measurement is of the maximum length of the astragalus on the medial side, not the length between particular points. However, landmarks must be on the same feature or maxima that do not vary. s2 is considered to roughly equate to the GLM measurement, however, should a true GLM measurement be required from a three-dimensional model, either s2 or s12 would have to be chosen depending upon which is the greatest distance from s3. s3 is the maximum of the medial distal articulation and a Type III landmark. This landmark, like s1, lies close to the vertical axis and at the bottom of the medial distal articulation. This pairs with s2 to roughly define the GLM (Figure 4.2, 4.7, von den Driesch 1976).

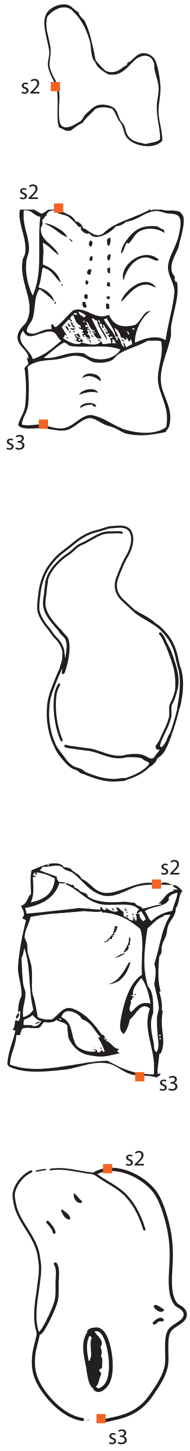


Figure 4.7: The proximal, dorsal, lateral, plantar, and medial views of landmarks s2 and s3.

The landmark s4 is part of a pair of Type III landmarks that define the maximum breadth of the distal articulation, Bd (Figure 4.2, 4.8 von den Driesch 1976). s4 is located on the medial edge of the distal articulation, viewed and placed from the dorsal view (Figure 4.8). s5 is the other part of this pair, and is the maximum on the lateral side of the distal articulation on the dorsal edge. s5 is also located at the dorsal end of the lateral distal articulation. It is important to note that this measurement has a high degree of variability in studies of two-dimensional measurements (Davis *et al.* 2000). This measurement is also quite difficult to find, as it does not lie on or near an axis. s5 describes the maxima of the distal articulation when viewed dorsally and indicates the edge of articular pad. The dorsal end of the lateral distal articulation can be used a guide for the location of s5 (Figure 4.8).

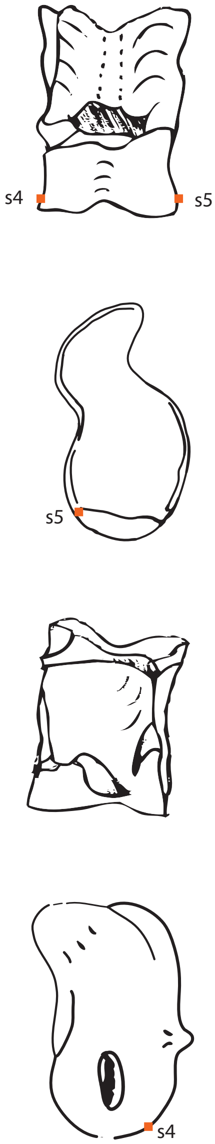


Figure 4.8: The dorsal, lateral, plantar, and medial views of landmarks s4 and s5.

The next four Type II landmarks were placed to give an approximation of the measurement of the depth of the lateral side (DL) (Figure 4.2, Figure 4.9, von den Driesch 1976). As the maximum of the lateral side is not between two points that are parallel to the horizontal axis, it is impossible to use just a pair of landmarks to describe these maxima. Instead, four landmarks are used to describe the maxima as well as describe the shape of the maxima and minima of the trochlea and articulations (Figure 4.9).

The landmark s6 defines the most dorsal point of the proximal trochlea. This landmark corresponds on the dorsal-plantar axis to s7, which is the meeting of the proximal trochlea and the top of the articular surface on the plantar surface

(Figure 4.9). s6 is noted by Fernandez (2001) as marking an important feature that differentiates between sheep and goat. The angle of intersection between the location of s6 and the bottom of the 'gulley' between the articular surfaces of the proximal articulation on the dorsal surface can be important in distinguishing between the two species (Figure 4.3, Fernandez 2001). Zeder and Lapham (2010, Figure 4.3) noted that the position of s7 could differentiate between sheep and goats and is also noted in Fernandez (2001, Figure 4.3).

The landmarks s8 and s9 mark the dorsal and plantar maximum width of the distal trochlea as viewed from the lateral side. s8 defines the most proximal point of the distal articulation on the lateral side, which also corresponds to the divot at which the distal articulation meets the proximal trochlea. s9 corresponds to the most proximal point of the lateral side of the plantar articular surface and the point which protrudes the farther in the plantar direction of the distal half when viewed laterally. (Figure 4.9) This locates the edge of this surface that can be affected by the presence of a divot that is located just below this landmark in sheep (Figure 4.3, Fernandez 2001). It is not possible with the landmark method to locate this divot as it is not a consistent feature, even within sheep. Instead, s9 not only marks a maximum depth on the lateral side, but also the change in shape of the edge of the plantar articulation that occurs when the divot is present and is located on a dorsal-plantar line across from s8.

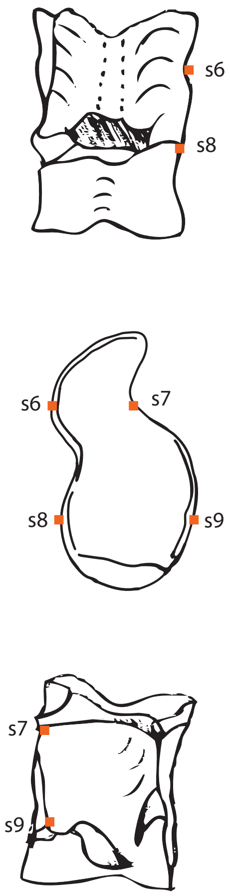


Figure 4.9: The dorsal, lateral, and plantar views of landmarks s6, s7, s8, and s9.

The landmarks s10 and s11 are paired Type II landmarks that correspond to a traditional biometric measurement of the depth of the medial side (DM)

(Figure 4.2, 4.10, von den Driesch 1976). s10 is located on the top of the distal articulation on the medial side in the medial view (Figure 4.10). s11 is located on the tip of a small tuberculum on the dorsal edge of the medial surface. The orientation of this tuberculum is important for distinguishing between sheep and goat (Zeder and Lapham 2010, Fernandez 2011, Prummel and Frisch 1986, Boessneck 1969, Figure 4.3, 4.4).

The last group of three Type II landmarks, s12, s13 and s14, define the orientation and shape of the tuberculum talus, which is located on proximal plantar medial edge of the astragalus (Figure 4.11). s12 is located on the tip of tuberculum. The beginning of the tuberculum on the distal side is marked by s13, and the end of the tuberculum on the proximal side is noted by s14. Both the orientation and the shape of this feature are critical and noted in all of the literature as a distinguishing feature between sheep, goats, and their wild predecessors (Boessneck 1969, Fernandez 2001, Prummel and Frisch 1986, Zeder and Lapham 2010, Figure 4.3, 4.4).

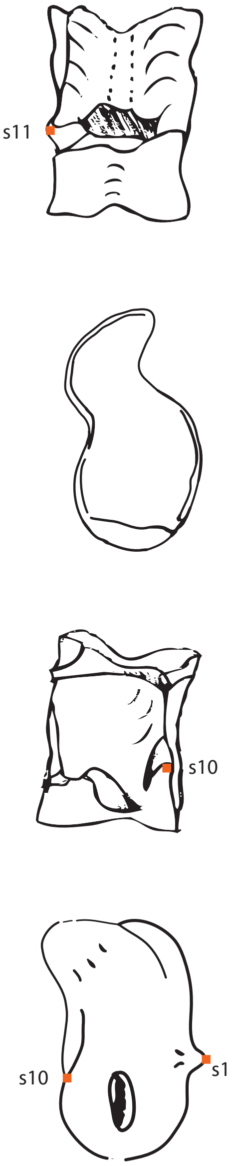


Figure 4.10: The dorsal, lateral, plantar, and medial views of landmarks s10 and s11.

4.4. Data Collection Method

Astragali were chosen from the collections of animal bones from each of the three sites discussed previously (Chapter 3). These collections were previously excavated by the principal investigators from each site and stored in paper bags with context labels. Astragali that were unworked and had good surfaces were selected for scanning. Specimens from neonatal animals and those with surface pitting were excluded from the study. Both left and right specimens were selected except in cases in which entire articulated ovicaprid skeletons were excavated in context, in which case the left astragalus was selected for scanning. Astragali were excluded from analysis if they showed chipping or damage over an area needed for landmark placement. Both sheep and goat specimens were scanned and then visually examined and sorted into species categories according to the criteria laid out by Boessneck (1969) and Fernandez (2001) which included the aforementioned table test.

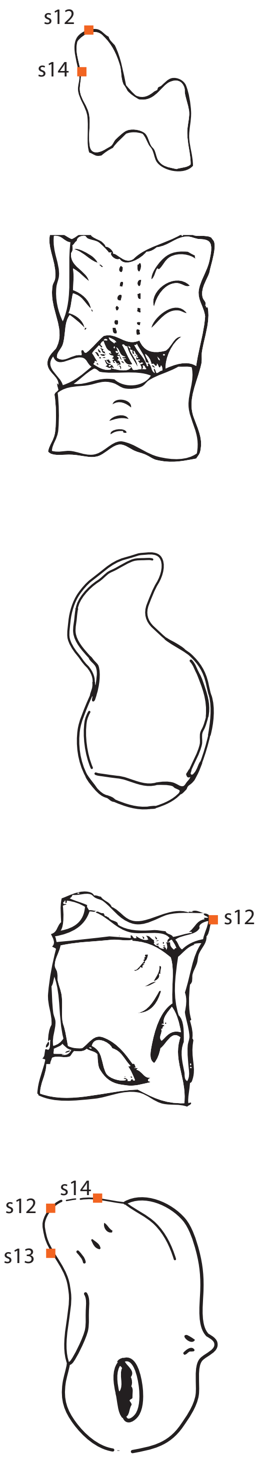


Figure 4.11: The proximal, dorsal, lateral, plantar, and medial views of landmarks s12, s13 and s14.

Specimens were scanned using a Next Engine 3D Laser Scanner, (Next Engine, Inc., Santa Monica, CA, USA) which uses twin arrays from four solid-state lasers to triangulate specimen surface and translate data into a point cloud. The Next Engine is preprogramed to settings calibrated in inches, and are listed here in both millimetres and inches for clarity.

Specimens were scanned in wide mode on the Auto Drive turntable (Next Engine, Inc., Santa Monica, CA, USA) with a dimensional accuracy of ± .381 mm (0.015 inches) at a field size of 343 x 257 mm (13.5 x 10.1 inches). Scan Studio HD software (Next

Engine, Inc., Santa Monica, CA, USA) was included as part of the scanner package, and this software controlled and directed scanning and positioning of the specimens on the Auto Drive.

Scanning was undertaken in a series of 360-degree scans that rotate the object in a full circle on the turntable and in a minimum of six divisions per scan. At least four 360-degree scans were done on each specimen to ensure that scans overlapped. This is essential for later processing of the scans. There must be an overlap for the software to accurately stitch together these scans into a unified model. Scans were taken at a standard resolution of 2500dpi (dots per inch). Surfaces were captured using RGB photos taken by the scanner before the start of each scan, which were layered over the texture surface by the Scan Studio HD software automatically.

After scan acquisition, scans were trimmed and the plate of the Auto Drive and any background data was deleted from the scans. Each bracket scan was stitched together using biologically consistent landmarks on the lateral and medial sides of the specimen. These scans were aligned to at least an accuracy of ±0.02mm (0.007 inches). Once aligned, the scans were fused together twice into a mesh. First the scans were fused using both a standard fusion at resolution ratio of 0.5 to keep edges sharp and textures were blended at a scale of 10 pixels to smooth out the smallest scan artefacts which would not distort the presence or location of landmarks. Then the scans were fused again as a volume mesh, which reduces the amount of cloud point data more efficiently without the need for the smoothing process. The astragali scans were fused twice to control for stitching and digitisation error for a pilot study (Chapter 5).

Once scans were trimmed, aligned and fused, they were exported as surface files in site groupings that contain point cloud data (.ply). These files were imported to Landmark (IDAV, University of California, Davis), a software program designed to handle point clouds and meshes of three dimensional objects. Within this program landmarks were located on each specimen (see above). The 15 landmarks chosen above were marked on the specimens. This was done visually and with the assistance of plantar-dorsal and proximal-distal axes. The landmarks were marked in a consistent order, which is necessary to avoid later data processing errors.

The user defined the first four landmarks on the lateral and medial surfaces, and then an auto-locate feature was used to ensure that the landmarks were placed in the correct order and location. The user ensured their correct placement and if necessary adjusted these auto-placed landmarks. Before the files could be exported, a dimensional primitive was defined for each model. The GLI measurement (the length of the lateral side between s0 and s1) (von den Driesch 1976) was used as the dimensional primitive for all of the models. Calliper measurements taken of the astragali were used for these primitives to scale the models to the correct size. The models were then exported individually as NTSYS files (.dta) into MorphoJ (Klingenberg 2011), a software program for the geometric morphometric analysis of both two and three dimensional landmark data.

The dataset was initially run through a generalised Procrustes analysis (GPA) to discard size data. In generalised Procrustes analysis, the landmark configurations are scaled to the same size (the centroid size), translated to the same location and rotated to the same orientation. Following this, the sum of the squared distances between corresponding landmarks is minimal (Dryden and Marida 1998, Rohlf and Slice 1990). The first set of landmark configurations was then used as the initial target configuration to which all other configurations were fit using a least-squares fit. Then a new average configuration was computed and all of the configurations were fitted to this new average. Another average configuration was computed and again the configurations were fit until the average configurations of landmarks no longer changed by more than an arbitrary small amount (Rohlf and Slice 1990).

A Procrustes ANOVA, a test to control for measurement and digitization error, was conducted as a pilot study. The astragali scans were fused and imported twice (each labeled as a and b respectively) and landmarks were applied twice to each of these imports to control for error in landmark placement and scanner error. It is critical for the pilot study to investigate the effects of these variables, which are discussed further below.

Outliers were controlled for by investigating the amount of variation of each landmark in each configuration from this average configuration. MorphoJ provides a multivariate normal distribution to compare the variability of individual configurations to look for configurations with abnormal variation. It is possible to exclude configurations from analysis or to reorder landmarks that may have been placed out of order. Within the Serektas, Kent and Turgen dataset, there was no unusual variation for the ovicaprid specimens. One deer specimen was found and excluded from analysis (Figure 5.1). Any exchanged or inverted landmarks were corrected at this stage.

A covariance matrix was generated from the GPA analysis. As the GPA had already controlled for scale a covariance matrix is preferable as it displays all of the relationships between landmarks. Additionally, covariance matrices are preferable for performing Principal Components Analysis (PCA). A PCA performed on a correlation matrix will find more variance in landmarks due to the way that they interpret variation, scale and rotation (Klingenberg 2012).

To generate the covariance matrix, a PCA was run to look for overall variation in the dataset and investigate shape change. This is useful for evaluating the efficiency of the landmarks and their relative placement. However, PCA will only show the most distinct of groups and is not ideal for investigating group structure. Subgroups may be visible in another dimension or on an oblique axis to the PC axes (Klingenberg 2012). The small number of specimens analysed contributes to the difficulty of describing intergroup variation, but it does not indicate a lack of such groups (see chapter 6). A Canonical variate analysis (CVA) is similar to a PCA but maximizes variation between predefined groups while taking into account the variation within groups and is ideal for investigating small sample sizes (Klingenberg and Monteiro 2005). Both the results of the PCA and CVA for all specimens from all sites are described in the following chapter.

The method chosen is designed to find maximum shape variance between sheep and goat from the three different sites in this study in an attempt to detect phenotypic variation, rather than ontogenetic variation. Research questions which seek to investigate developmental instability, using techniques such as fluctuating asymmetry, were not included in this research design. Size data is also excluded from this analysis, which excludes an investigation of allometry (size correlation with shape change) from this research (Klingenberg 1996). Future research using geometric morphometric methods may wish to reintroduce size to investigate correlations of size and shape differences between sites and species.

Chapter 5: Geometric Morphometric Results

Scans were taken of left and right astragali from both *Ovis aries* and *Capra hircus* specimens from Late Bronze Age sites Serektas, Turgen and Kent. Specimens which were worked into artefacts and those which were not suitable for analysis due to software corruption errors were excluded from analysis (Table 5.1) All specimens were measured using digital calipers in the field.

Table 5.1: Astragali scanned and analysed from all sites.

Site Analysied	Scanned Specimens	Unsuitable Specimens	Worked Specimens	Total Analysied
Kent	132	123	1	8
Serektas	16	2	2	12
Turgen	34	1	1	32

Measurements were taken according to von den Driesch (1976) (Table 8.1, 8.2., 8.3). These measurements were used in the stitching and landmarking process to create metadata and correctly size the digital scans of the specimens.

For the geometric morphometric analysis, landmark data from the program Landmark (IDAV) was imported into MorphoJ (Klingenberg 2011) as one dataset. Specimens were reviewed for outliers and reversed landmarks followed by a generalised Procrustes analysis to discard size data. A covariance matrix was generated from the dataset and principal components analysis was run from this covariance matrix.

Principal component analysis, or PCA is used to measure overall variation in a given data set. PCA sorts the data into principal components, which are uncorrelated and account for the maximum possible amount of variation in the data. For example, the first principle component is always associated with the most variation within the data set and the amount of this is displayed as an Eigenvalue. In traditional morphometrics, it is always assumed that size accounts for the most variation, however as size was removed during the GPA, the principal components in this study all relate to shape variation. For easiest visualisation, a principal component score can be exported from MorphoJ and mapped onto a sample specimen in Landmark to display the associated shape change related to that particular principal component.

5.1 Controlling for Measurement Error

The data from Serektas was chosen for a pilot study to apply a Procrustes ANOVA procedure to measure the amount of random error generated by the data collection methodology. This pilot study consisted of all 12 scans from Serektas. These scans were aligned in ScanStudio HD (Next Engine Inc,. Santa Monica, CA, USA) twice by manual control (see Chapter 4) and saved as separate models appended with ‘a’ or ‘b’. These models were then imported into Landmark (IDAV, University of California at Davis) and landmarks applied twice and appended with ‘1’ or ‘2. There were four landmark configurations describing one scanned astragalus, each labeled as a1, a2, b1, or b2 with accompanying metadata to describe the specimen, site, and side (Figure 5.1, Table 5.4).

All landmark configurations (48) were imported into MorphoJ (Klingenberg 2011) for analysis. A Procrustes fit preceded the application of the Procrustes ANOVA procedure. The Procrustes ANOVA procedure quantifies variation at and between multiple levels of error (Bailey and Brynes 1990, Klingenberg and McIntyre 1998, Klingenberg et al. 2002). In this case, the hierarchy of error describes two types of random error introduced by the operator. During the scan stitching process, manual control could be a source of random error. In the same vein, landmarks must be applied in Landmark (IDAV, University of California at Davis) by an operator, which allows random error as landmarks could be inconsistently located (Figure 5.1). This random error can be measured by replicating data at each of these steps, and measuring the amount of variation present between the levels of the data processing (Figure 5.1).

The Procrustes ANOVA procedure for the Serektas pilot returned three levels as described in Figure 5.1. Both centroid size and shape were analysed separately. Both tables show variation at the biological level, called ‘Specimen’ (Table 5.2). Measurement error is divided into two levels, ‘Stitching Error’ and ‘Landmark Error’ (Table 5.2). Error is assumed to be isotropic; variance is distributed in a spherical manner around an average landmark location (Klingenberg et al 2002).

Table 5.2: Procrustes ANOVA. Classifiers used for Procrustes ANOVA: Individuals: Individual Specimen, Error 1: Scanning Error, Resiudal: Landmark Error.

Centroid size:					
Effect	SS	MS	df	F	p (param.)
Specimens	552.609268	50.237206	11	506.7	<.0001
Stitiching Error	1.189757	0.099146	12	0.81	0.6405
Landmark Error	2.946413	0.122767	24		

Shape, Procrustes ANOVA:					
Effect	SS	MS	df	F	p (param.)
Specimens	0.22381872	5.4×10^{-4}	418	15.05	<.0001
Stitiching Error	0.01622741	$3.6 \text{ X } 10^{-5}$	456	.43	1
Landmark Error	0.07634232	$8.4 \text{ X } 10^{-5}$	912		

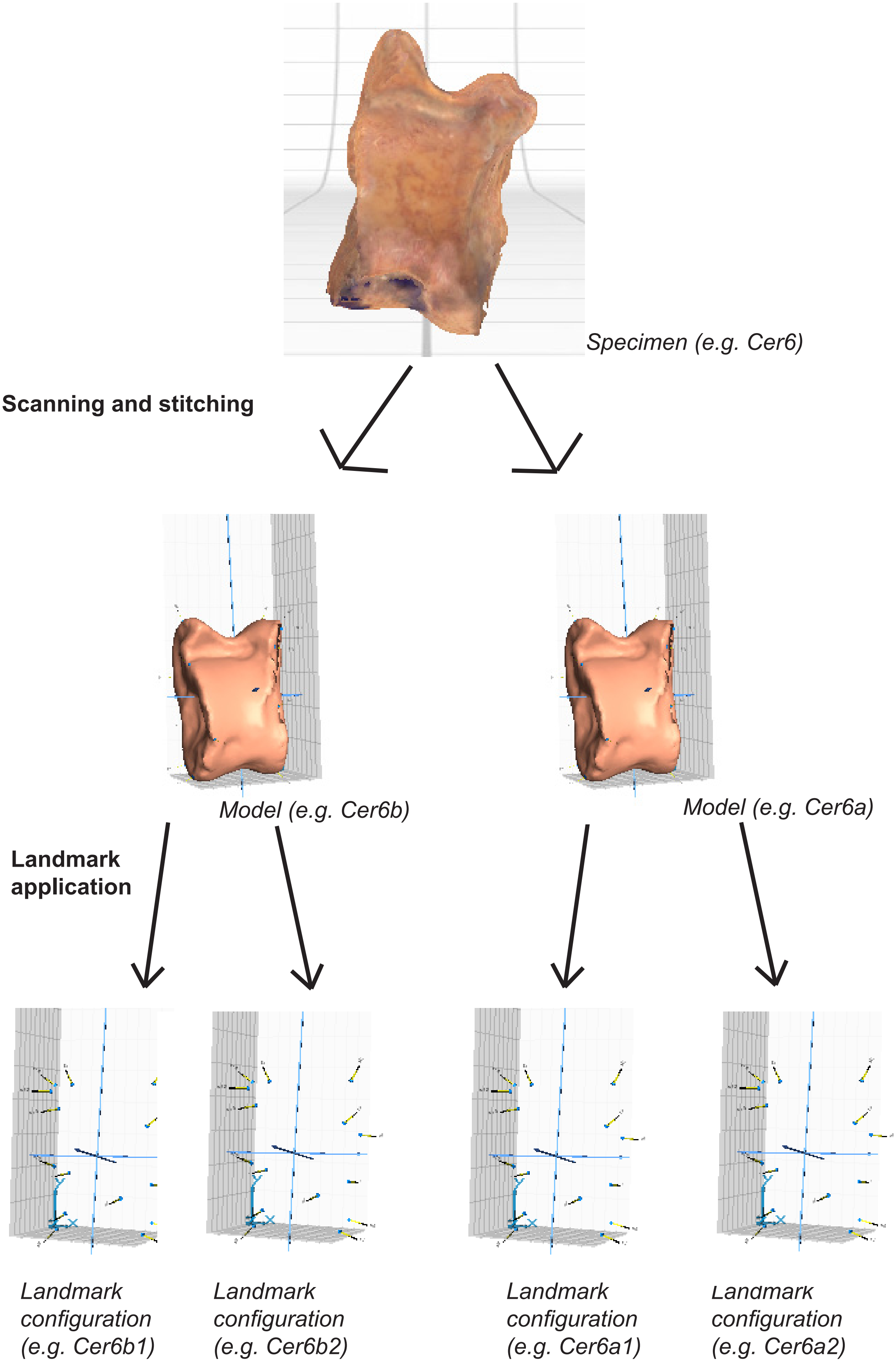


Figure 5.1: Hierarchy of error.

Centroid size uses a conventional two factor ANOVA which has been used in studies of morphometrics (Bailey and Brynes 1990). Sum of squares (SS) is the sum of squared effects of variance across all coordinates. The degrees of freedom are calculated based on the number of specimens. For ‘Specimens’ the degrees of freedom (df) equal n, where n is the number of specimens. For ‘Stitching Error’, degrees of freedom is equal to n-1. The degrees of freedom for ‘Landmark Error’ is equal to 2n. Mean squares (MS) describes the variance associated with an effect and is calculated by dividing the sum of squares by degrees of freedom for an effect.

The F-value is the most pertinent value for interpreting the variance between levels. The F-value is a ratio of mean squares (MS) between levels. For example, to calculate the F-value for ‘Specimens’, the equation would be:

$$F = MS_{\text{Specimen}}/MS_{\text{Stitiching Error}}$$

The F-value indicates how much variance there is at a level relative to that at a lower level.

In the Procrustes ANOVA for centroid size, the F-value for ‘Specimens’, which is the level of biological interest, is 506.7. This value indicates that biological error is much greater than the next level, ‘Stitching Error’. The lowest level, ‘Landmark Error’, has nearly the same mean square value as ‘Stitching Error’ and therefore the F-value for ‘Stitching Error’ is close to 1. This indicates that these two lowest levels possess similar amounts of variance, which are much less than biological variance. Both of these lowest levels of error have much less variance than the level of biological interest.

The table for shape variance is calculated in a similar way. Sum of squares and mean squares are both the same, although for shape, the direction of variance around an average landmark is no longer of importance; only the amount of variation is calculated.

Degrees of freedom are calculated in a much more complicated manner. To find the degrees of freedom for ‘Specimens’ where n equals the number of specimens and k equals the number of landmarks then

$$df= (n-1)(3k-7)$$

In this instance, n=12 and k=15, which results in

$$(12-1)(3*15-7)= 418$$

To calculate the degrees of freedom for the first measurement error, ‘Stitching Error’, the degrees of freedom are calculated:

$$(n-1)(3k-7)+(3k-7)$$

which is

$$(12-1)(3*15-7)+(3*15-7)= 456$$

Finally, to calculate the degrees of freedom for ‘Landmark Error’, the formula is:

$$2n(n-1)(3k-7)$$

In this pilot study is:

$$2*12(12-1)(3*15-7)=912$$

Again, the F-value is the most informative in describing the amount of variation between levels. While smaller, the F-value for ‘Specimens’ is 15.05, which is enough to show that for investigations of shape, measurement error is again negligible.

The F-value of the biological variation is large enough to suggest that human induced random error does not need to be controlled for with a refinement of data processing or a duplication of data. F-values for biological variation less than six would suggest that random errors would confuse any further analyses and prompt a methodological review. However, with an F-value of 15 for shape any patterns within the data set using the current methodology is likely due to biological variation as opposed to human induced measurement error.

5.2 Caprid Speciation

Ovis aries and *Capra hircus* were separated according to qualitative characteristics at the same time as zooarchaeological identification of other elements in the field (Chapter 3). The astragalus is one of few elements which have proven useful for delineating sheep and goat (Boessneck 1969, see Payne 1969, 1985 for metacarpals and teeth respectively). These qualitative characteristics particularly relied upon the Prummel and Frisch (1986), Zeder and Lapham (2010), and Boessneck (1969). The astragali were described in detail during analysis. Ovid and caprid qualitative characteristics were noted for each. Specimens with more qualitative characteristics of one species were assigned to that species. The reliability of this identification was tested by a k-means cluster analysis. This statistical test is an iterative procedure in which the number of clusters, k, is defined the by user. Cluster means are assigned randomly, and specimens assigned to the closest mean. The means are then updated accordingly and the process run again until there is no variation in the number of specimens between iterations. It should be noted that individual specimens can vary between clusters depending on the initial placement of cluster means, but this is normal behaviour in this type of analysis.

A k-mean cluster analysis was performed in the statistical package PAST using a matrix of landmarks that were subjected to a Generalised Procrustes Analysis. K was defined as 2, one for each species. The cluster assignments for each specimen were compared against the species ID given during zooarchaeological analysis. There is 79% correct identification of species to cluster (Table 5.3). *Capra hircus* specimens accounted for most of the misidentified specimens, while *Ovis aries* specimens were more likely to be identified correctly.

Zeder and Lapham identified in their review of qualitative characteristics (2010) that for astragali, approximately 20% of *Ovis aries* would be misidentified as *Capra hircus*. The results in Table 5.broadly agree with this misidentification rate. Only two sheep were misclassified (18%) while nine out of eleven goats were misclassified (81%). Additionaly, the overall percentage of specimens that were misidentified agrees with Zeder and Lapham's finding of a 20% misidentification rate of species using the astragalus.

This indicates that utilising qualitative characteristics is not an entirely reliable method for speciation. A one in five chance in misidentification would seriously call into question the proportions of Ovis aries and Capra hircus in a flock.

Ratio index methods are also used to investigate speciation, sex, and breeds by describing specimen shape (Albarella 1997). The ratios of Bd/Dl and Dl/GLl as defined in von den Driesch 1976 are plotted to investigate for species clusters (Davis in press). This method controls for the amount of depth of the astragalus which has been shown to separate sheep and goat samples in Mediterranean and European contexts (Davis in press). This method has varied utility and often

Table 5.3: K-means cluster anlaysis. Results for classification rates of *Ovis aries* and *Capra hircus.*

11 misclassifed	
9 goats	81% of mis
2 sheep	18% of mis
42 correct	
8 goats	19% of correct
34 sheep	80% of correct

has overlap between specimens of known species, such as between primitive breed sheep and goats in the UK. However in Cypriot and Portugese contexts, this method reveals clear clusters of species in modern and archaelogical contexts (Davis in press). The values for the European and Mediterranean populations in this baseline study fall in the region of Bd/Gl > 1.10 and Dl/GLl <0.56.

When the sheep and goat specimens from this investigation are plotted using this method, they fall across a range of values in a mixed group. There are no clear clusters of specimens based on the depth of the astragali. This suggests that the Kazakh specimens do not have the same morphological signatures as European caprids and hence cannot be investigated using this technique.

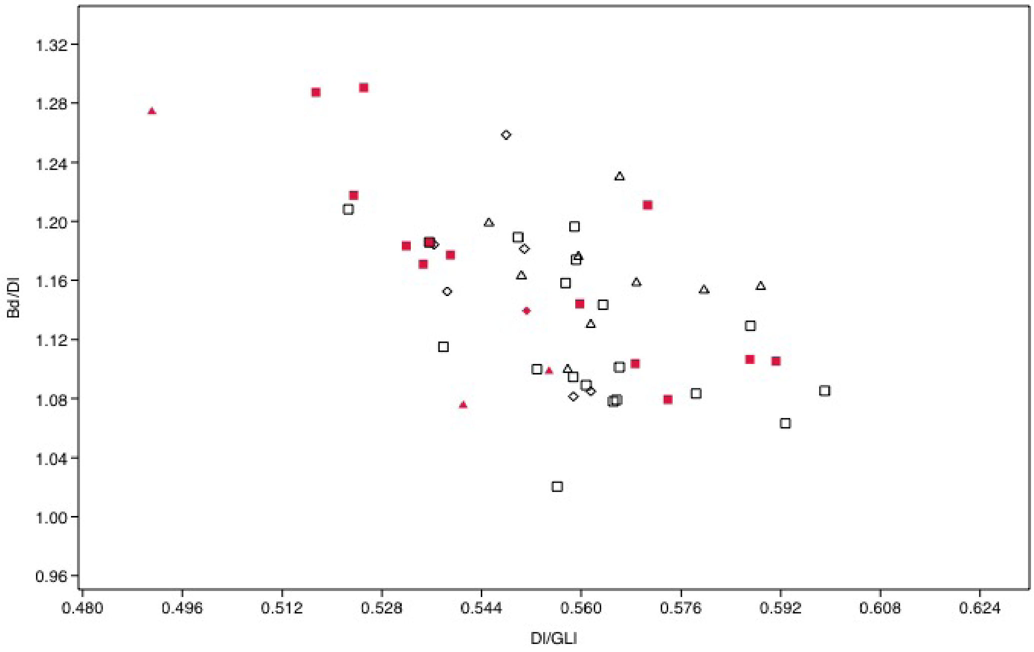


Figure 5.2: Specimens from all sites plotted using Davis (in press) ratio method for sheep and goat sepearation. Goats are filled symbols, and sites vary by symbol. Kent is a diamond, Serektas a triangle, and Turgen a square.

Other ratio indices, such as plots with a uniform denominator (Figure 5.3), also reveal a lack of clusters of any kind. Speicmens are labelled by both site and species and show that there are no distinct site or species clusters revealed using this technique.

This is lack of speciation of Central Asian caprids which applies to European specimens is supported by the inconsistent presence of qualitative features on Central Asian caprid specimens. For these techniques to be effective modern reference material is needed to form the basis of an exploratory investigation into the separation of sheep and goat specimens using caliper measurements. Yet while the ratio index method may suggest that shape does not reveal species differences in this Central Asia context, geometric morphometric methods have precision to measure smaller amount of shape difference that do point towards species differentiation.

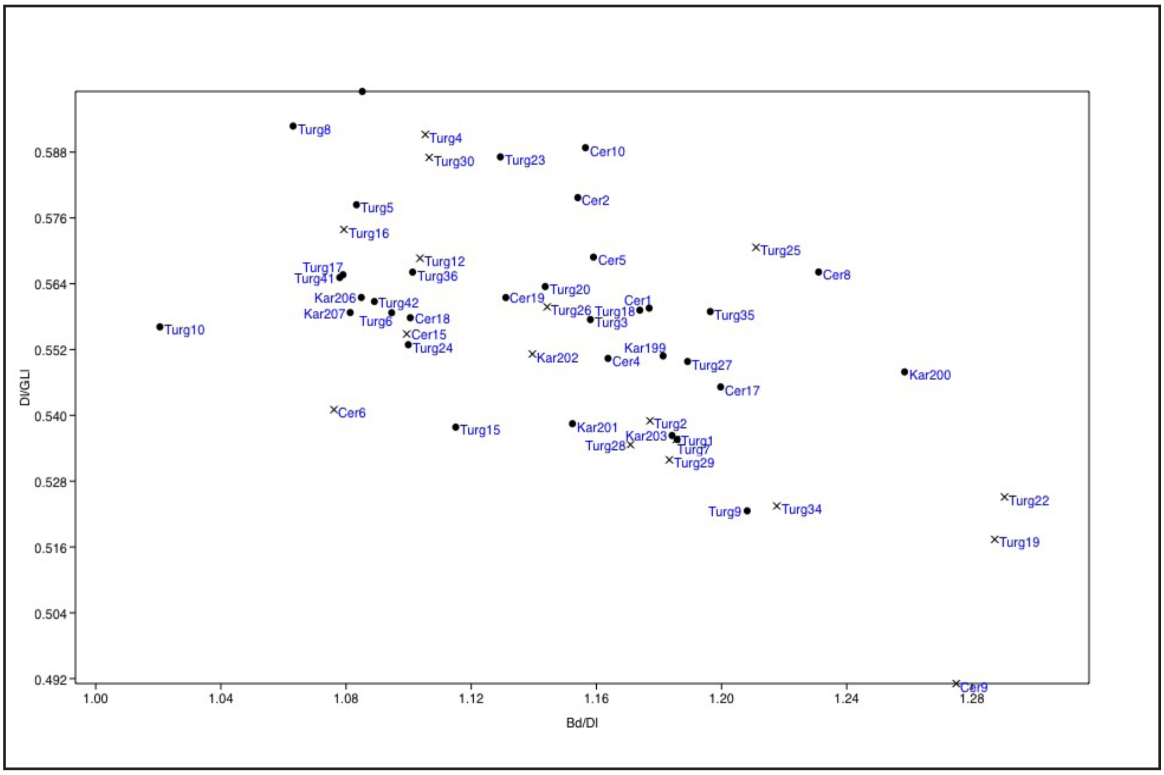


Figure 5.3: Specimens from all sites plotted using a uniform denominator. Goats are crosses, while sheep are filled circles.

Table 5.4: Specimens analysed from Kent.

Specimen	Site	Species	Side	Quadrant	Feature	Depth (cm from surface)
Kent199	Kent 2007	*O. aries*	Left			
Kent200	Kent 2007	*O. aries*	Left			
Kent201	Kent 2007	*O. aries*	Left			
Kent202	Kent 2007	*O. aries*	Right			
Kent203	Kent2007	*O. aries*	Left			
Kent204	Kent2007	*C. hircus*	Left			
Kent206	Kent 2007	*O. aries*	Left			
Kent207	Kent 2007	*O. aries*	Right			

5.2.1 Principal Component Analysis for *Ovis aries* and *Capra hircus* from Kent

The geometric morphometric methods discussed above were applied to each site separately and the combined for a thorough analysis of shape changes which control for the difference betweens sheep and goats.

Eight specimens were analysed from Kent (Table 5.4). There are seven Eigenvalues, the first four of which account for 77% of shape related variation (Table 8.4). The specimens are plotted along the first four principal components (Figure 5.4- 5.8). The one *Capra hircus* specimen, Kent204, trends out clearly along principal component 2 (Figure 5.4, 5.6, 5.8).

Principal component 1 is plotted against principal component 2 in Figure 5.2. Kent 206 and Kent 200 mark the end of the range of variability along principal component 1. Kent 203 and Kent 204 mark the end of the range of variability along principal component 2. The *Capra hircus* specimen, Kent 204 clearly lies away from the main cluster of *Ovis aries* specimens along the principal component 2 axis.

Principal component 1 is plotted against principal component 3 in Figure 5.4. Kent 206 and Kent 200 mark the end of the range of variability along principal component 1. Kent 201 and Kent 207 mark the end of the range of variability along principal component 3. The *Capra hircus* specimen, Kent204, does not trend out and is located near the middle of the spread of specimens along both principal component axes.

Principal component 2 is plotted against principal component 3 in Figure 5.5. There is a cluster of *Ovis aries* specimens along principal component 2. Kent204 and Kent 203 mark the end of the range of variability along principal component 2. As in Figure 5.4, Kent204 is plotted apart from the cluster of *Ovis aries* specimens. Likewise, the end of the range of variability for principal component 3 is still marked by Kent 201 and Kent 207.

Principal component 1 is plotted against principal component 4 in Figure 5.7. Kent200 and Kent206 mark the end of the range of variability along principal component 1 while Kent 199 and Kent 207 mark the end of the range of variability along principal component 4. In this plot, the *Capra hircus* specimen, Kent 204, does not trend out along the principal component axes.

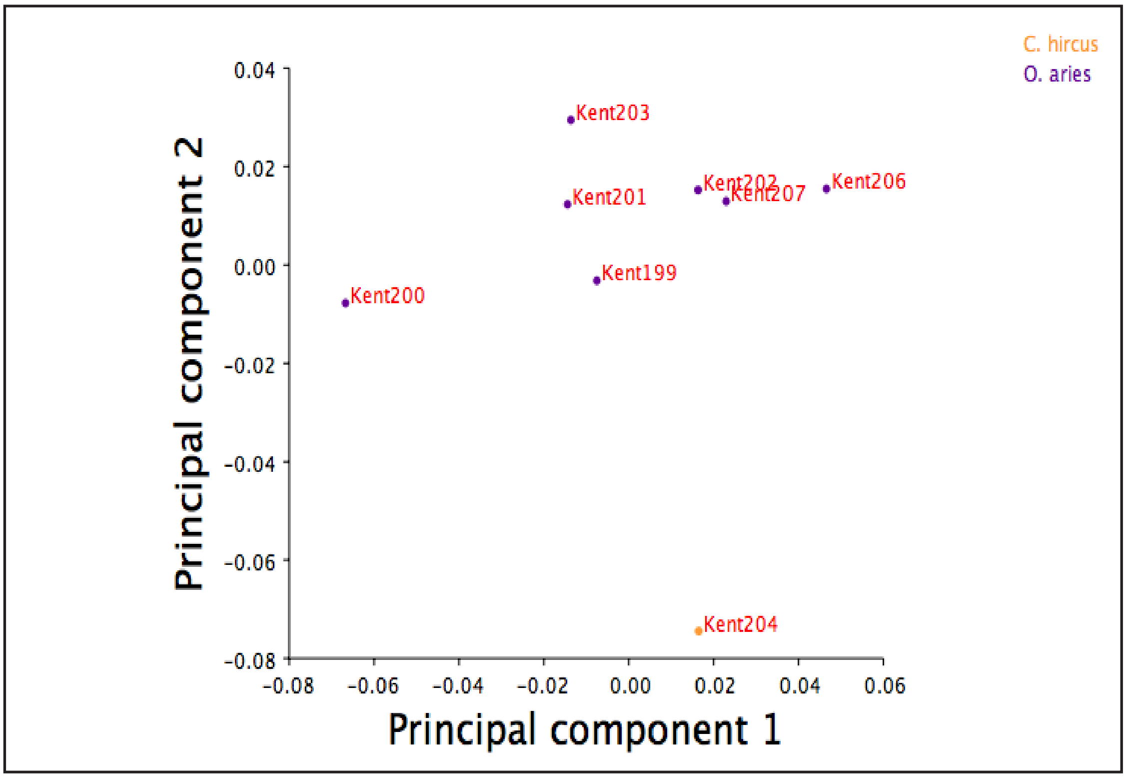


Figure 5.4: Principal Component Scores PC1 and PC2 plotted for all specimens from Kent.

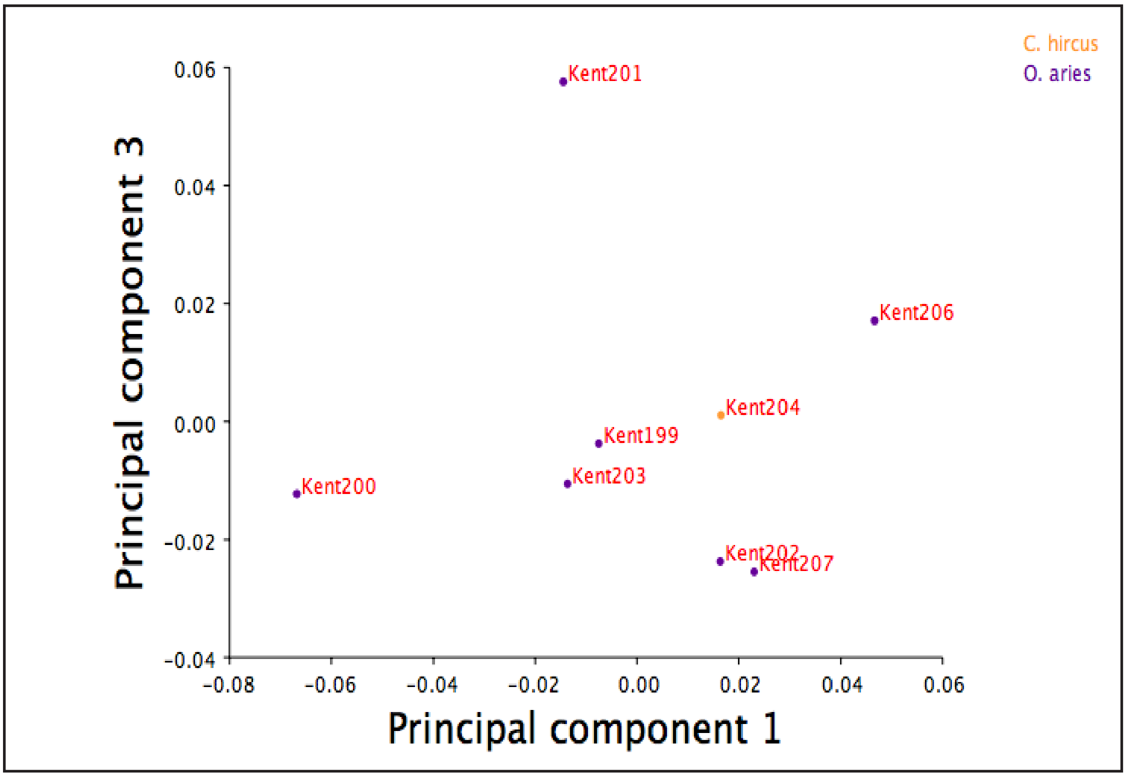


Figure 5.5: Principal Component Scores PC1 and PC3 plotted for all specimens from Kent.

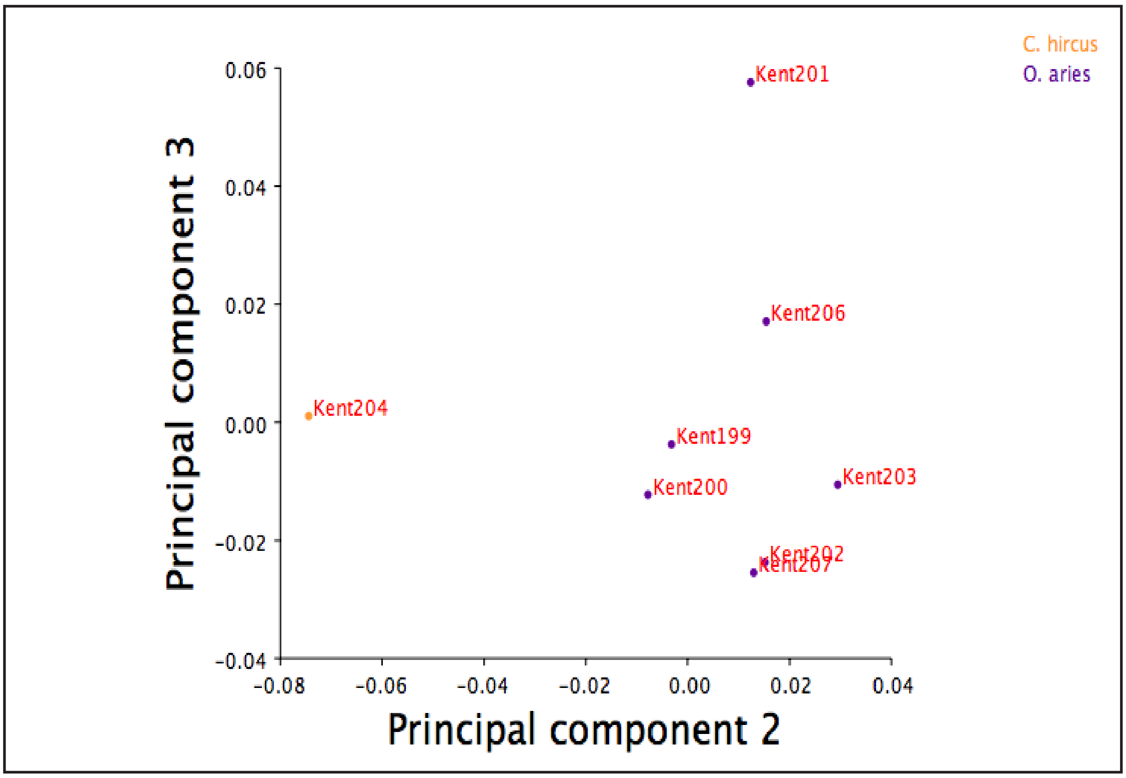


Figure 5.6: Principal Component Scores PC2 and PC3 plotted for all specimens from Kent.

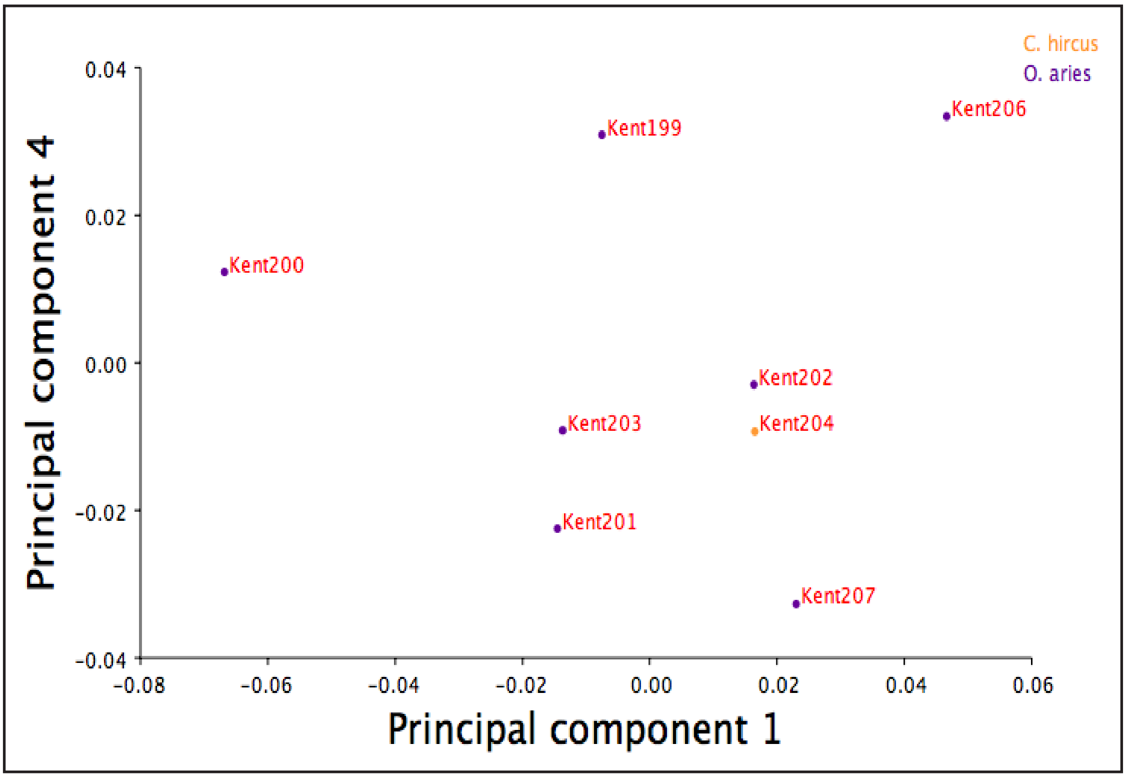


Figure 5.7: Principal Component Scores PC1 and PC4 plotted for all specimens from Kent.

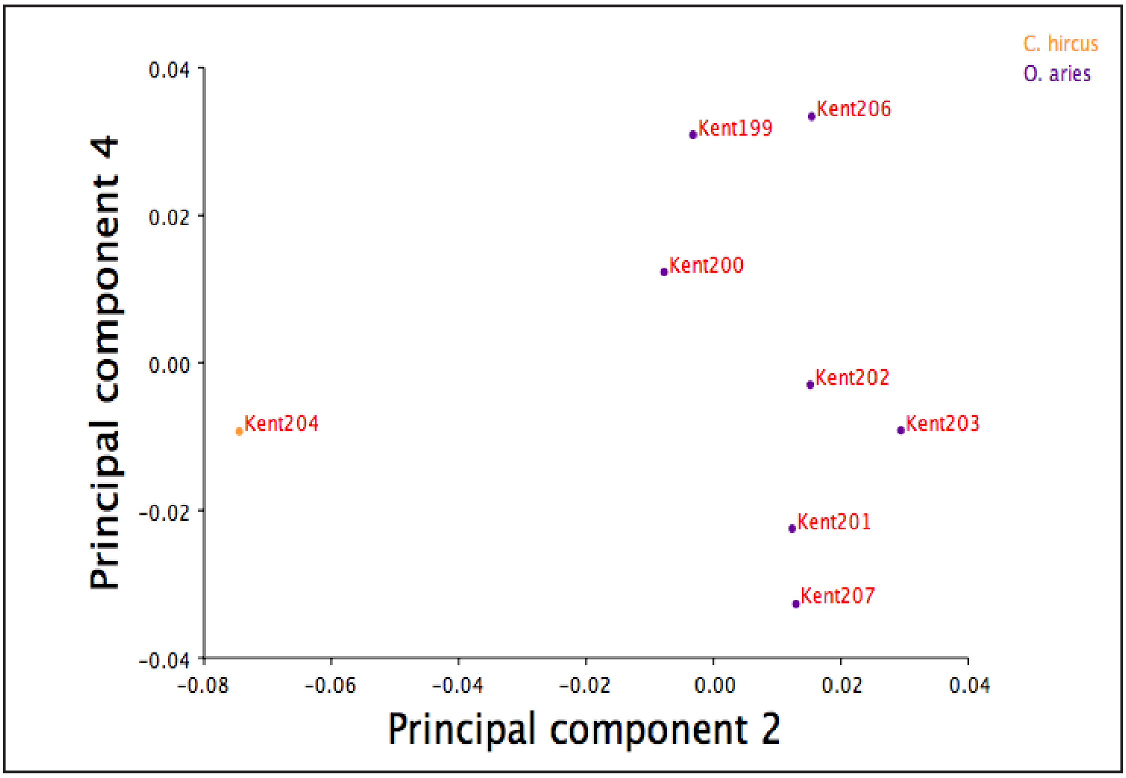


Figure 5.8: Principal Component Scores PC2 and PC4 plotted for all specimens from Kent.

Principal component 2 is plotted against principal component 4 in Figure 5.8. Kent204 and Kent203 mark the end of the range of variability for principal component 2. Kent206 and Kent 203 mark the end of the range of variability for principal component 4. Once again, the *Capra hircus* specimens plots seperately from the *Ovis aries* specimens along principal component 2.

This suggests that shape variation described by this principal component differentiates *Ovis aries* and *Capra hircus* specimens. The variation described by principal component 2 was mapped onto an example specimen in Figure 5.9. Principal component 2 describes a change in shape which includes a reorientation of the distal laterial articular pad towards the dorsal plane, an increase in the difference in heights of the proximal articular condyles, and an increase in the prominence of the tuberculum tali medially (Figure 5.9).

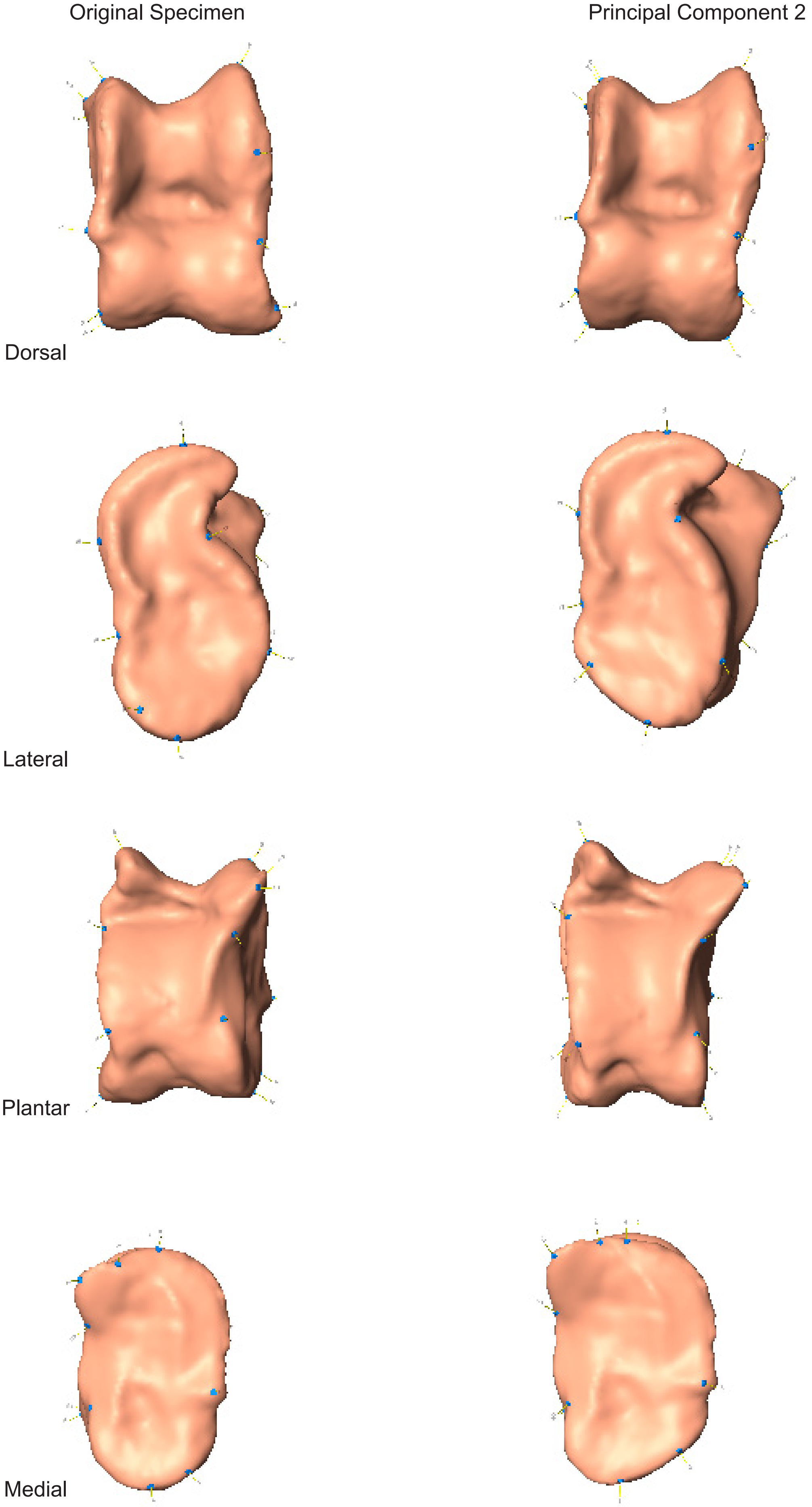


Figure 5.9: Principal component 2 plotted onto three dimensionanl left astragalus model Kent199 with a scanle factor of 0.1. Origin model Kent 199 on left, principal component 2 on the right.

5.2.2 Principal Component Analysis for *Ovis aries* and *Capra hircus* specimens from Serektas

Twelve specimens were analysed from Serektas (Table 5.5). There are eleven eigenvalues, of which the first four Principal components account for 74% of shape variation (Table 8.6). The specimens are plotted along the first four principal components and there are three *Capra hircus* specimens, Cer6a, Cer9a, and Cer15a (Figures 5.10- 5.14).

Principal component 1 is plotted against principal component 2 in Figure 5.11. Cer1a and Cer10a mark the end of the range of variability along principal component 1, while Cer17a and Cer6a mark the end of the range of variability along principal component 2. It is clear that two *Capra hircus* specimens, Cer6a and Cer9, trend out along both principal component 1 and principal component 2 while the other *Capra hircus* specimen, Cer15a, does not trend out.

Principal component 1 describes a reorientation of the tuberculum talus and a flattening of the plantar articular surface on the distal end that is associated with a change in the orientation of the lateral distal articulation towards the dorsal side (Figure 5.15). Principal component 2 describes a change of shape of the tuberculum talus from a point to a flattened surface as well as a narrowing of the plantar articular surface that is associated with a narrowing of the entire bone while the proximal condyles have a height difference. The *Capra hircus* specimens Cer6a and Cer9a trend out along principal component 2 in such a way that suggests that the change of shape in the tuberculum talus and other shape changes may control for species within Serektas. The the height difference of the proximal condyles is noted as a significant marker for *Capra hircus* by Fernandez (2001) while the change in orientation of the tuberculum

Table 5.5 Specimens analysed from Serektas. Note that Quadrants are labelled with the Cyrillic alphabet.

Specimen	Site	Species	Side	Quadrant	Feature	Depth (cm from surface)
Cer1a	Serektas	O.aries	Left	2A		40-60, 60-80
Cer2a	Serektas	O. aries	Left	3б-3В	хозяист яма	
Cer4a	Serektas	O. aries	Left	2Б		50-70, 40-60
Cer5a	Serektas	O. aries	Left			
Cer6a	Serektas	C. hircus	Right	4B		150
Cer8a	Serektas	O. aries	Left	2Б		60-80
Cer9a	Serektas	C. hircus	Left	2B		130-150
Cer10a	Serektas	O. aries	Left	3A*		40
Cer15a	Serektas	C. hircus	Right	1Г		100-120
Cer17a	Serektas	O. aries	Right			
Cer18a	Serektas	O. aries	Left			
Cer19a	Serektas	O. aries	Left	3A		130-150

talus is noted as a significant feature for speciation by Boessneck (1969) and Frisch (1988).

Principal component 1 is plotted against principal component 3 in Figure 5.11. Cer1a and Cer10a still define the end of the range of variability along principal component 1, while Cer5a and Cer17a describe the end of the range of variability along principal component 3. There is no clear delineation of *Ovis aries* and *Capra hircus* specimens in this plot. While Cer6a and Cer9a still trend out along principal component 1, the separation is not as clear with the variability between specimens along principal component 3.

Principal component 2 is plotted against principal component 3 in Figure 5.12. Cer6a and Cer1a mark the end of the range of variability along principal component 2, while Cer17a and Cer5a mark the end of the range of variability along principal component 3. The *Capra hircus* specimens plot in the upper right hand corner but do not lie in a distinct cluster.

Principal component 1 is plotted against principal component 4 in Figure 5.13. Cer1a and Cer10a mark the ends of the range of variability along principal component 1 while Cer9a and Cer15a mark the end of the range of variability along principal component 4. The *Capra hircus* specimens Cer6a, Cer9a, and Cer15a are located on the right hand side of the plot, largely sepated by principal component 1. The variation of principal component 4 has revealed a cluster of *Ovis aries* specimens, but the separation of the *Capra hircus* specimens is spread across both principal components and spread widely across principal component 4. Principal component 4 controls for a change in the orientation of the tubuerculum talus towards the plantar plane, a broadening of the plantar articular surface, a slight difference in the heights of the proximal condyles and an change in the orientation of the lateral distal articular pad towards the dorsal surface (Figure 5.15).

Principal component 2 is plotted against principal component 4 in Figure 5.14. Cer6a and Cer1a mark the end of the range of variability along principal component 2 while Cer9a and Cer15a mark the end of variability along principal component 4. The *Capra hircus* specimens are all located at the end of variability for both principal components at the right side and bottom while the *Ovis aries* specimens clearly cluster together near the center.

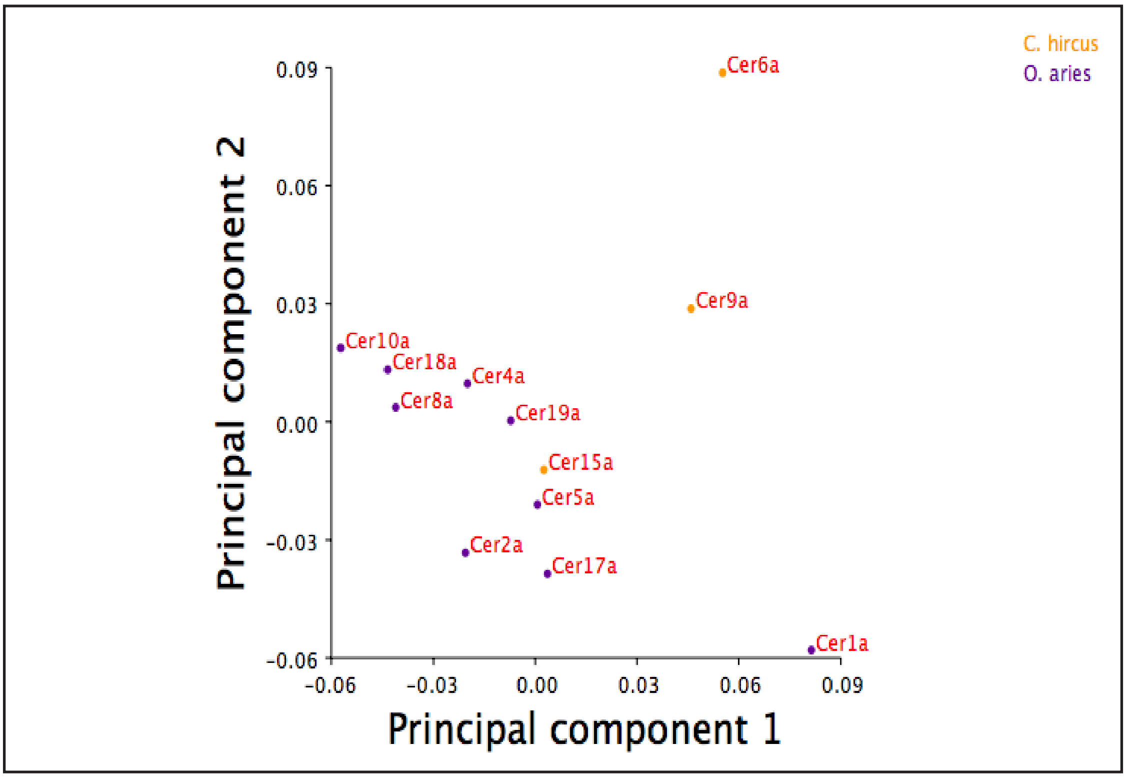


Figure 5.10: Principal Component Scores PC1 and PC2 plotted for all specimens from Serektas.

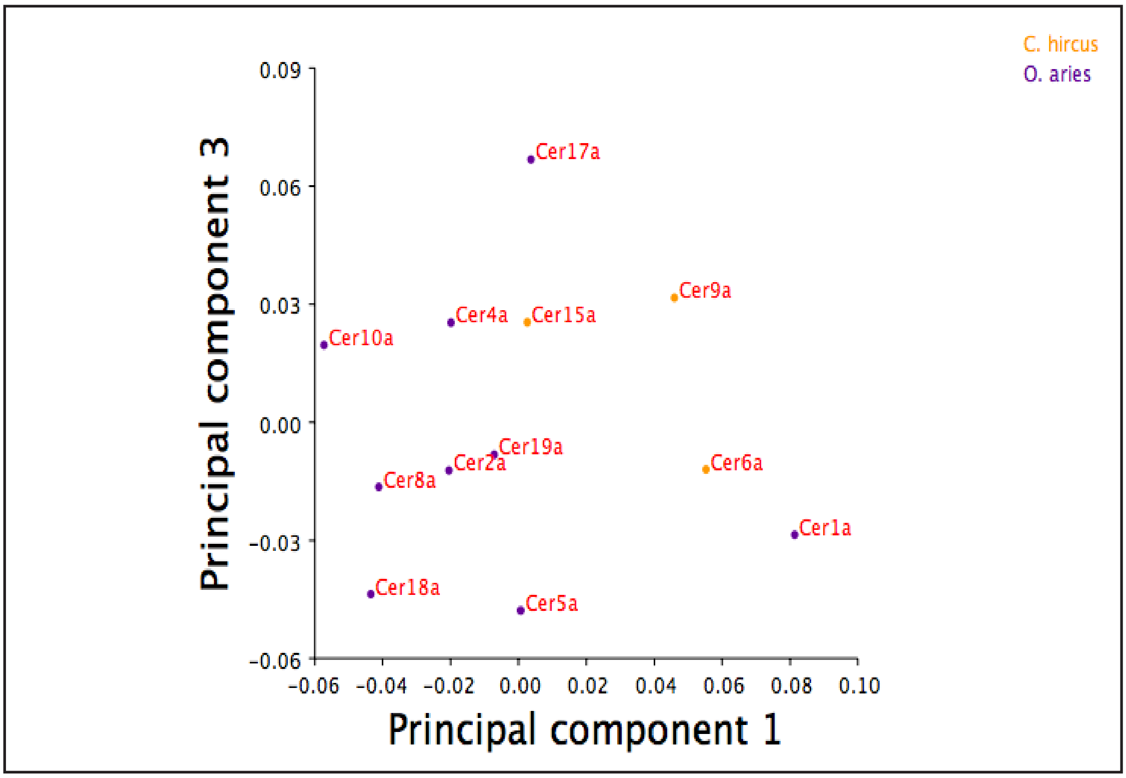


Figure 5.11: Principal Component Scores PC1 and PC3 plotted for all specimens from Serektas.

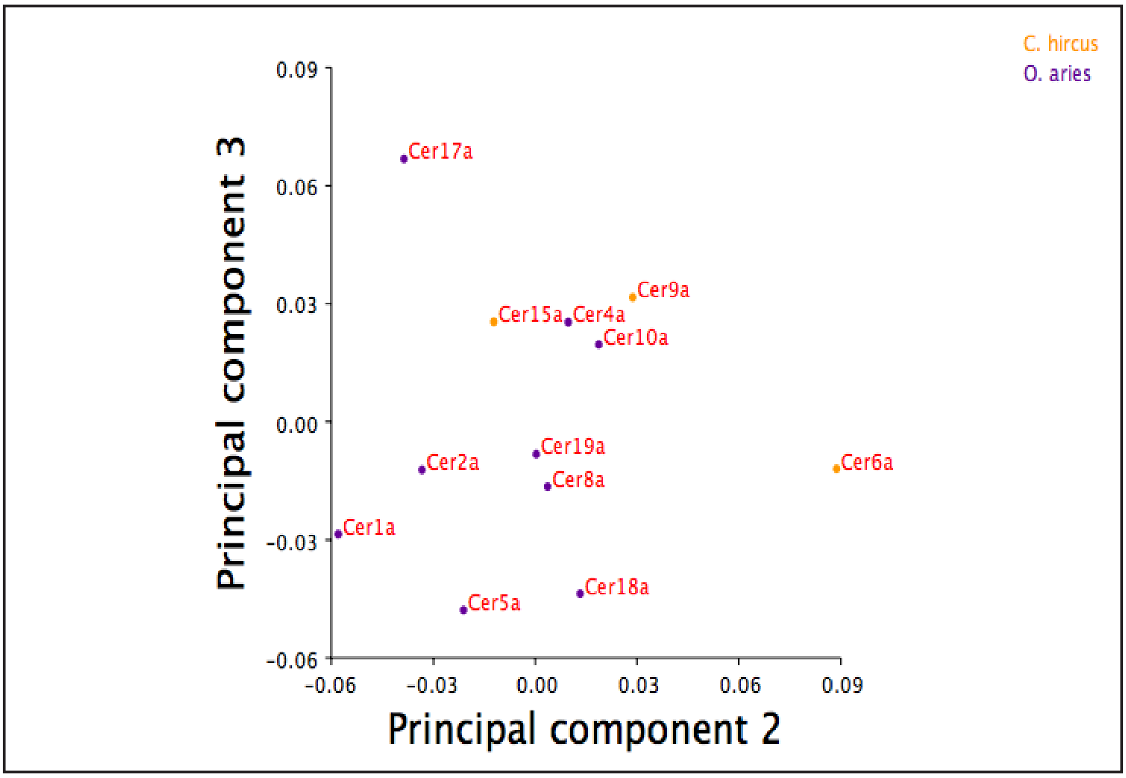


Figure 5.12: Principal Component Scores PC2 and PC3 plotted for all specimens from Serektas.

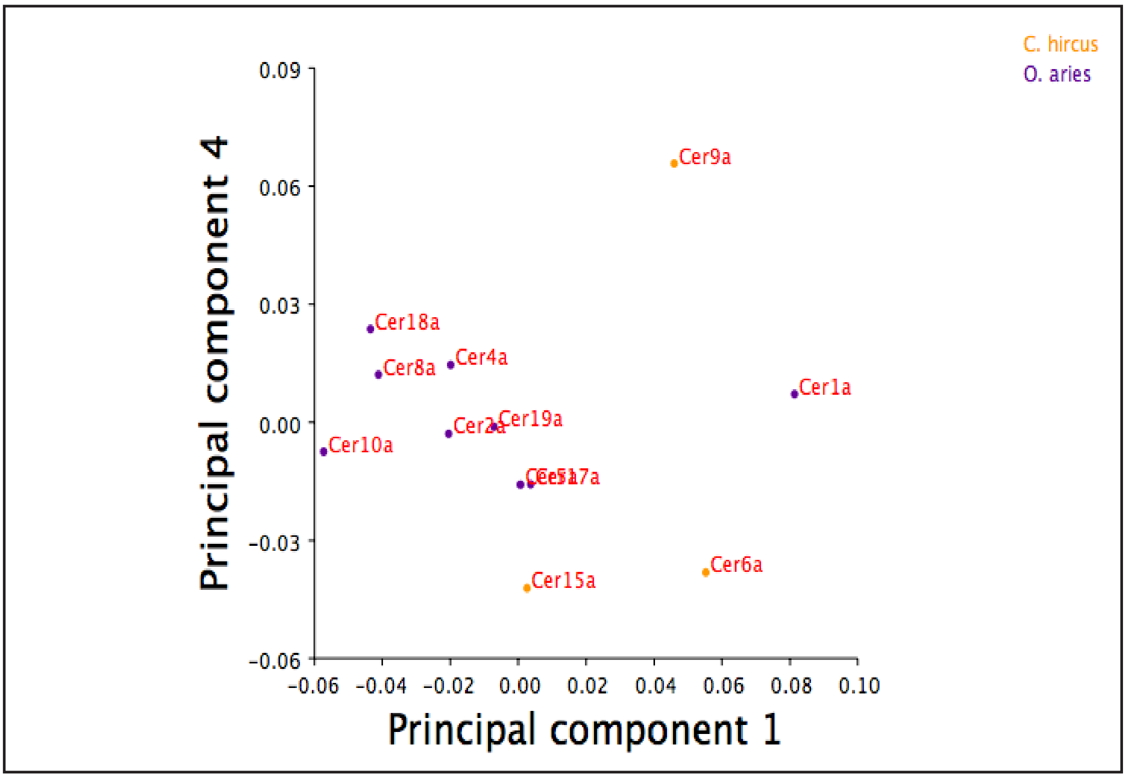


Figure 5.13: Principal Component Scores PC1 and PC4 plotted for all specimens from Serektas.

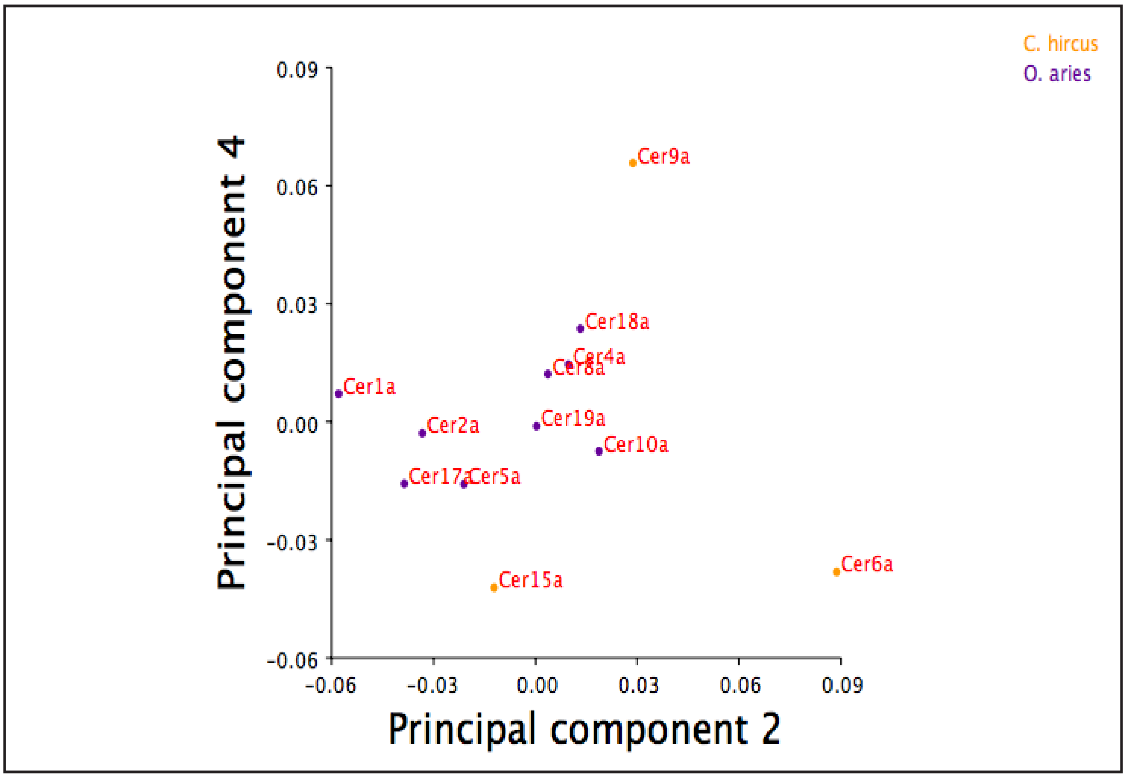


Figure 5.14: Principal Component Scores PC2 and PC4 plotted for all specimens from Serektas.

There is a delineation of *Ovis aries* and *Capra hircus* on plots that include principal component 2 and 4 (Figure 5.14). Cer15 does not group as tightly with other *Capra hircus* specimens along principal component 2 (Figure 5.10, 5.12, 5.14) but does plot near Cer6a along principal component 4. Both of these principal components describe shape changes of the tuberculum talus, the orientation of the lateral distal articular pad and a difference in the heights of the proximal condyles. All of these characteristics have been described as important for speciation by qualitative assessment (Boessneck 1969, Fernandez 2001, Frish 1988, Zeder and Lapham 2010).

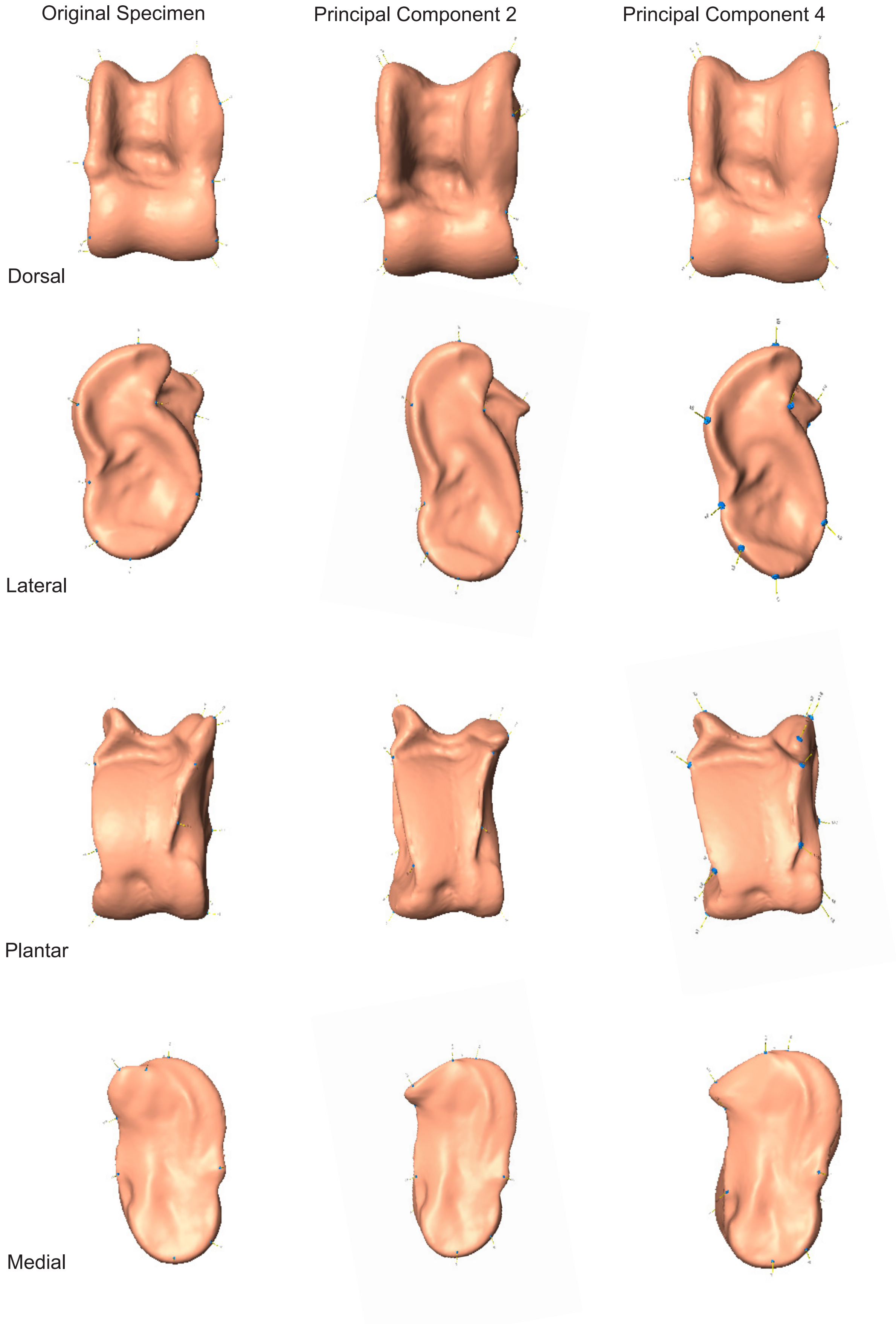


Figure 5.15: Principal component 2 and 4 plotted onto three dimensionanl left astragalus model Cer19a with a scanle factor of 0.1. Origin model Cer19a on left, principal component 2 in the middle, principal component 4 on the right.

5.2.3 Principal Component Analysis for *Ovis aries* and *Capra hircus* specimens from Turgen

Thirty-two specimens were anlaysed from Turgen (Table 5.6). Principal component analysis was run for all specimens included in the analysis. There are thirty-one eigenvalues, of which the first four principal components account for 52% of shape variation (Table 8.9)

For clarity, both labeled and unlabeled plots are included for Turgen. Principal component 1 is plotted against principal component 2 in Figure 5.16. Tur19a and Turg6a mark the end of the range of variability along principal component 1 while Turg20a and Turg1a mark the end of the range of variability along principal component 2. In the unlabeled version of this plot, it is clear that the *Ovis aries* specimens cluster towards the lower left hand corner, largely along principal component 1.

Principal component 1 describes a small change in the orientation of the tuberculum talus towards the plantar surface and a change in the difference in heights of the proximal condyles (Figure 5.21). This is similar to the shape changes associated with speciation in Serektas and Kent. The shape changes associated with principal component 1are subtle, but it is clear that principal component 1 controls for the separation of *Ovis aries* and *Capra hircus*.

Principal component 1 is plotted against principal component 3 in Figure 5.17. Tur19a and Turg6a mark the end of the range of variability along principal component 1 while Turg2a and Turg26a mark the end of the range of variability along principal component 3. The *Ovis aries* specimens are still clustered in the lower left hand corner along principal component 1.

Principal component 1 is plotted against principal component 4 in Figure 5.18. Tur19a and Turg6a mark the end of the range of variability along principal component 1 while Turg10a and Turg26a mark the end of the range of variability along principal component 3. The *Ovis aries* specimens continue to cluster along the left hand side of the plot along principal component 1.

Principal component 2 is plotted against principal component 3 in Figure 5.19. Tur20a and Turg1a mark the end of the range of variability along principal component 2 while Turg2a and Turg26a mark the end of the range of variability along principal component 3. The *Ovis aries* specimens do not cluster out clearly from the *Capra hircus* specimens.

Principal component 2 is plotted against principal component 4 in Figure 5.20. Tur20a and Turg1a mark the end of the range of variability along principal component 2 while Turg10a and Turg26a mark the end of the range of variability along principal component 4. Both species cluster evenly along these principal components.

Capra hircus specimens separate from the *Ovis aries* specimens along principal component 1. This PC accounts for 19.55% of shape variance within the Turgen sample. The change in shape and orientation of the tuberculum talus as well as the difference in height of the proximal condyles are both noted as qualitative characteristics for differentiating between sheep and goats (Boessnech 1969, Fernandez 2001). The principal compnents which control for speciation from all sites control for shape changes associated with the height of the proximal condyles, the orientation of the lateral distal articular pad, and the orientation of the tubuerculm talus. These features have been noted as useful in

Table 5.6: Specimens analysed from Turgen. Note that Quadrants are labelled with the Cyrillic alphabet.

Speci-men	Site	Species	Side	Quadrant	Feature	Depth (cm from surface)
Turg1	Tugen	C. hircus	Left	B2		
Turg2	Turgen	C. hircus	Left	Г1		
Turg3	Turgen	O. aries	Left	Г1		
Turg4	Turgen	C. hircus	Right	Г1-Г2		
Turg5	Turgen	O. aries	Left	Г1-Г2		
Turg6	Turgen	O. aries	Right	Б-3		40-60
Turg7	Turgen	O. aries	Left	A'4-A'5		
Turg8	Turgen	O. aries	Left	A'4-A'5		
Turg9	Turgen	O. aries	Left	A'4-A'5		
Turg10	Turgen	O. aries	Right	Г2		
Turg11	Turgen	O. aries	Left	Г2		
Turg12	Turgen	C. hircus	Left			
Turg15	Turgen	O. aries	Left	Б6		40-60
Turg16	Turgen	C. hircus	Left	Г5	Яма	
Turg17	Turgen	O. aries	Right	B6-Г6		20-30
Turg18	Turgen	O. aries	Left	A1-A2	Др3	
Turg19	Turgen	C. hircus	Left	Б'5		
Turg20	Turgen	O . aries	Right	A'8		
Turg22	Turgen	C. hircus	Left	A'8		
Turg23	Turgen	O. aries	Right	A'8		
Turg24	Turgen	O. aries	Left	Г'7		
Turg25	Turgen	C. hircus	Left	Курган 8		
Turg26	Turgen	C. hirus	Right	Курган 8		
Turg27	Turgen	O. aries	Right	B8	Дери	
Turg28	Turgen	C. hircus	Left			
Turg29	Turgen	C. hircus	Left	B6		0-40
Turg30	Turgen	C. hircus	Left	Г'4-Г'5		
Turg34	Turgen	C. hircus	Right	Б7		
Turg35	Turgen	O. aries	Left	Г'6		
Turg36	Turgen	O. aries	Left	Г'6		
Turg41	Turgen	O. aries	Right	Г'6		
Turg42	Turgen	O. aries	Left	Г'6		

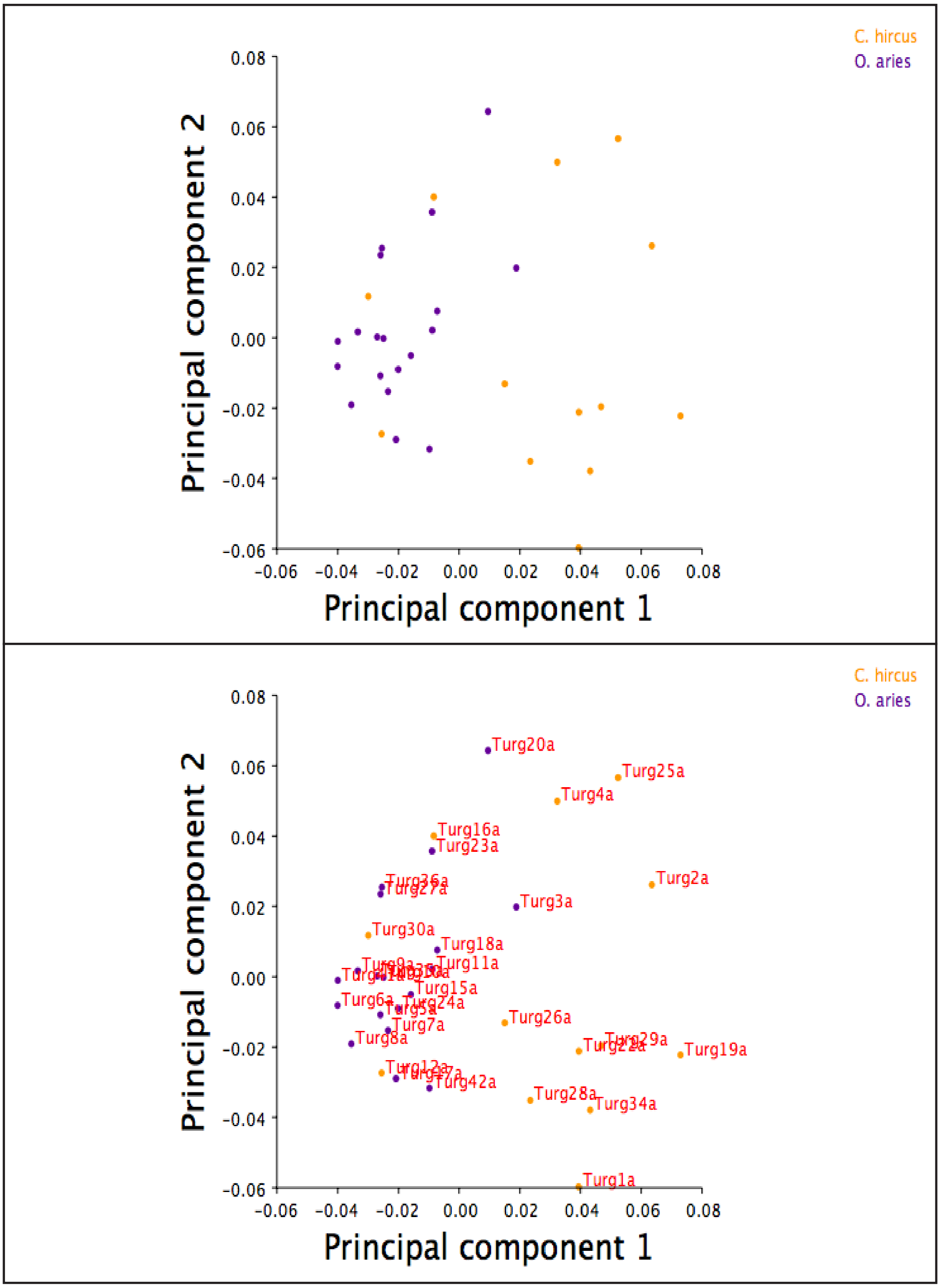


Figure 5.16: Principal Component Scores PC1 and PC2 plotted for all specimens from Turgen with and without labels.

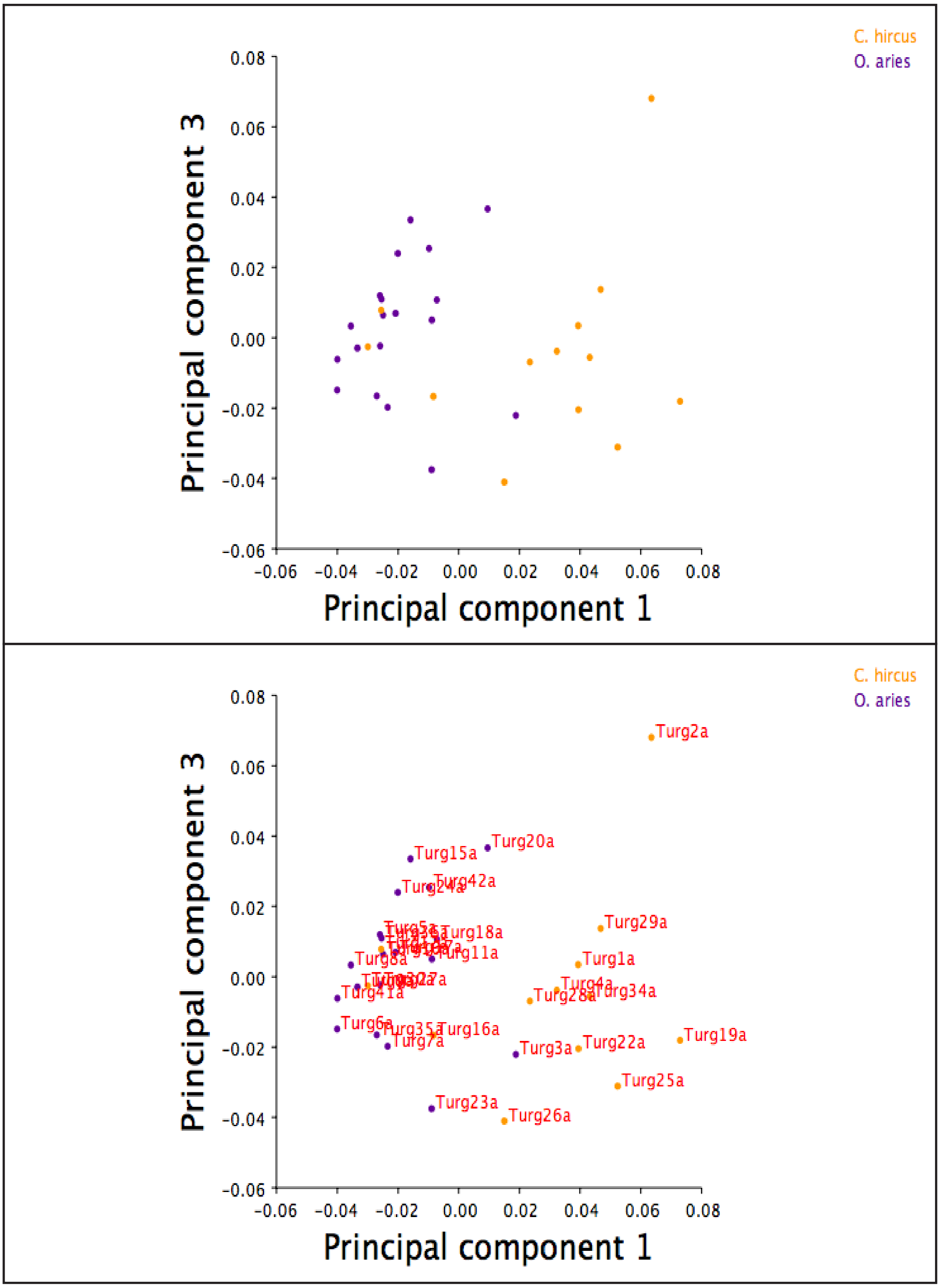


Figure 5.17: Principal Component Scores PC1 and PC3 plotted for all specimens from Turgen with and without labels.

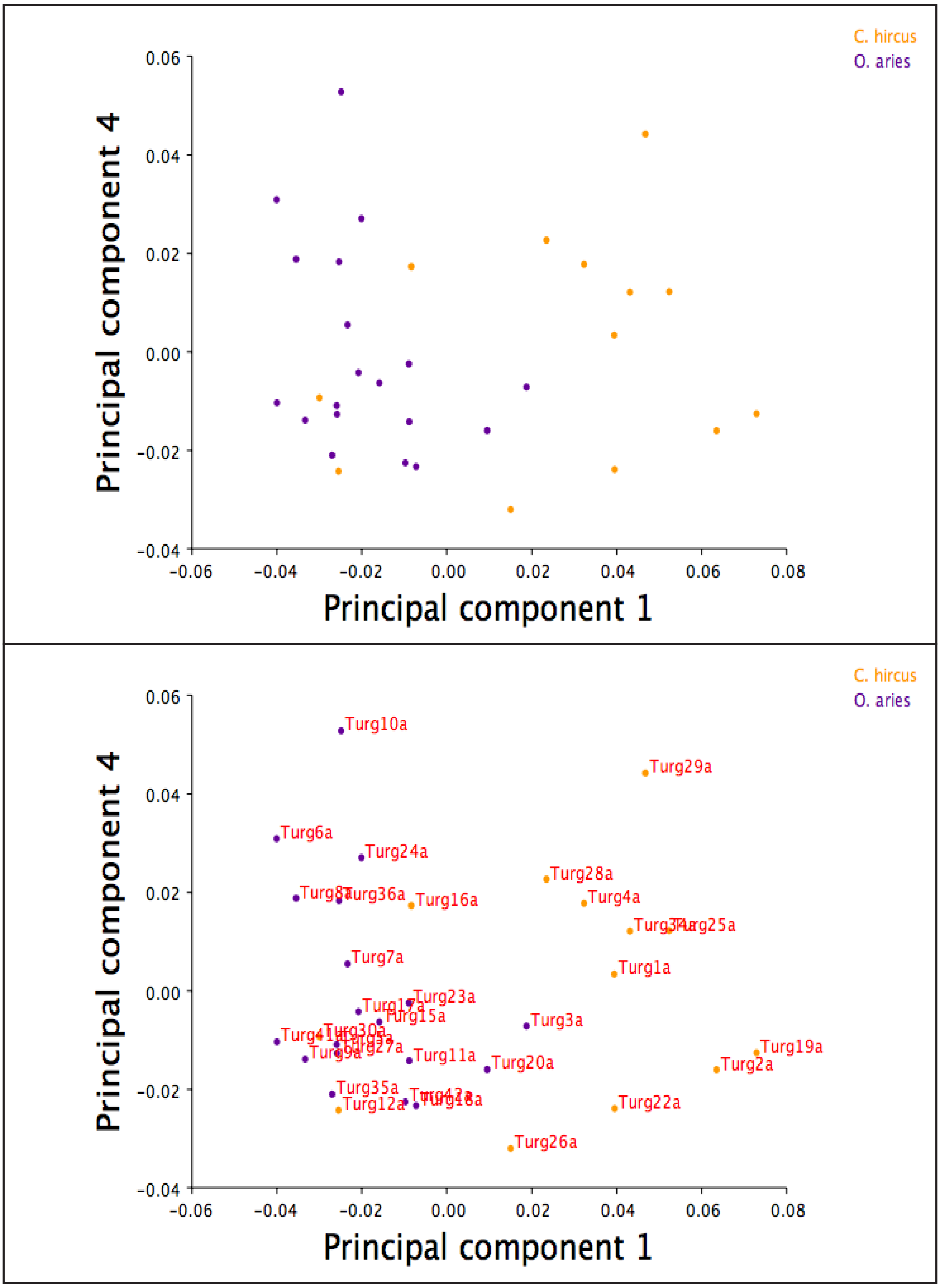


Figure 5.18: Principal Component Scores PC1 and PC4 plotted for all specimens from Turgen with and without labels.

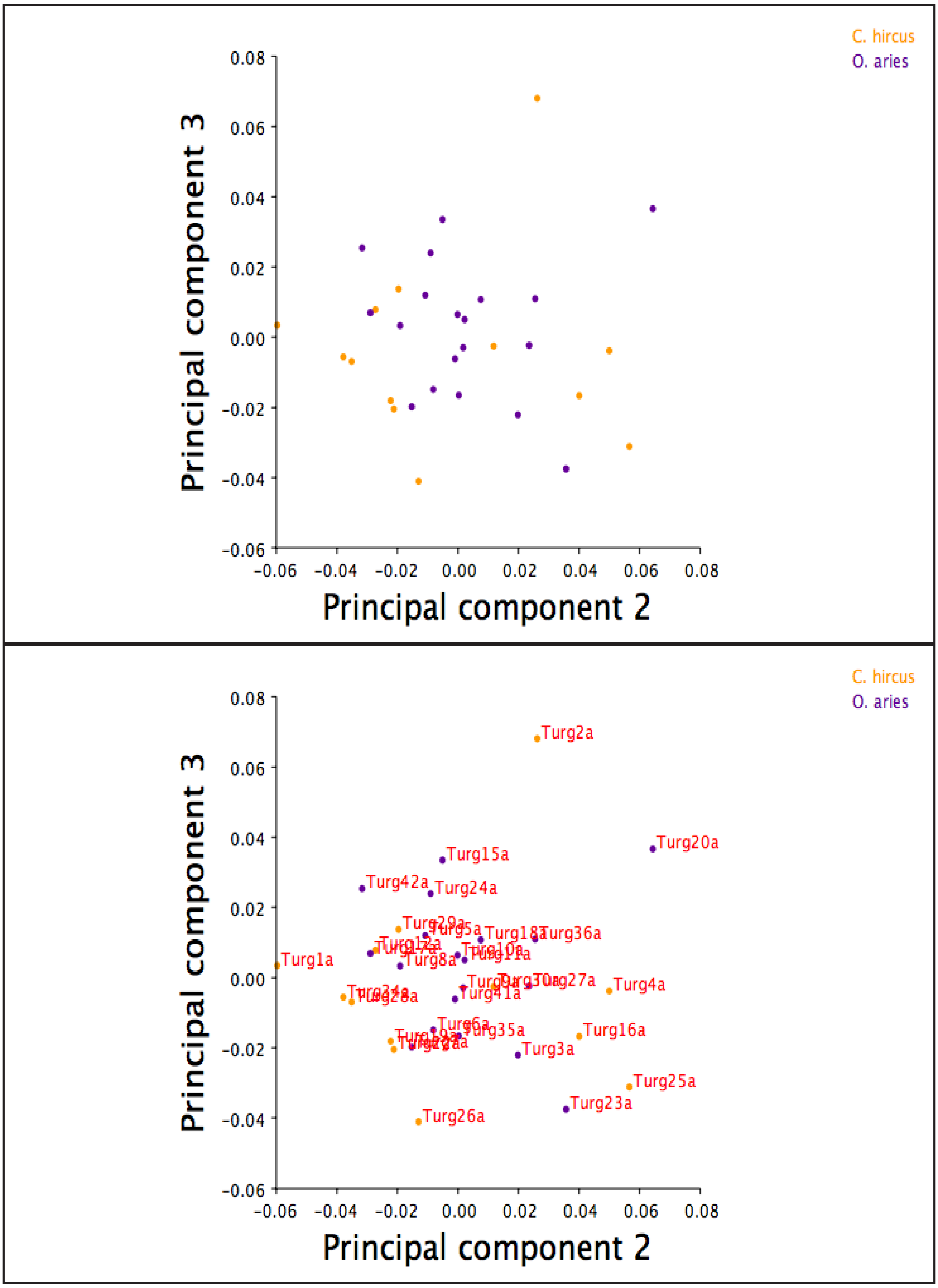


Figure 5.19: Principal Component Scores PC2 and PC3 plotted for all specimens from Turgen with and without labels.

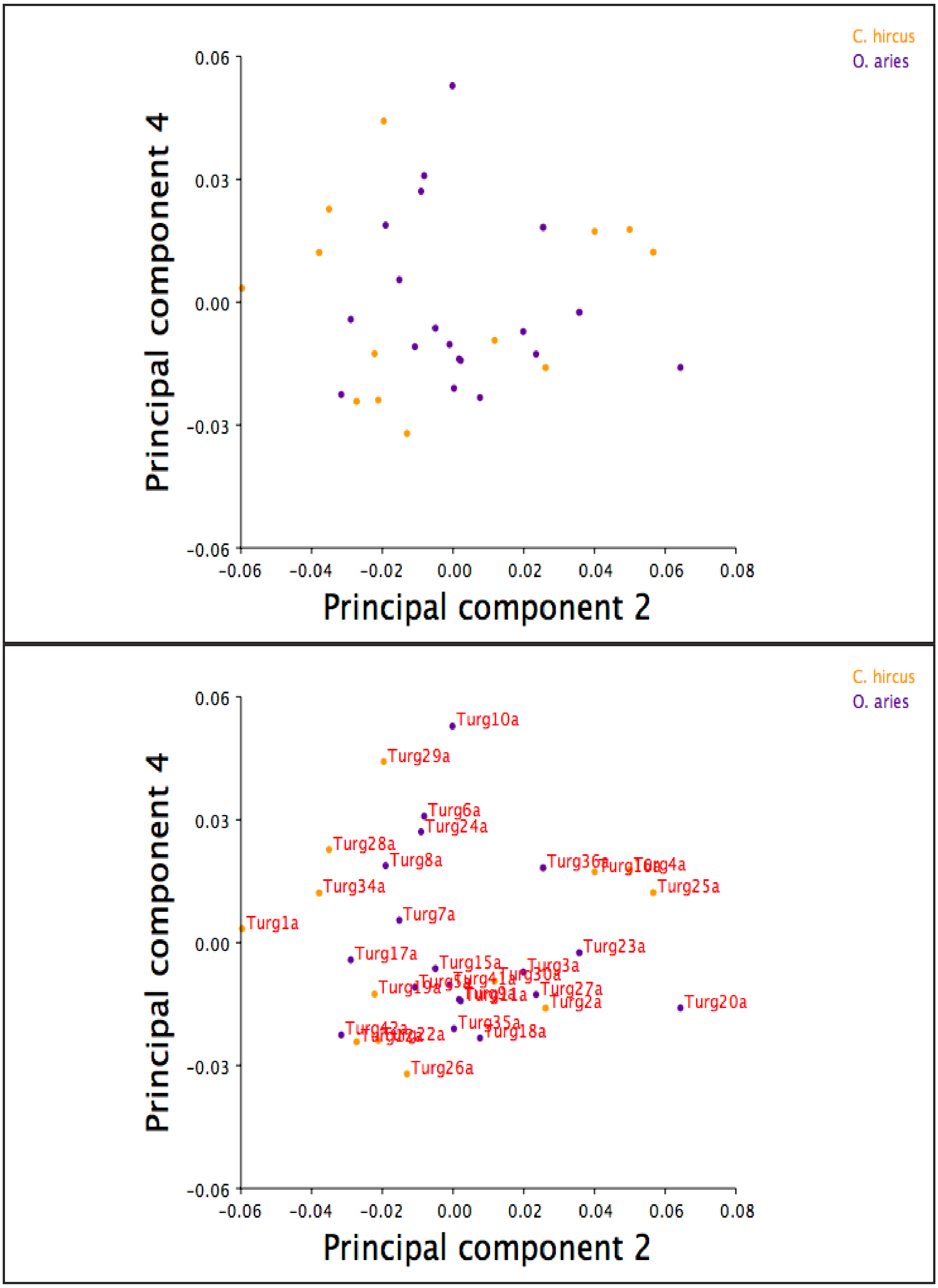


Figure 5.20: Principal Component Scores PC2 and PC4 plotted for all specimens from Turgen with and without labels.

differentiating between sheep and goats in the qualitative literature.

5.2.4 Principal Component Analysis for *Ovis aries* and *Capra hircus* at all sites

A principal component analysis on all specimens from all sites was conducted to investigate species delineation. The first four principal components are plotted here, account for 46% of shape variation (Table 8.10).

Principle component 1 is plotted against principal component 2 in Figure 5.22. The specimens are color coded. The top figure describes specimens by site, while the bottom version describes specimens by species. There is no clear separation of specimens by site, but there is a clear separation of *Ovis aries* and *Capra hircus*. The first two principal components both control for species delineation and account for 29% of variation (Table 8.10).

The first principal component describes a shape change of the plantar articular surface which is wider at the distal end and angles less towards the lateral side and is cuboid in overall appearance. The plantar ridge lies at a more acute angle to the medial surface. The tuberculum talus has a point which protrudes proximally. The lateral distal articular surface is oriented more dorsally than in the origin figure (Figure 5.27).

The second principal component describes a change in the orientation of the tuberculum talus toward the plantar plane and a corresponding thickening of the plantar ridge (Figure 5.27). The entire specimen is much more compressed in

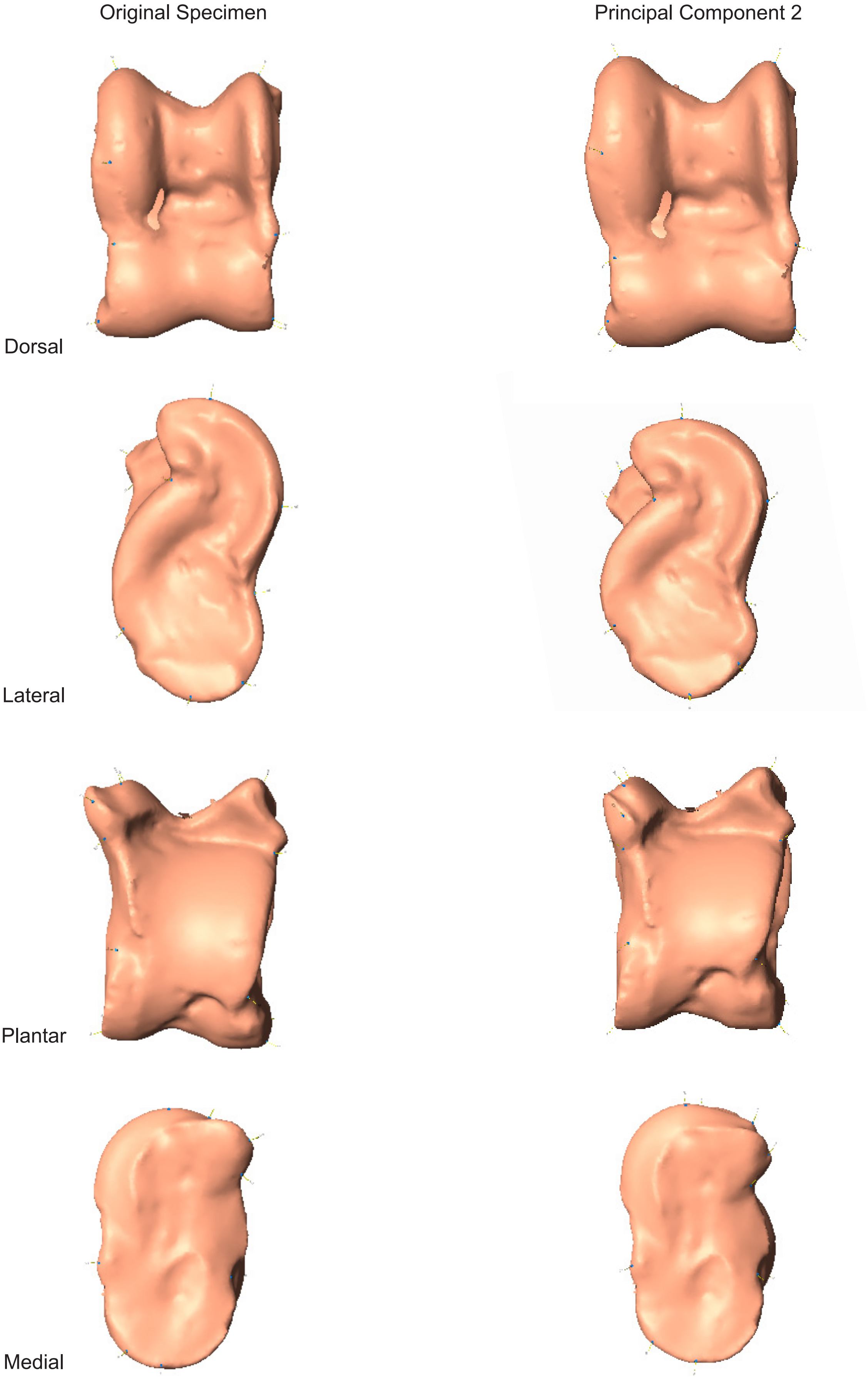


Figure 5.21: Principal component 1 plotted onto three dimensionanl right astragalus model Turg17a with a scanle factor of 0.1. Origin model Turg17a on left, principal component 1 on the right.

the proximal-distal axis. The distal half of the astragalus is compressed and flat, while the proximal articulations are larger and the end points of these condyles on the dorsal surface, marked by landmarks s8 and s10, end past the mid-point of the specimen (Figure 5.27). The proximal condyles project toward the proximal plane unevenly for both principal components.

Principal component 1 is plotted against principal component 3 in Figure 5.23 and principal component 1 is plotted against principal component 4 in Figure 5.24. As in the previous figure, the specimens are colour coded by site and then by species. There are no clusters of specimens for either site or species.

Principal component 2 is plotted against principal component 3 in Figure 5.25. The *Ovis aries* specimens tend towards the left hand side of the plot. Principal component 2 is plotted against principal component 4 in Figure 5.26. The *Ovis aries* specimens tend towards the left hand side of the plot much more clearly than in Figure 5.38.

Principal component 2 clearly controls for species separation much more than principal component 1, although both play a role in separating the two species. Site membership is obscured in this analysis, likely by the variance between the two species. The shape changes associated with the principal components from this regional analysis are similar to those from individual site anlaysis. The tuberculum talus is clearly a highly variable feature which is critical for speciation. The orientation and location of the landmark s5, which controls for the orientation of the lateral distal articular surface, is associated with all prinicpal components with control for speciation (Figure 5.27) The lateral distal articular surface is considered critical for caprid speciation (Fernandez 2001,

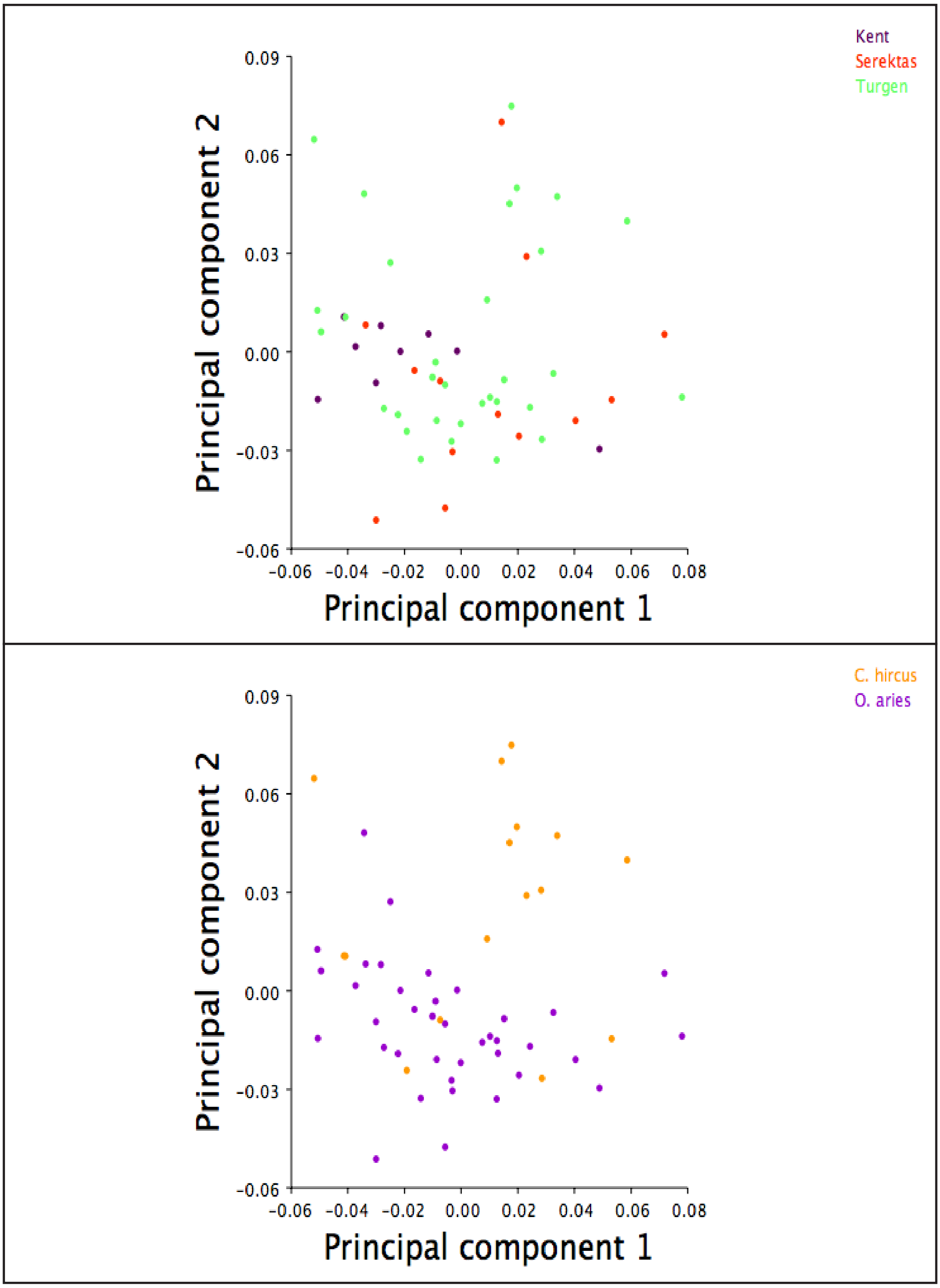


Figure 5.22: Principal Component Scores PC1 and PC2 plotted for all specimens from all sites with colour coding for sites and species.

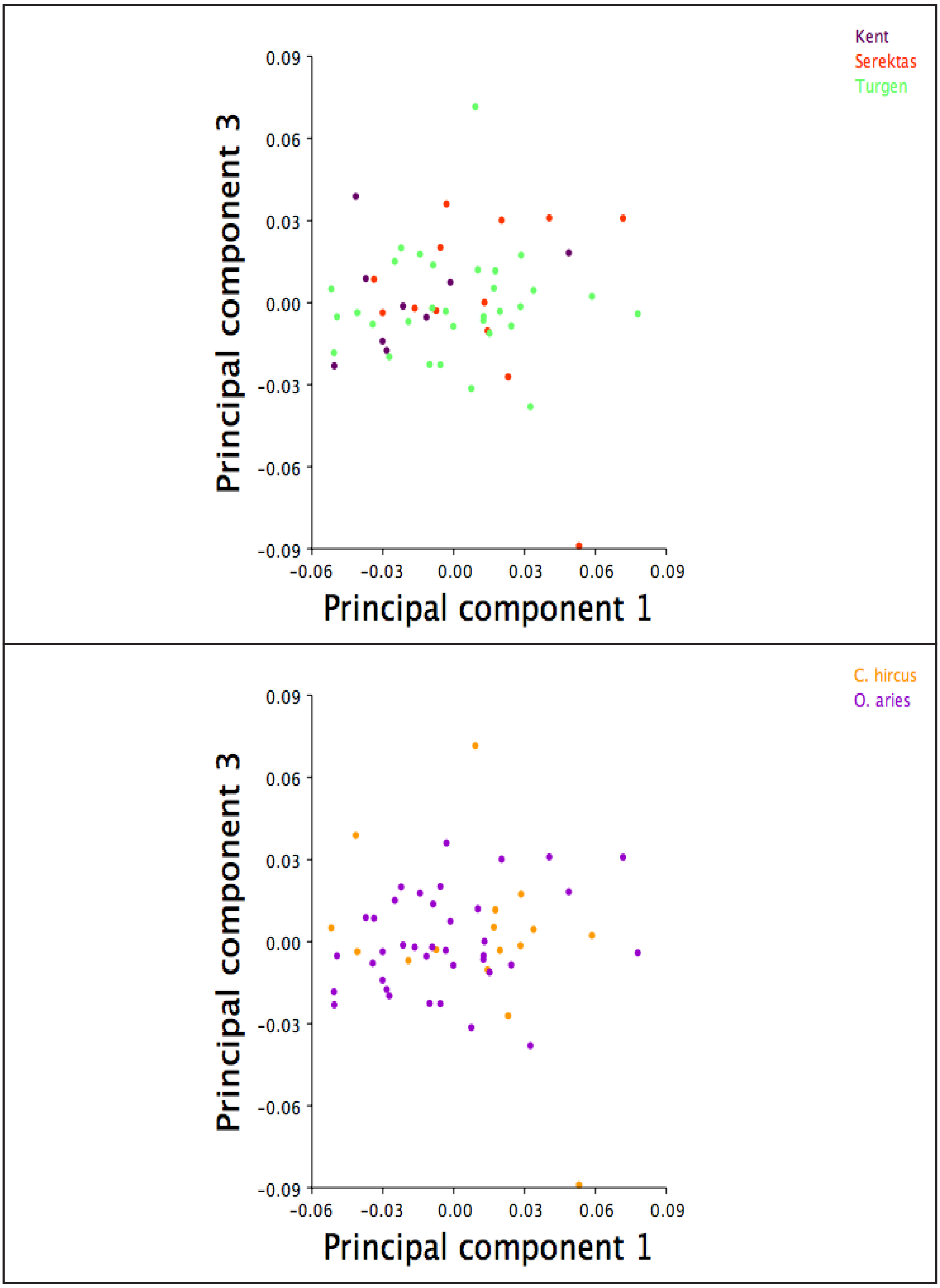


Figure 5.23: Principal Component Scores PC1 and PC3 plotted for all specimens from all sites with colour coding for sites and species.

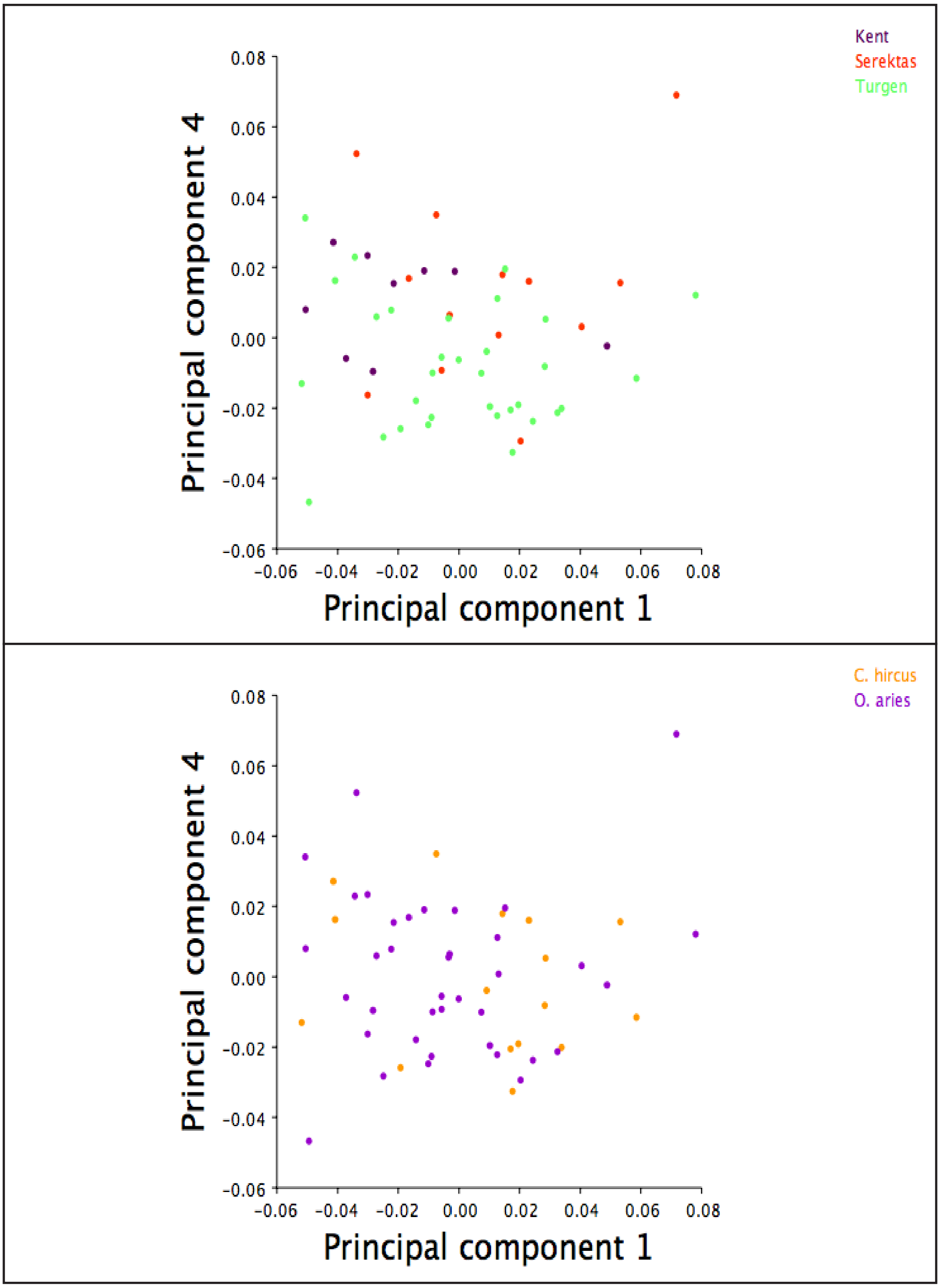


Figure 5.24: Principal Component Scores PC1 and PC4 plotted for all specimens from all sites with colour coding for sites and species.

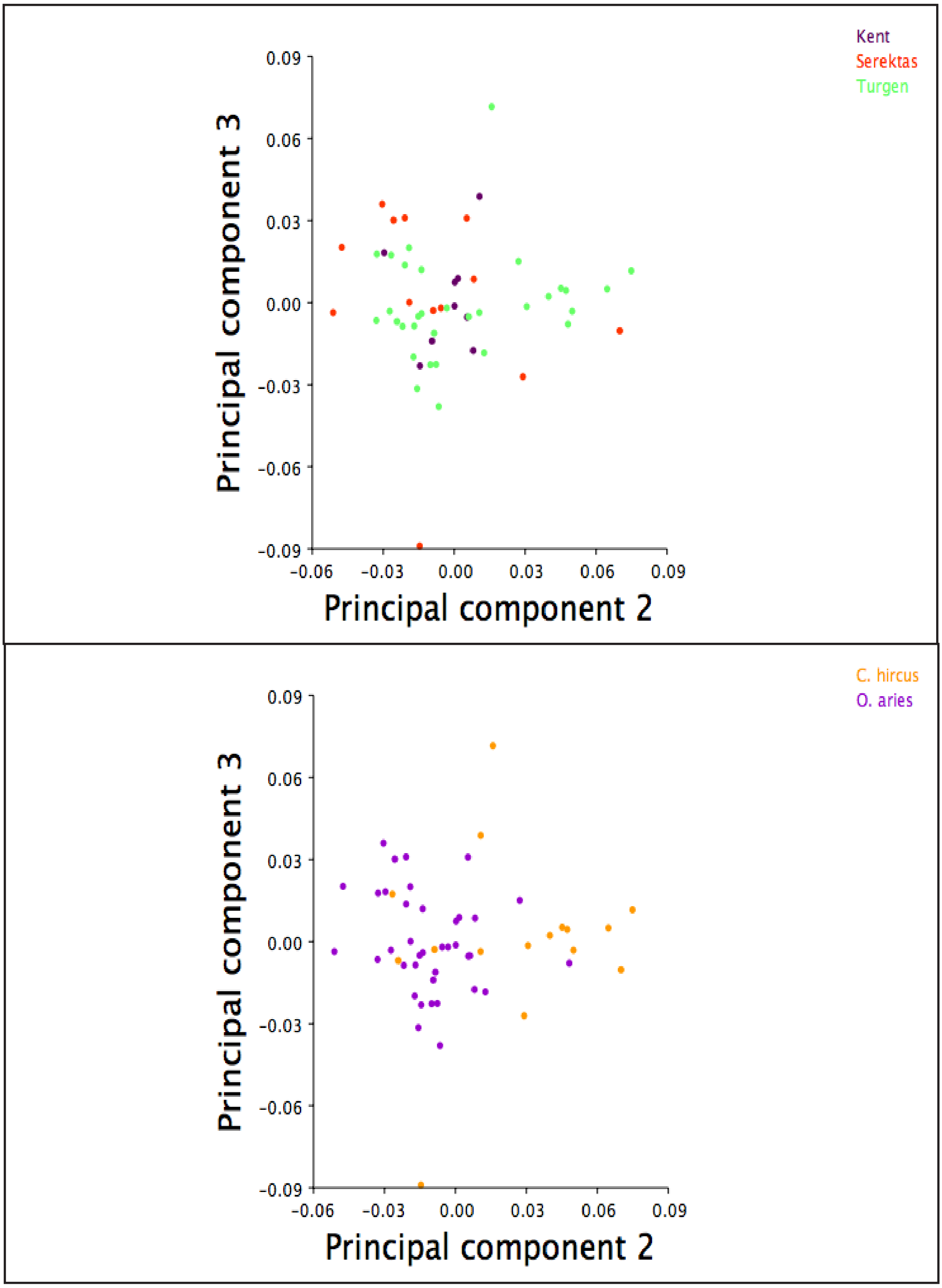


Figure 5.25: Principal Component Scores PC2 and PC3 plotted for all specimens from all sites with colour coding for sites and species.

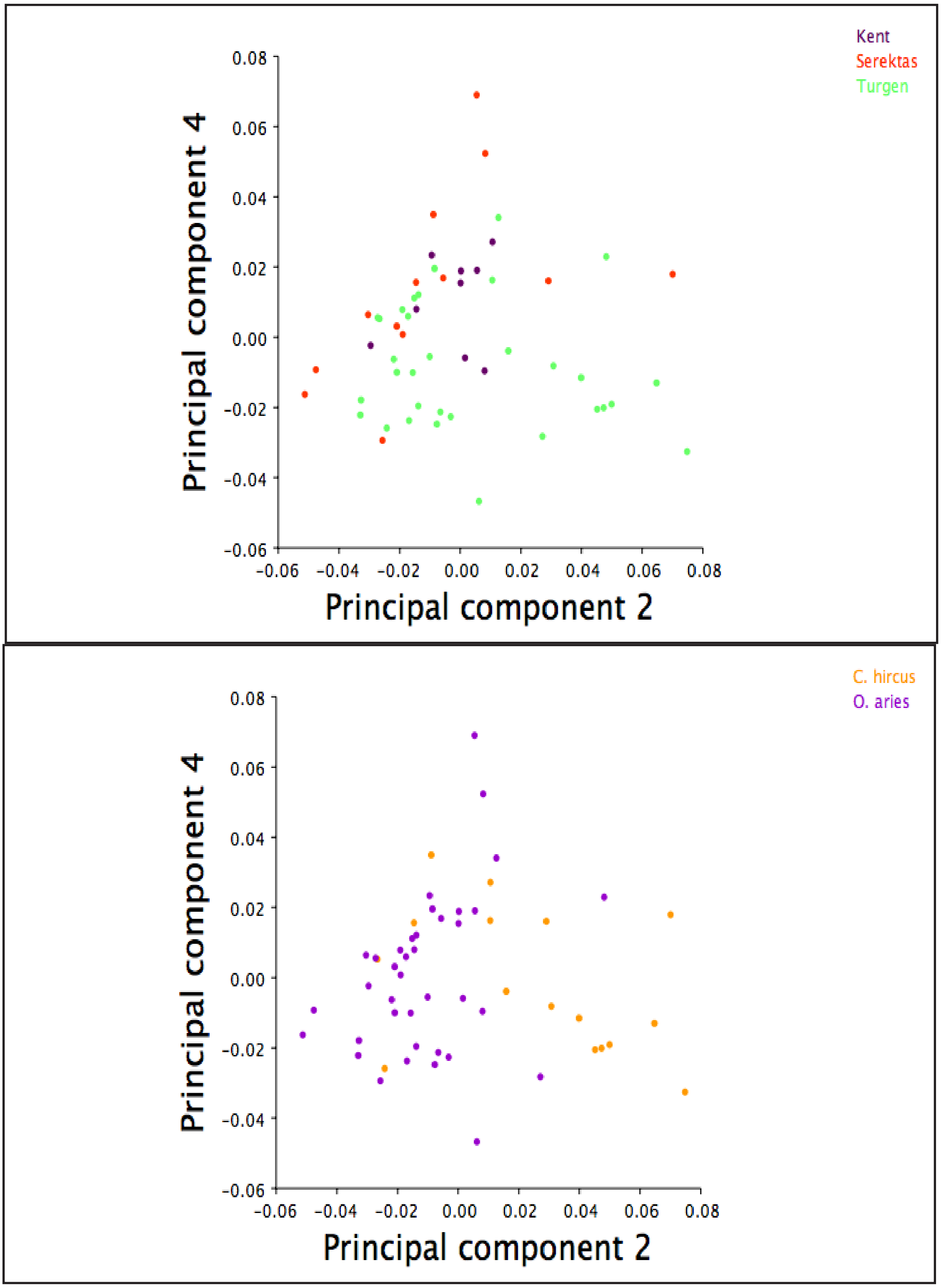


Figure 5.26: Principal Component Scores PC2 and PC4 plotted for all specimens from all sites with colour coding for sites and species.

Prummel and Frisch 1986) in qualitative assessments as is the difference in height in the proximal condyles. These two features along with the variability of the tuberculum talus, control for the differentiation between *Ovis aries* and *Capra hircus* specimens from these sites. Qualitative characteristics, such as the orientation of the protruberance of the medial articular ridge, marked in this study as s11, were shown to not be useful in delineating between species (Fernandez 2001). This suggests that some qualitative features described on ancient Middle Eastern and modern European specimens by the literature are not accurate for Central Asian contexts.

The unreliability of the quantitative characteristics and quantitative method for species separation reveal the weakness of applying regional techniques globally. Yet the GMM results suggest that some of the qualitative characteristics may be accurate for Central Asian specimens. While the variation of the tuberculum talus dominated shape change in all Principal components in all analyses, it is interesting to note that a change in the orientation of the lateral distal articular surface was associated with PCs from the analysis of all specimens from all sites that controlled for species clustering (Figure 5.27). Boessneck (1969) and Prummel and Frisch (1986) suggest using this small qualitative characteristic to speciate the astragalus. In a review of qualitative characteristics, this characteristic was found to be the most reliable for species differentiation (Fernandez 2001). Geometric mophometric methods in this instance proved to be more useful in finding shape differences between species than ratio indices. While the numbers of *Capra hircus* specimens are few, this suggests that removing the landmarks from the tuberculum talus and instead locating more landmarks around this lateral distal articular surface may be a fruitful avenue of enquiry to resolve speciation issues in the future.

While the majority of the specimens analysed here are classified correctly, it is prudent to refrain from drawing conclusions about speciation based on morphological variation between the two species groups that have been identified in this study due to samplng issues (see Chapter 6). As such, while results involving the combination of *Ovis aries* and *Capra hircus* are useful descriptive measures for directing future study they should not be taken as significant delineation of speciation. The very small number of *Capra hircus* specimens and the high p-values for *Capra hircus* CVA (Table 6.3) indicates that the morphological analyses have revealed largely descriptive features. Hence the *Capra hircus* specimens are not included for further analysis of the divergence of phenotypes.

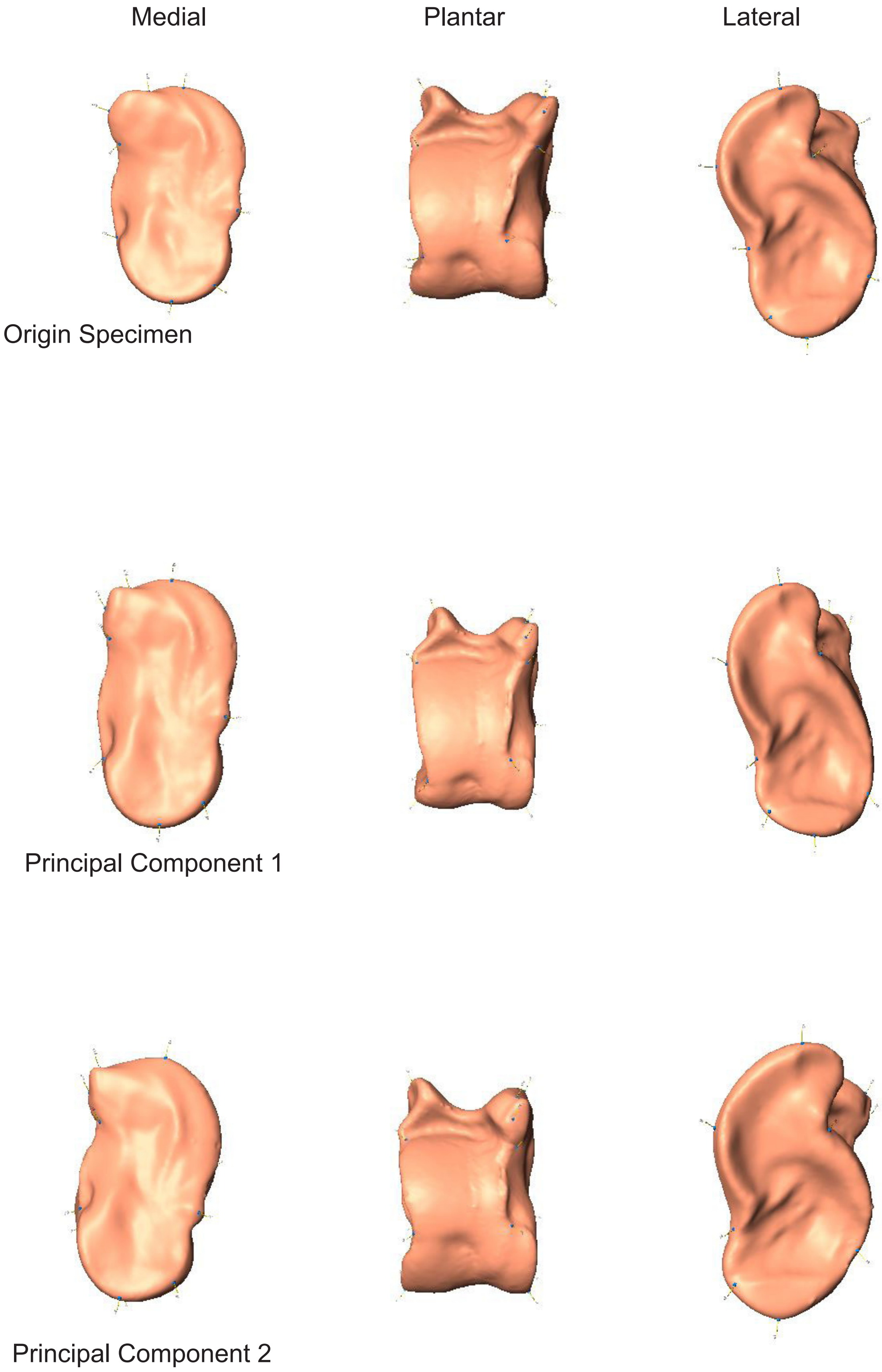


Figure 5.27: Principal component scores 1 and 2 for all species on a left astragalus three dimensional model, Cer19a, using a scale factor of .1.

5.3 Variation of *Ovis aries* by site

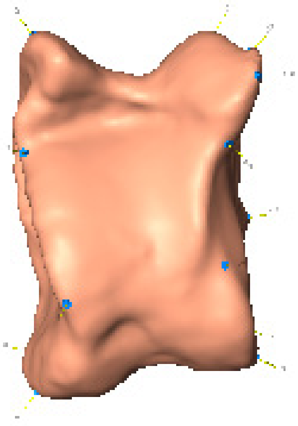
5.3.1 Kent

Originally 132 astragali of *Ovis aries* and *Capra hircus* specimens were scanned. However, 123 scans were corrupted by software problems in the field, unfortunately leaving only nine complete scans. In total eight specimens were analysed from Kent (Table 5.4) and seven of these were from *Ovis aries*.

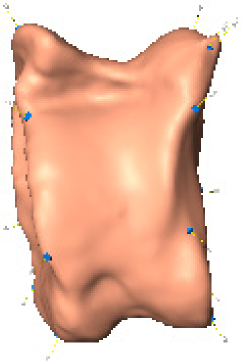
The *Capra hircus* specimen, Kent 204, was removed and the principal component analysis was run again to investigate shape variation within *Ovis aries* specimens. In Figure 5.29, principal component 1 is plotted against principal component 2. Kent 200 and Kent 206 mark the end of the range of variability along principal component 1, while Kent 201 and Kent 207 mark the end of the range of variability along principal component 2. There is no clear group or cluster within the *Ovis aries* specimens.

The first principal component affects the prominence of the lateral distal corner where landmarks s1 and s5 are located (Figure 5.28). Specimens that exhibit the full positive effect of principal component 1, such as Kent 206, have the least prominent lateral distal articular edges. The second principal component affects the tuberculum talus, located on the proximal medial corner of the astragalus (Figure 5.28). Landmarks s12, s13, and s14 are located on this feature. Specimens that exhibit the full positive expression of this variation, such as Kent 207, have very prominent and slightly divoted tuberculum tali .

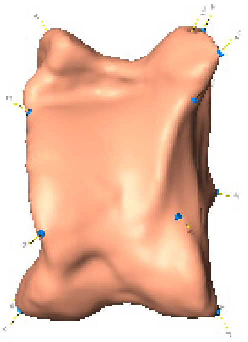
Principal component 1 is plotted against principal component 3 in Figure 5.30. Again, Kent 200 and Kent 206 mark the end of the range of variability along principal component 1. Kent 199 and Kent 207 mark the end of the range of variability along principal component 3. The third principal component affects



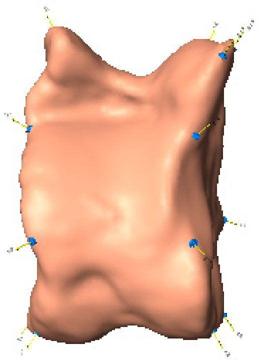
Origin Astragalus



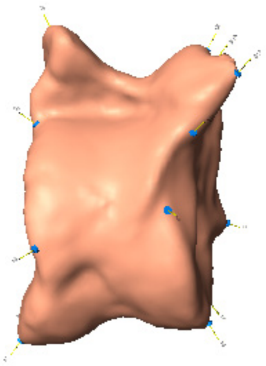
PC1 variation on sheep



PC2 variation on sheep



PC3 variation on sheep



PC4 variation on sheep

Figure 5.28: PC Scores plotted onto three dimensional left astragalus model for all *Ovis aries* specimens from Kent with a scale factor of .1 using Kent199 as the model.

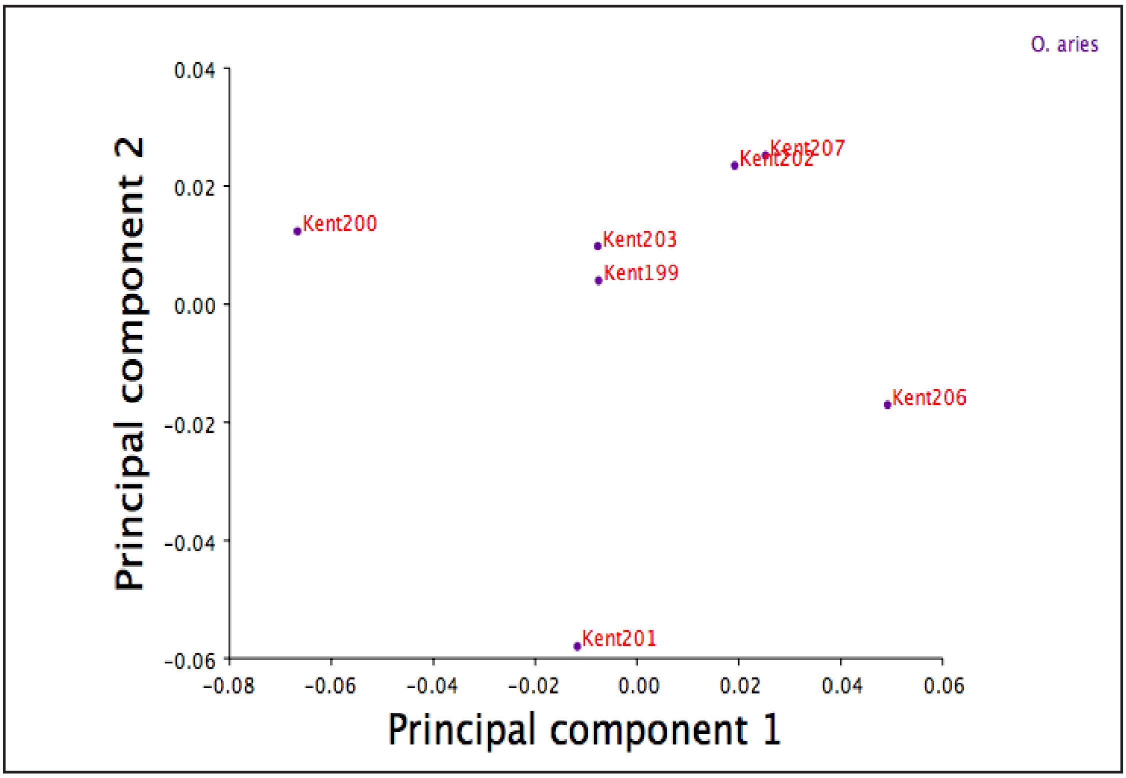


Figure 5.29: Principal Component Scores PC1 and PC2 plotted for *Ovis aries* specimens from Kent.

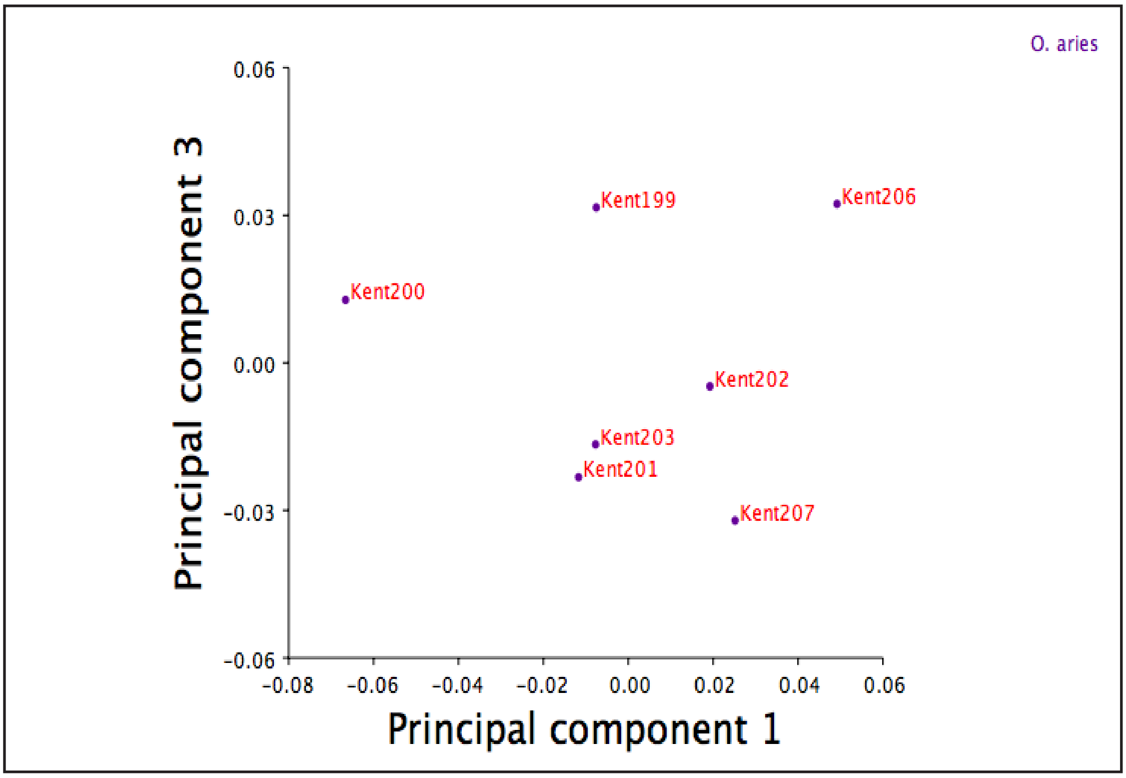


Figure 5.30: Principal Component Scores PC1 and PC3 plotted for *Ovis aries* specimens from Kent.

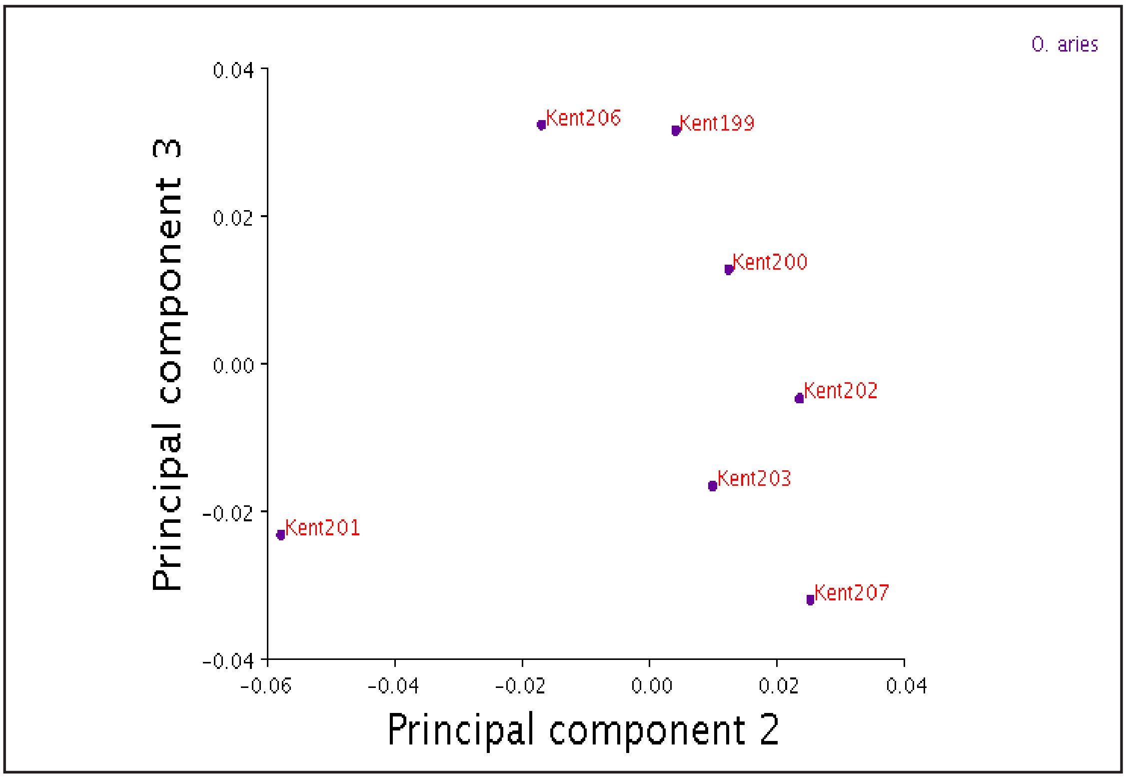


Figure 5.31: Principal Component Scores PC2 and PC3 plotted for *Ovis aries* specimens from Kent.

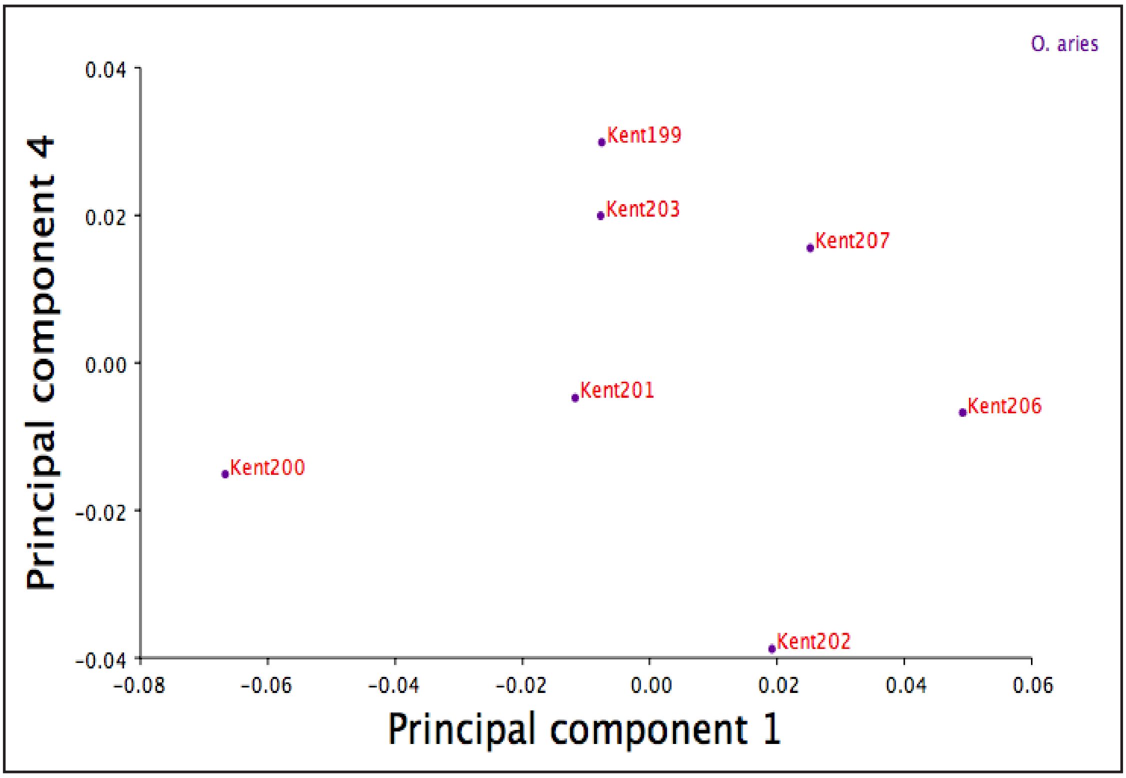


Figure 5. 32: Principal Component Scores PC1 and PC4 plotted for *Ovis aries* specimens from Kent.

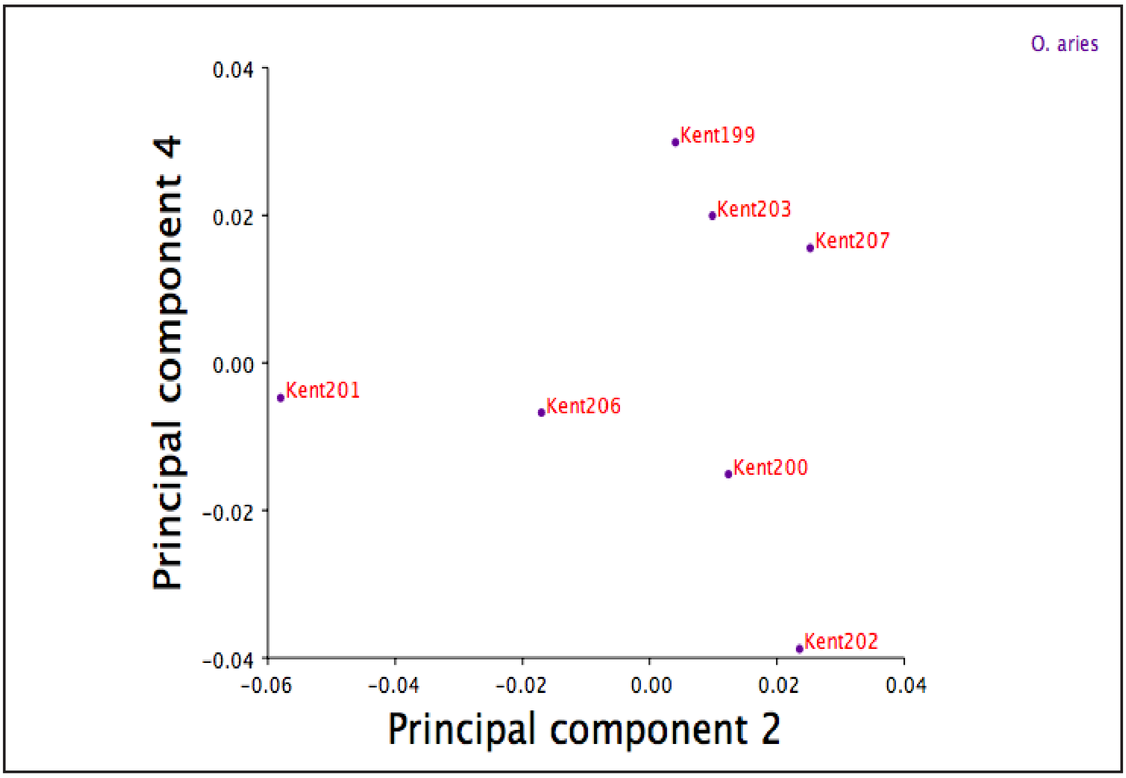


Figure 5.33:Principal Component Scores PC2 and PC4 plotted for Ovis aries specimens from Kent.

the breadth of the astragalus and the amount of medial twist on the plantar articular surface (Figure 5.28). Specimens that lie at the positive extreme of this trait exhibit the least medial twist in the astragali and are generally more square in appearance.

Principal component 2 is plotted against principal component 3 in Figure 5.31. Kent 201 and Kent 207 mark the end of the range of variability along principal component 2, while Kent 206 and Kent 207 mark the end of the range of variability along principal component 3. There is a cluster of specimens along the end of principal component 2, indicating that Kent201 has a different shaped tuberculum talus that the other *Ovis aries* specimens.

Principal component 1 is plotted against principal component 4 in Figure 5.32.

Kent 200 and Kent 206 mark the ends of the range of variability along principal component 1, while Kent 202 and Kent 199 mark the ends of the range of variability along principal component 4. The fourth principal component affects both the prominence of the lateral distal corner and the prominence of the tuberculum talus. The plantar articular surface of specimens at the full range of variation would have a lateral twist (Figure 5.28).

Finally principal component 2 is plotted against principal component 4 in Figure 5.33. Kent 201 and Kent 207 mark the end of the range of variability along principal component 2, while Kent 199 and Kent 202 mark the end of the range of variability along principal component 4. The cluster of specimens seen in Figure 5.31 along principal component 2 is not as definite in Figure 5.33.

There is an even spread and no clear separation of the specimens along any of the principal components (Figure 5.29- 5.33), aside from the differently shaped tuberculum talus of Kent 201 pushing other specimens into a narrow band of variation along principal component 2. However, there are no groupings within the *Ovis aries* specimens that are clearly indicated.

Individual variation within the *Ovis aries* specimen dataset from Kent is largely limited to the prominence and shape of the tuberculum talus and the lateral distal corner (Figure 5.28). These features are at diagonally opposite corners of the specimen. The tuberculum talus is not an articular surface. It protrudes from the proximal medial corner of the articulation between the distal tibia and the calcaneous. The lateral distal corner articulates with the fused central and fourth tarsal, the cuboid and the navicular bones. The astragalus pivots on this surface forward and backward. The motion is limited by the ends of this articular surface at landmarks s8 and s10. This corner takes most of the downward force of the hind limb and is a critical pivot point for converting that downward force while transferring the direction of the force into forward motion.

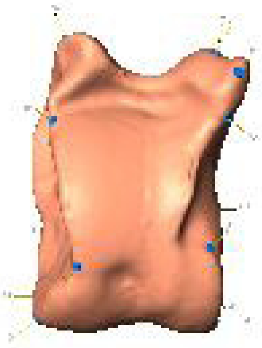
5.3.2 Serektas

Sixteen specimens were scanned from the Serektas assemblage. Two of these specimens, Cer3 and Cer11 were excluded from analysis as they were worked into playing pieces. Two additional specimens Cer7 and Cer12 were excluded, as they were unsuitable due to software corruption errors. In total twelve specimens were included in the analysis (Table 5.5).

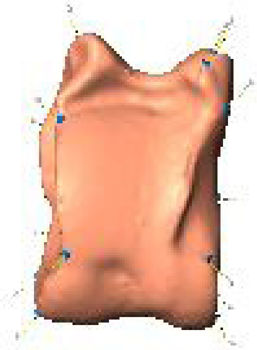
Principal component analysis was run without *Capra hircus* specimens, Cer6, Cer9, and Cer15. There are nine eigenvalues, and the first four principal components account for 81.7% of shape variation (Table 8.7). There are no clear groups within the *Ovis aries* specimens from Serektas.

Principal component 1 was plotted against principal component 2 in Figure 5.35. Cer1a and Cer10a mark the end of the range of variability along principal component 1 while Cer17a and Cer18a mark the end of the range of variability along principal component 2. There are no clear clusters of specimens. Principal component 1 describes a change in the orientation of the tip of the tuberculum talus and the small protuberance on the medial dorsal corner marked by landmark s11, while principal component 2 describes the change in the prominence of the ridge that runs along the lateral edge of the plantar articular surface, and an increase in curvature of the lateral plantar articular surface, as welll as a reduction in the curvature of the lateral distal articular surface (Figure 5.34).

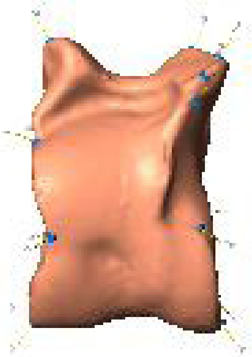
Principal component 1 is plotted against principal component 3 in Figure 5.34.



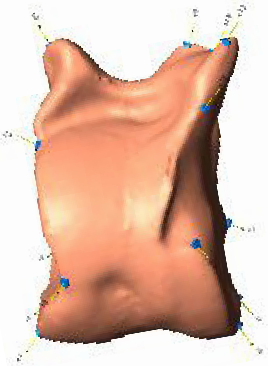
Origin Astragalus



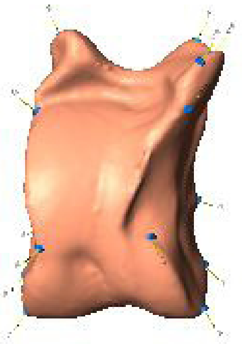
PC1 variation on sheep



PC2 variation on sheep



PC3 variation on sheep



PC4 variation on sheep

Figure 5.34: PC Scores plotted onto three dimensional left astragalus model for all specimens and for all *Ovis aries* specimens from Serektas with a scale factor of .1 using Cer19a as a model.

Cer1a and Cer10a mark the end of the range of variability along principal component 1 while Cer2a and Cer4a mark the end of the range of variability along principal component 3. Principal component 3 describes an increase in the prominence of the lateral ridge on the plantar articulation, a change in shape of the lateral distal articulation from oblong to more triangular in shape and oriented dorsally. There is also an increase in the relative prominence of the tuberculum talus (Figure 5.34).

Principal component 1 is plotted against principal component 4 in Figure 5.37. Cer1a and Cer10a mark the end of the range of variability along principal component 1 while Cer8a and Cer5a mark the end of the range of variability along principal component 4. Principal component 4 describes an even greater prominence of the plantar ridge and a slight change to the orientation of the point of the tuberculum talus, marked by landmark s12 (Figure 5.34).

Principal component 2 is plotted against principal component 3 in Figure 5.38. Cer17a and Cer18a mark the end of the range of variability along principal component 1 while Cer2a and Cer4a mark the end of the range of variability along principal component 3. This appears to be the most evenly distributed figure for *Ovis aries* from Serektas as there are no clear grouping or outliers.

Principal component 2 is plotted against principal component 4 in Figure 5.39. Cer17a and Cer18a mark the end of the range of variability along principal component 2 while Cer8a and Cer10a mark the end of the range of variability along principal component 4. Once again there are no clear groups of specimens.

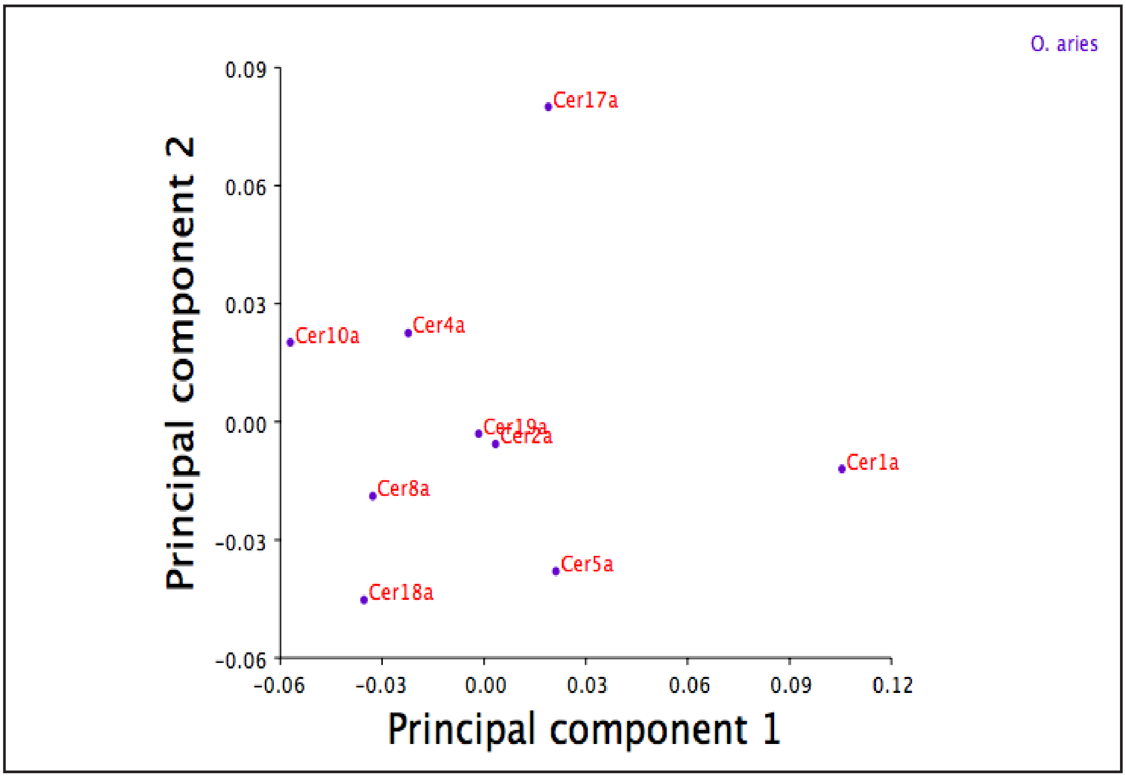


Figure 5.35: Principal Component Scores PC1 and PC2 plotted for *Ovis aries* specimens from Serektas.

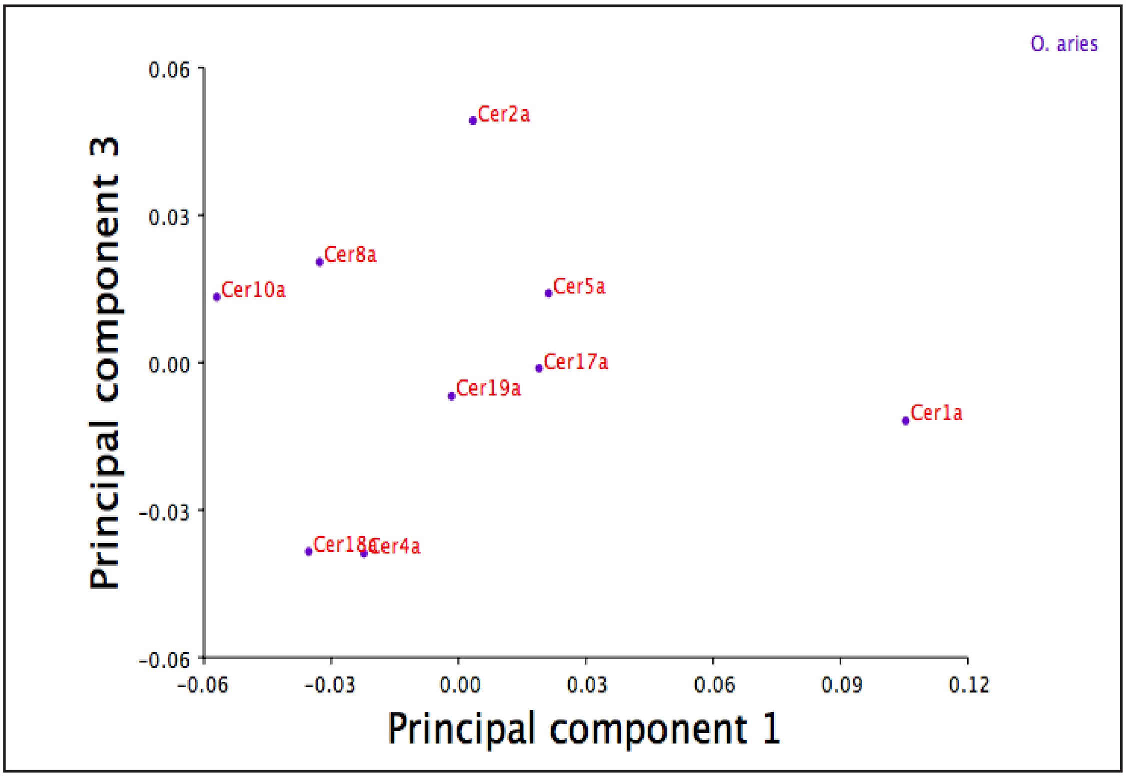


Figure 5.36: Principal Component Scores PC1 and PC3 plotted for *Ovis aries* specimens from Serektas.

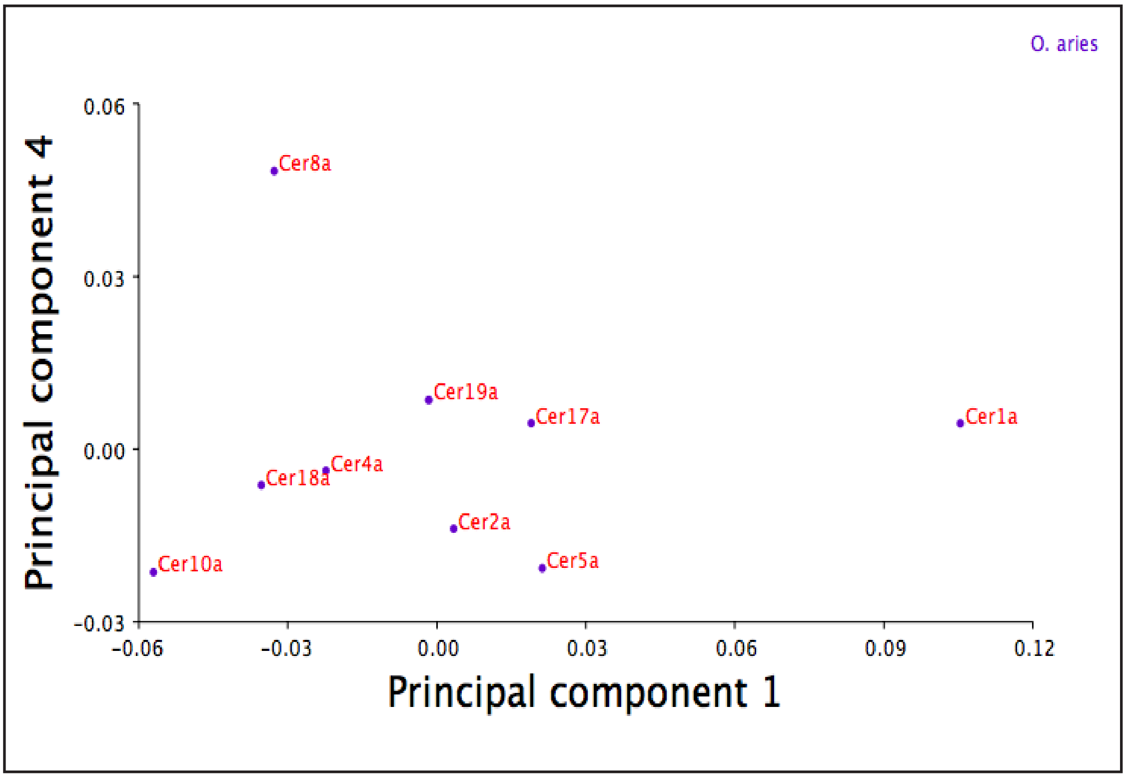


Figure 5.37: Principal Component Scores PC1 and PC4 plotted for *Ovis aries* specimens from Serektas.

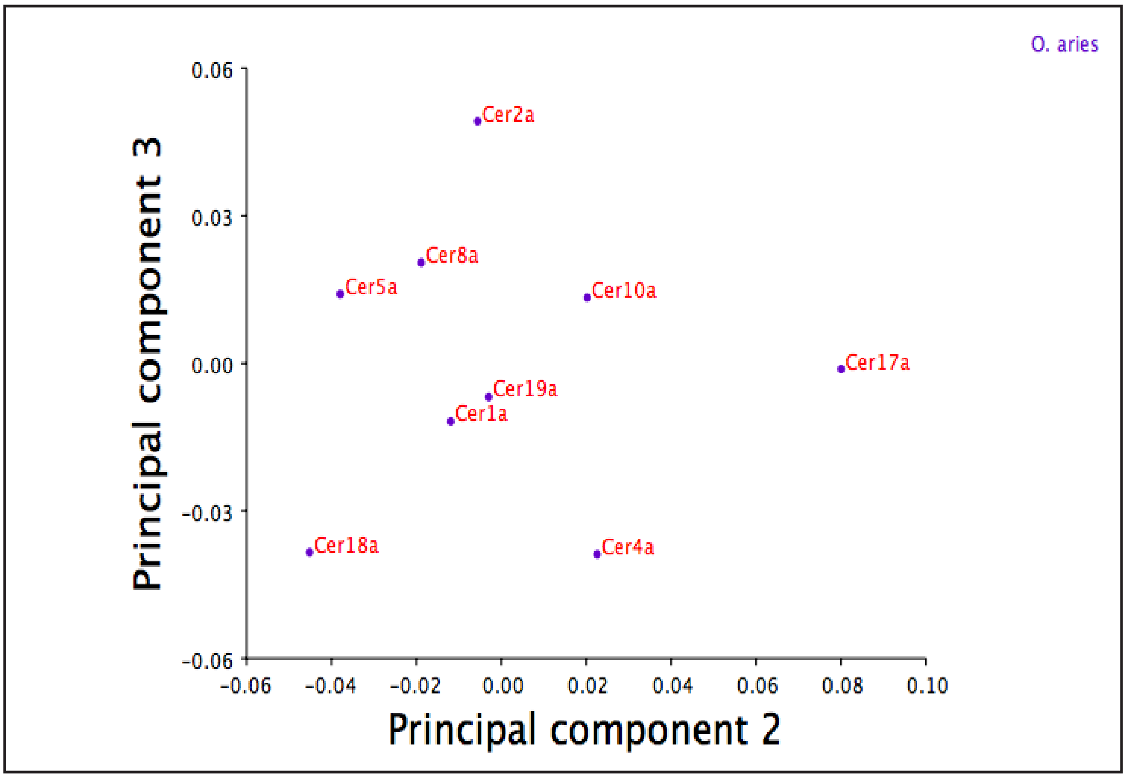


Figure 5.38: Principal Component Scores PC2 and PC3 plotted for *Ovis aries* specimens from Serektas.

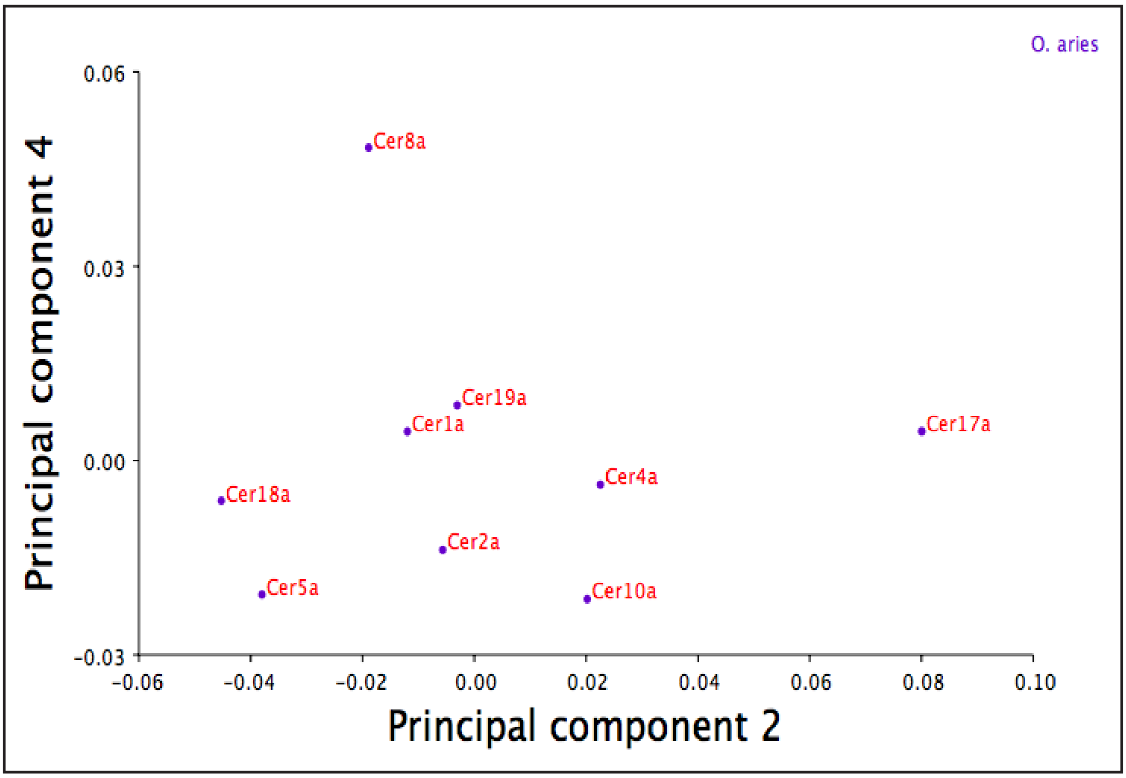


Figure 5.39:Principal Component Scores PC2 and PC4 plotted for *Ovis aries* specimens from Serektas.

There are no clear groupings of *Ovis aries* specimens, aside from the outliers of Cer1a and Cer17a which trend out on principal component 1 and principal component 2, respectively. These two specimens show changes to the shape and orientation of the tuberculum talus, as well as some small changes to the shape of the distal articular surface.

Shape variation of the *Ovis aries* specimens from Serektas is largely limited to the orientation and prominence of the tuberculum talus and the associated ridge along the plantar articular surface. Principal component 1 describes the most distinct shape change. The proximal articular surface shows a change in the orientation of both the tuberculum talus and the proximal lateral surface. In contrast with the very similar set of shape changes for principal component 1 for all species from Serektas, the shape change for *Ovis aries* specimens does not indicate that the tuberculum talus becomes smooth, but instead retains a pointed end. The shape variation depicted within the *Ovis aries* dataset from Serektas describes individual variation with no intra-group structure.

5.3.3 Turgen

Thirty-four specimens were scanned from Turgen. Two were excluded from analysis; Turg13 was damaged and Turg14 was a species of deer. Thirty-two specimens were analysed (Table 5.6).

Nineteen *Ovis aries* specimens were subjected to a principal components analysis. There are eighteen eigenvalues, for which the first four principal components account for 55% of shape variation (Table 8.8). The principal components do not isolate groups within the *Ovis aries* specimens from Turgen: the specimens plot evenly across the first four principal components (Figures 5.41-5.45).

Principal component 1 is plotted against principal component 2 in Figure 5.41. Tur20a and Turg8a mark the end of the range of variability along principal component 1 while Turg24a and Turg23a mark the end of the range of variability along principal component 2. There are no clear clusters of *Ovis aries* in this plot.

Principal component 1 describes a change in the orientation of the tuberculum talus towards the plantar surface and the increased prominence of a small node under the lateral proximal articulation, landmarked with s6 (Figure 5.40). Principal component 2 again describes a lateral flare of the tuberculum talus. Additionally, the lateral distal articular surface is flatter and there is a corresponding change in the shape of the lateral distal articular surface with an

Origin Astragalus

PC1 variation on sheep

PC2 variation on sheep

PC3 variation on sheep

PC4 variation on sheep

Figure 5.40: PC Scores plotted onto three dimensional right astragalus model for all specimens and for all *Ovis aries* specimens from Turgen with a scale factor of .1 using Turg17a as a model.

oblong shape lengthening towards the plantar articular surface (Figure 5.40).

Principal component 1 is plotted against principal component 3 in Figure 5.42. Tur20a and Turg8a mark the end of the range of variability along principal component 1 while Turg23a and Turg42a mark the end of the range of variability along principal component 3. Principal component 3 describes a lateral orientation of the tuberculum talus, and an increased prominence of the small node under the lateral proximal articulation which was also affected by principal component 1. There is also a slight medial curvature of the entire astragalus and flattening of the plantar ridge that connects to the tuberculum talus (Figure 5.40).

Principal component 1 is plotted against principal component 4 in Figure 5.43. Tur20a and Turg8a mark the end of the range of variability along principal component 1 while Turg36a and Turg3a mark the end of the range of variability along principal component 4. Principal component 4 describes an increase in the prominence of the plantar medial ridge, and an increase in the difference between the heights of the proximal condyles. There is an acute angle where the proximal articular condyles meet (Figure 5.40).

Principal component 2 is plotted against principal component 3 in Figure 5.44. Turg24a and Turg23a mark the end of the range of variability along principal component 2 while Turg23a and Turg42a mark the end of the range of variability along principal component 3. There are no clusters of specimens in this plot.

Principal component 2 is plotted against principal component 4 in Figure 5.45. Turg24a and Turg23a mark the end of the range of variability along principal

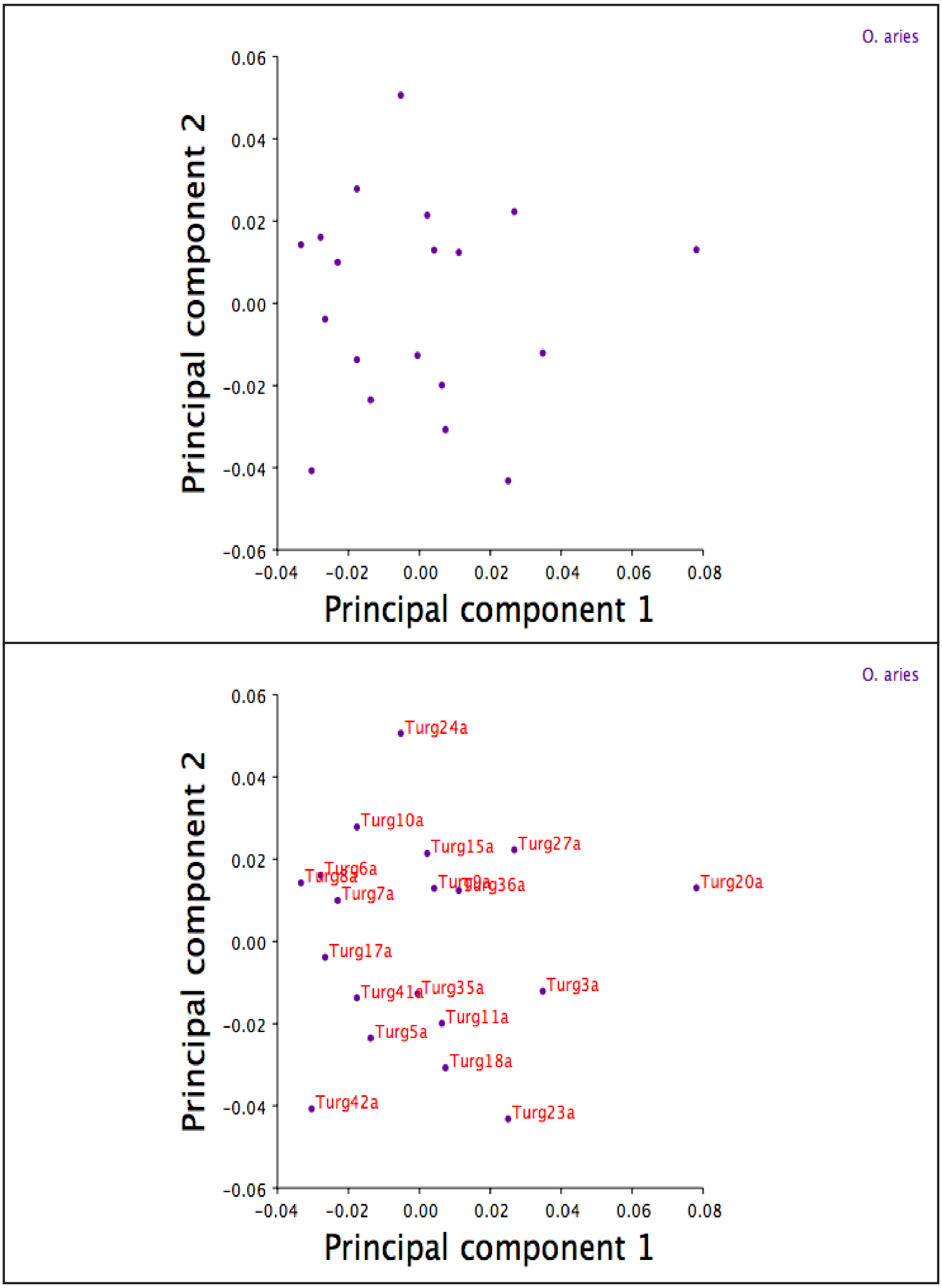


Figure 5.41: Principal Component Scores PC1 and PC2 plotted for all *Ovis aries* specimens from Turgen with and without labels.

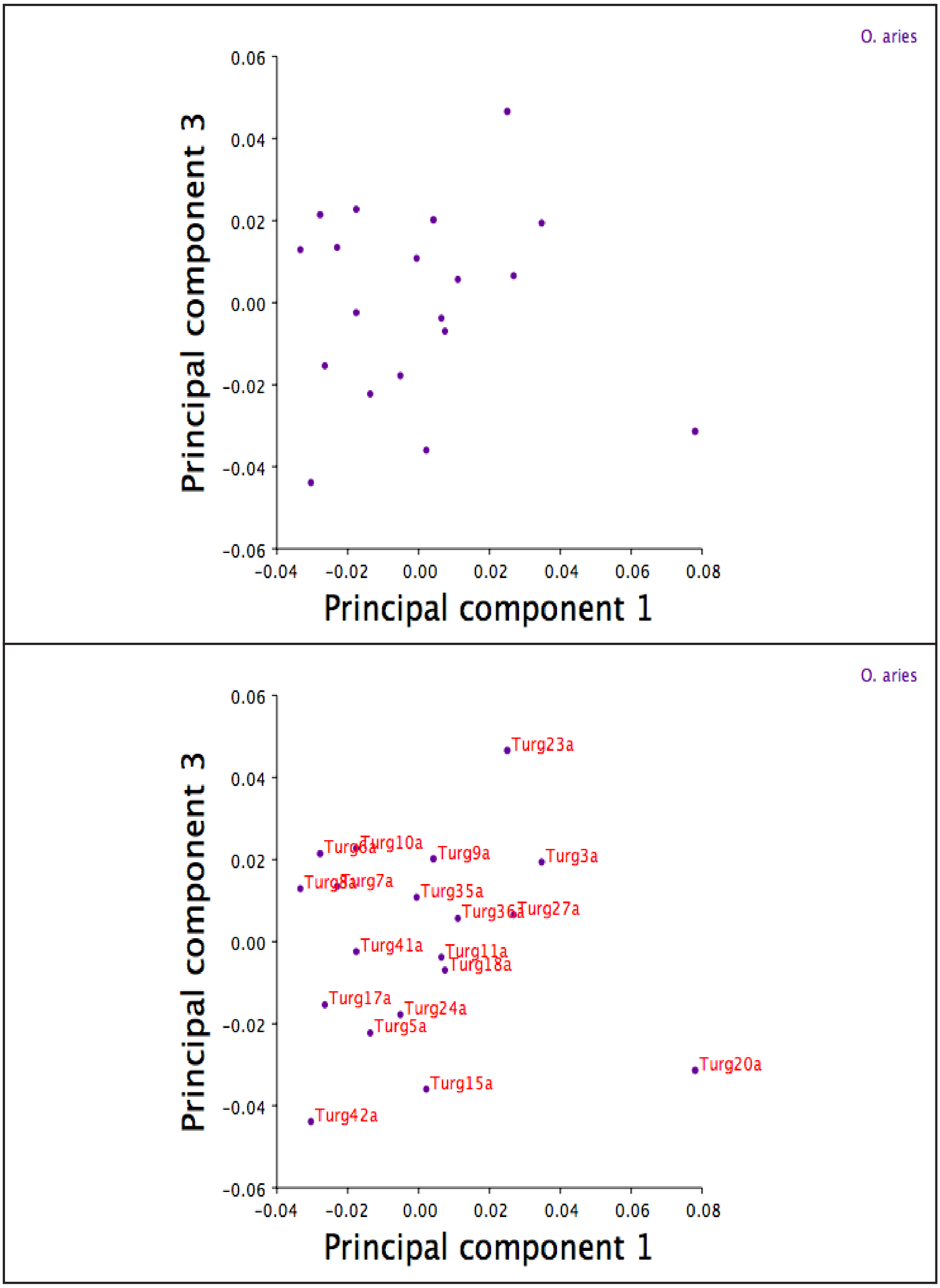


Figure 5.42: Principal Component Scores PC1 and PC3 plotted for all *Ovis aries* specimens from Turgen with and without labels.

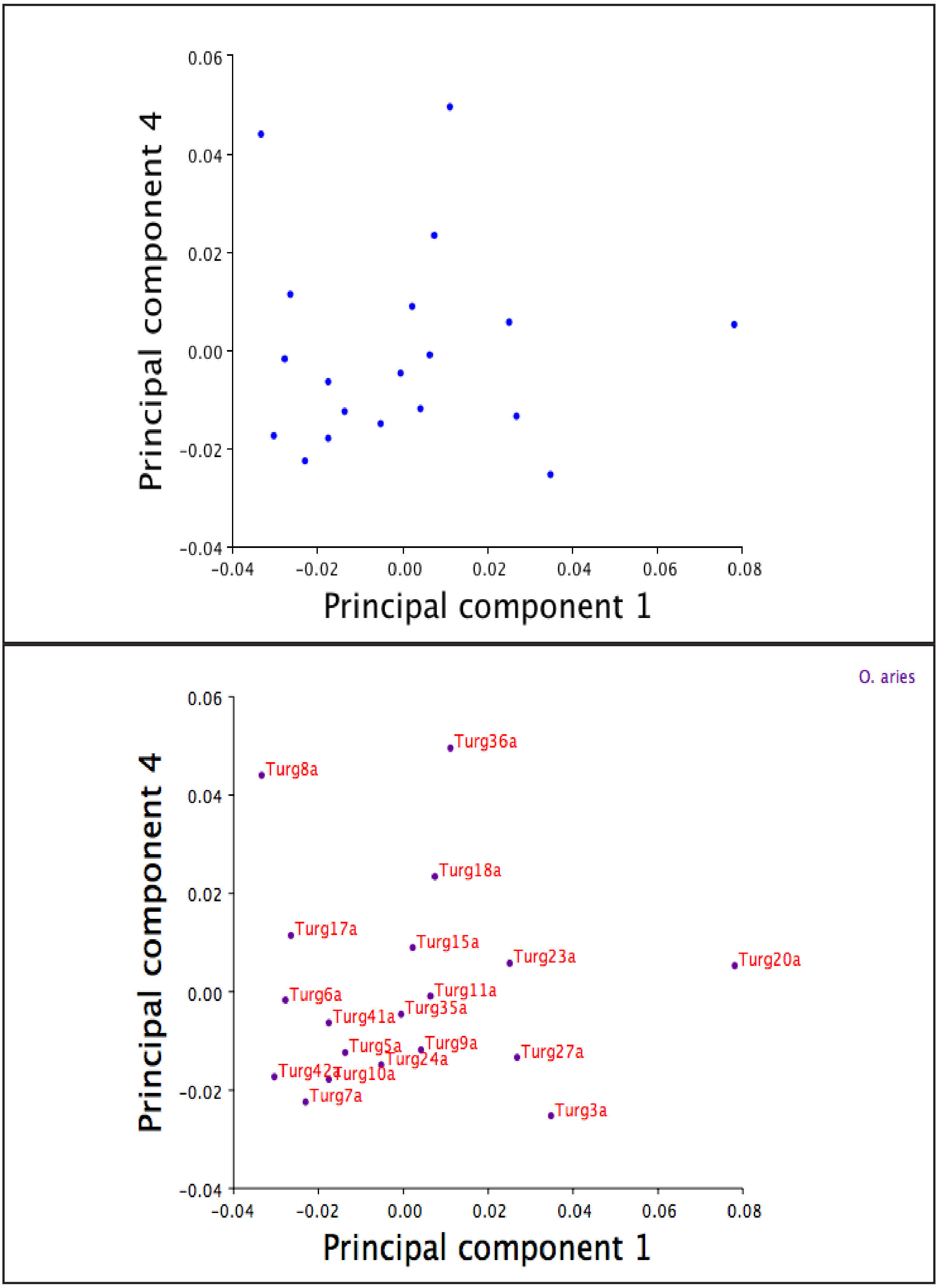


Figure 5.43: Principal Component Scores PC1 and PC4 plotted for all *Ovis aries* specimens from Turgen with and without labels

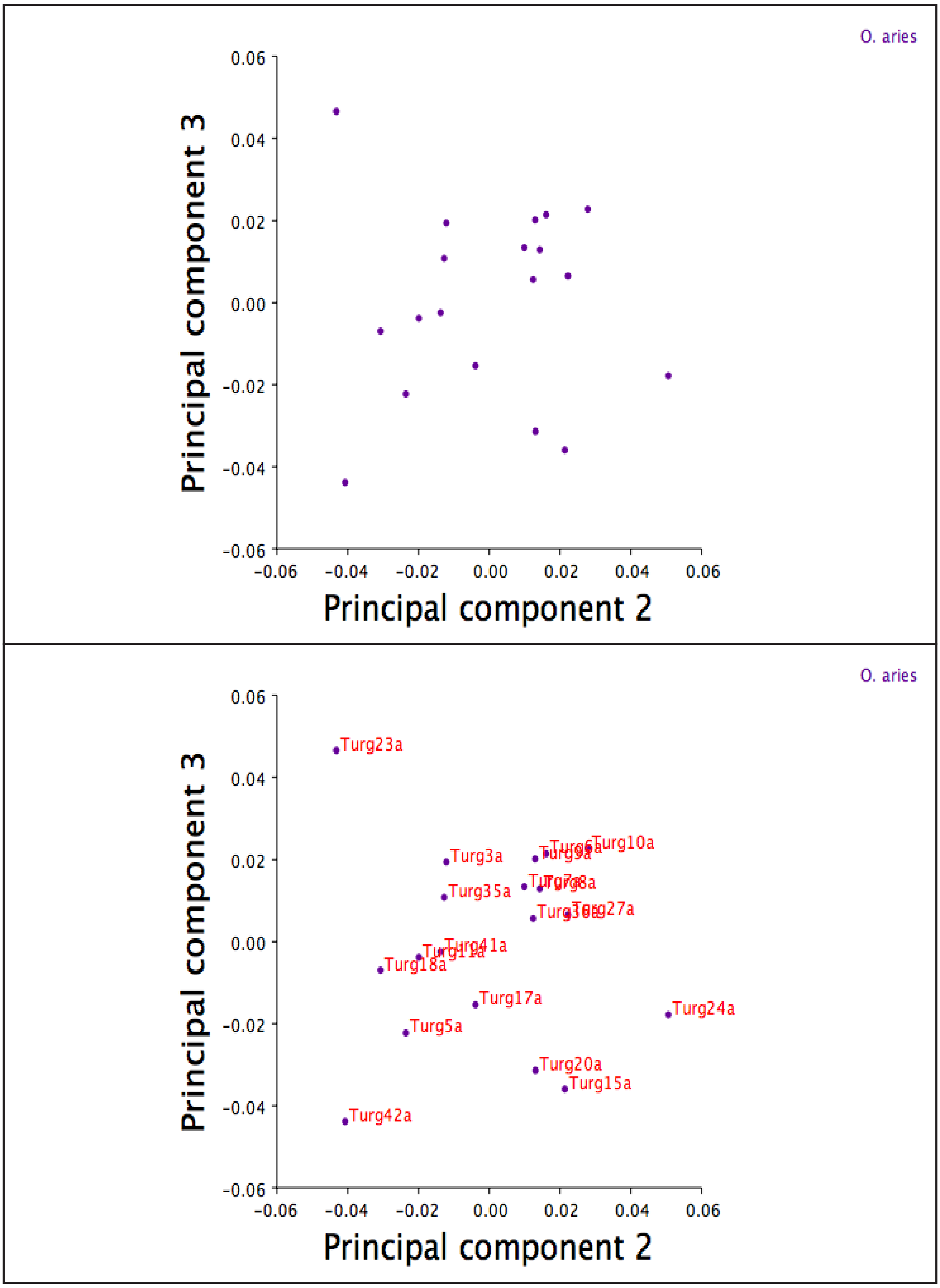


Figure 5.44: Principal Component Scores PC2 and PC3 plotted for all *Ovis aries* specimens from Turgen with and without labels.

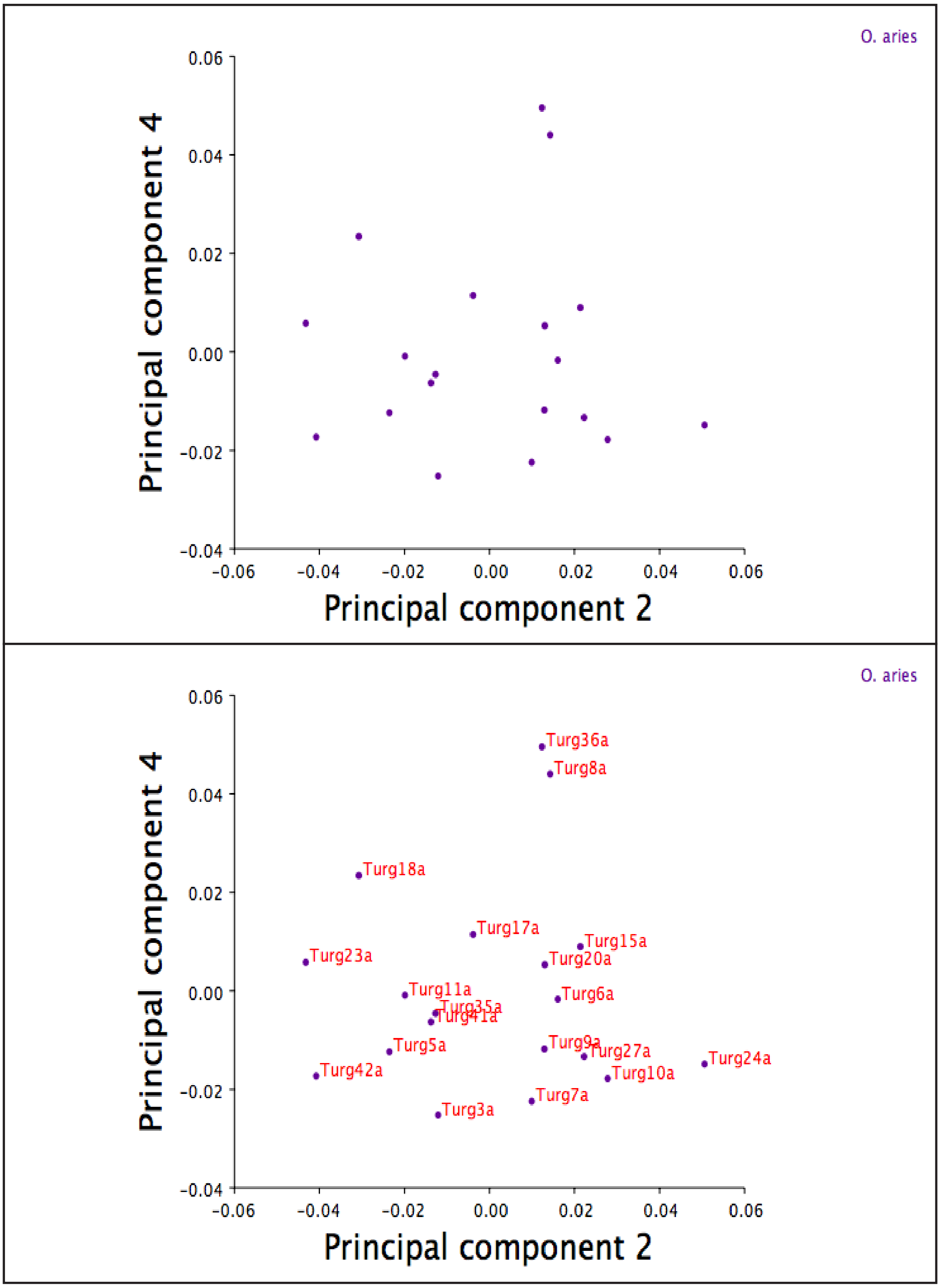


Figure 5.45: Principal Component Scores PC2 and PC4 plotted for all *Ovis aries* specimens from Turgen with and without labels.

component 2 while Turg36a and Turg3a mark the end of the range of variability along principal component 4. Once again, there are no clusters within this plot.

There are no clear clusters of *Ovis aries* specimens in these plots. The outliers along the principal components do not compress other specimens into a small range of variability along principal components. Like the other sites, the shape changes within the *Ovis aries* population at Turgen is largely described by the prominence and orientation of the tuberculum talus, with changes in some associated features, such as the plantar ridge. Additionally, the *Ovis aries* specimens show some variation in the prominence of the proximal condyles, particularly along principal component 4.

5.4 Intrasite Comparisons

Ovis aries specimens were labelled by site and principal component analysis was run again. Specimens are color coded by site and presented with and without labels for clarity. Results of a PCA of all *Capra hircus* specimens are listed in the Appendix as they are not significant (Figure 8.1-8.7).

Principal component 1 is plotted against principal component 2 in Figure 5.46. The end of the range of varability is marked by Cer1a and Turg20a along principal component 1 and Cer10a and Cer1a along principal component 2. There is no clear clustering of specimens, although the Kent specimens lie towards the lower left hand corder while the majority of the Turgen and Serektas specimens lie in a large cluster away from outliers Turg13 and Cer1a.

Principal component 1 is plotted against principal component 3 in Figure 5.47. The end of the range of variability is marked by Cer1a and Turg20a along principal component 1 and Cer1a and Turg13 along principal component 3. There is no clear clustering of specimens into sites and Cer1a and Turg13a continue to push the other specimens together towards the left hand side along the first principal component.

Principal component 1 is plotted against principal component 4 in Figure 5.48. The end of the range of variability is marked by Cer1a and Turg20a along principal component 1 and Cer8a and Turg42a along principal component 4. The specimens from all sites are distributed across the plot. The Serektas specimens trend towards the top of the cluster, the Kent specimens towards the left, while the Turgen specimens are evenly distributed along the entire left handside, overlaping the other sites.

Principal component 2 is plotted against principal component 3 in Figure 5.49. The end of the range of variability is marked by Cer10a and Cer1a along principal component 2 and Turg13a and Cer1a along principal component 3. The specimens are evenly distributed within a central cluster.

Principal component 2 is plotted against principal component 4 in Figure 5.50. The end of the range of variability is marked by Cer10a and Cera1a along principal component 2 and Cer8a and Turg42a along principal component 4. Serektas specimens lie in a band along principal component 2, while Turgen and Kent specimens are distributed within a central cluster.

Principal component 4 appears to control for some degree of site clustering, particularly for Serektas. However there is no clear patterns of specimens clustering into sites along the first four principal components.

Canonical variate analysis (CVA) is an ordination technique used to explore for differences between groups. CVA runs on the assumption of group membership of the landmark configurations and produces canonical variates which maximize between group variance relative to intragroup variance (Klingenberg and Monteiro 2005, Viscosi and Cardini 2011). Canonical variates are uncorrelated within and between groups and the number of canonical variates is one less than the number of groups analysed.

Canonical variate analysis is useful for depicting and describing differences among groups and is superior for investigating inter-group structure. principal component analysis is primarily a general investigation into variation that is not driven by a hypothesis. While group structure may not have been clearly visible from the results of a principal component analysis, this does not preclude the possibility of a group structure. However, a lack of group structure using Principcal Component analysis suggests that the largest amount of variation does not originate from group membership but instead from other variables.

Ovis aries were subjected to a CVA (see Appendix for results). The dataset was averaged by species before the covariance matrix and then the CVA run. Canonical variate 1 is plotted against canonical variate 2 in Figure 5.51. There is a clear separation of the specimens from individual sites along canonical variate 1. This indicates that there is clear group shape differences for *Ovis aries*. Although this pattern does not show in the PCA plots, this does not indicate that the separation is not present. The CVA reveals relationships and clustering that was not possible to see in the PCA.

Canonical variate 1 was exported onto a model astragalus in Figure 5.52. The change in shape is subtle, and hence the scale factor of the shape change has been set to 10 to emphasize the changes and make them visible. The medial side of the astragalus is narrower and the bony folds are more prominent. The lateral distal articulation has a flatter and broader surface, particularly on the medial half. The plantar articular surface is broader and the plantar ride runs parallel to the proximal-distal axis. The tuberculum talus flares distally and laterally. The shape of the distal half of the lateral side changes from a rounded ellipsoid to a teardrop shape. The lateral distal articulation changes to a more devloped distal point and a triangular shape.

Canonical variate 2 has much more dramatic shape changes. The tuberculum talus is more compressed on the medial and plantar aspects towards the proximal-distal axis (Figure 5.52). The medial side of the plantar articulation is also compressed, while the plantar ridge extendes distally down the plantar surface. Any appearance of change in orientation is an artefact of the origin specimen. The distal articular surface is flatter, with a smaller divot between the two articular surfaces. The proximal lateral corner of the plantar aritcular surface projects further out towards the lateral plane. The lateral distal articular surface flattens while the plantar point of the proximal lateral condyle is not as prominent but the angle between the proximal condyles is more acute.

These shape changes are similar to shape changes associated with variation within sites. However, the tuberculum talus does not feature as a main component of shape variation. Instead, the distal articular surface and the orientation of the plantar articular surface and plantar ridge vary considerably. This suggests that the high variability of the tuberculum talus as seen in the PCA analyses was a biological shape change that is maximised by individual specimens, and does not contribute to group membership.

Both of these features articulate with other bones in the ankle joint. The amount of surface area of the distal articulation would change the pressure and angle of inclination at the bottom of the ankle joint. Changes to the plantar articular surface affects the degree of lateral twist in the ankle joint. As the proximal end of the calcaneous moves dorsally as the leg is contracted, the medial edge of the calcaneous is guided by the plantar ridge. Extension of this ridges stabilises the joint.

Serektas and Kent display the variation shown along canonical variate 1, while Serektas shows more of the shape characteristics displayed by canonical variate 2 than both Kent and Turgen. This suggests that while both Serektas

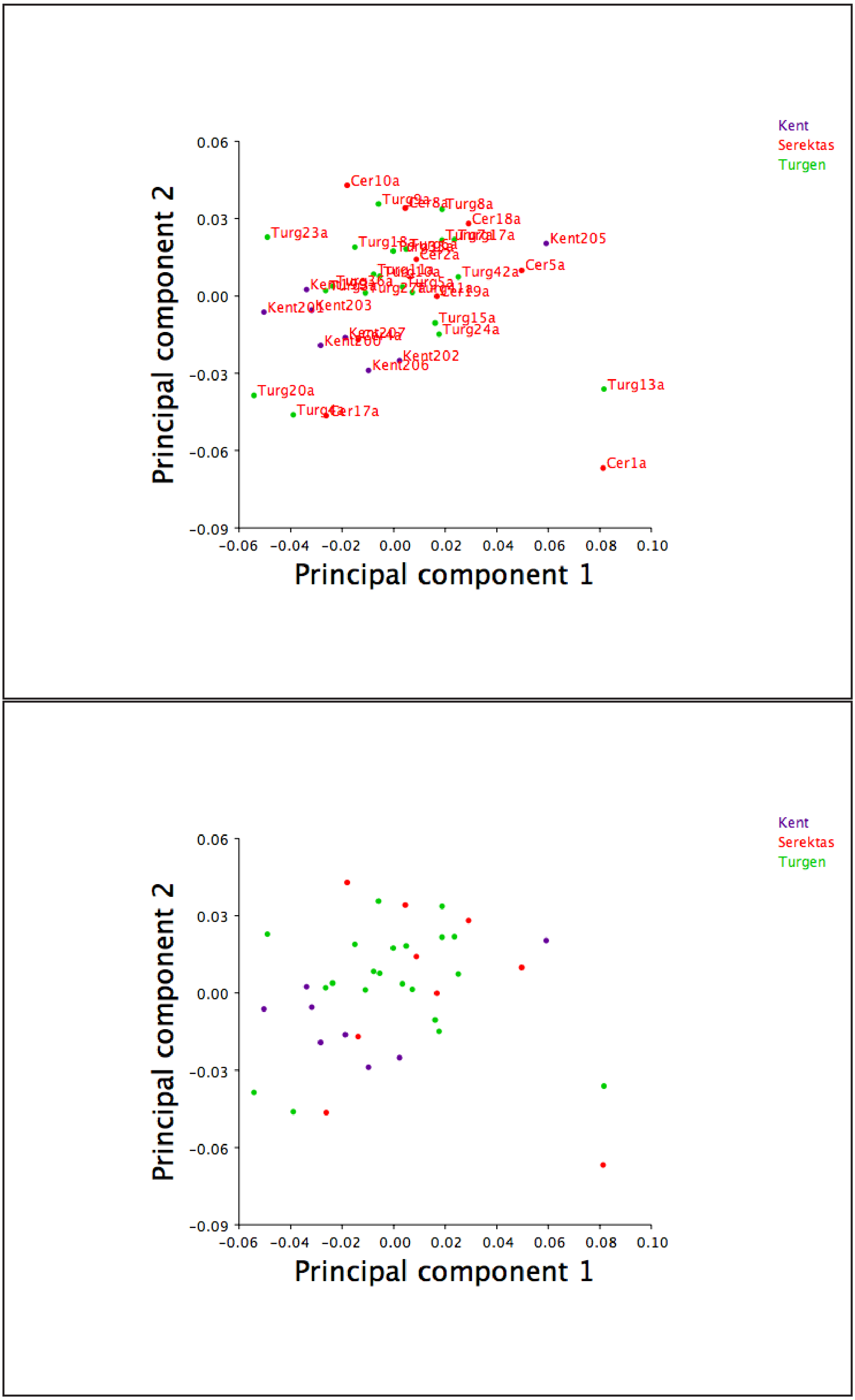


Figure 5.46: Principal Component Scores PC1 and PC2 plotted for all *Ovis aries* specimens from all sites with colour coding for sites with and without labels.

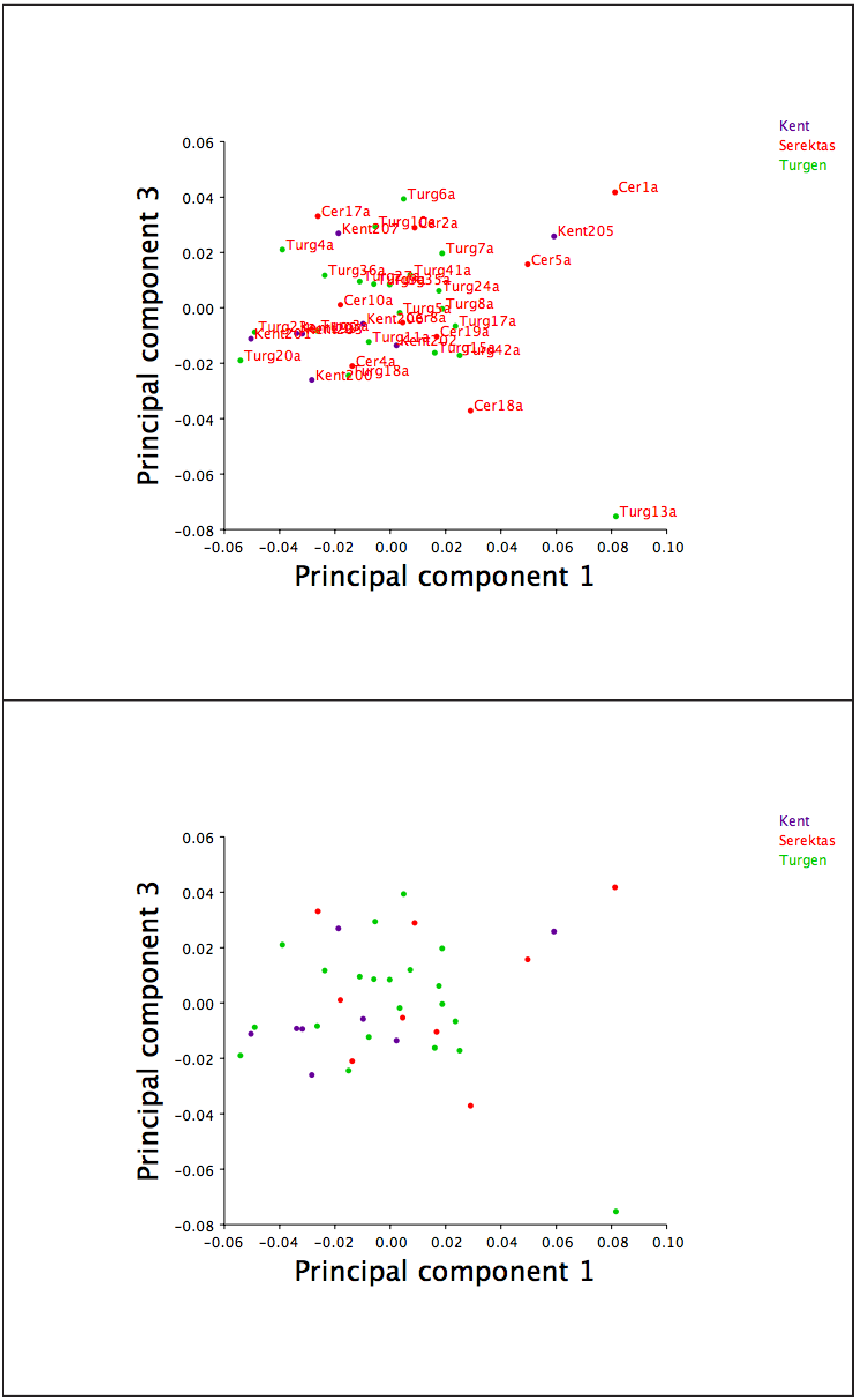


Figure 5.47: Principal Component Scores PC1 and PC3 plotted for all *Ovis aries* specimens from all sites with colour coding for sites with and without labels.

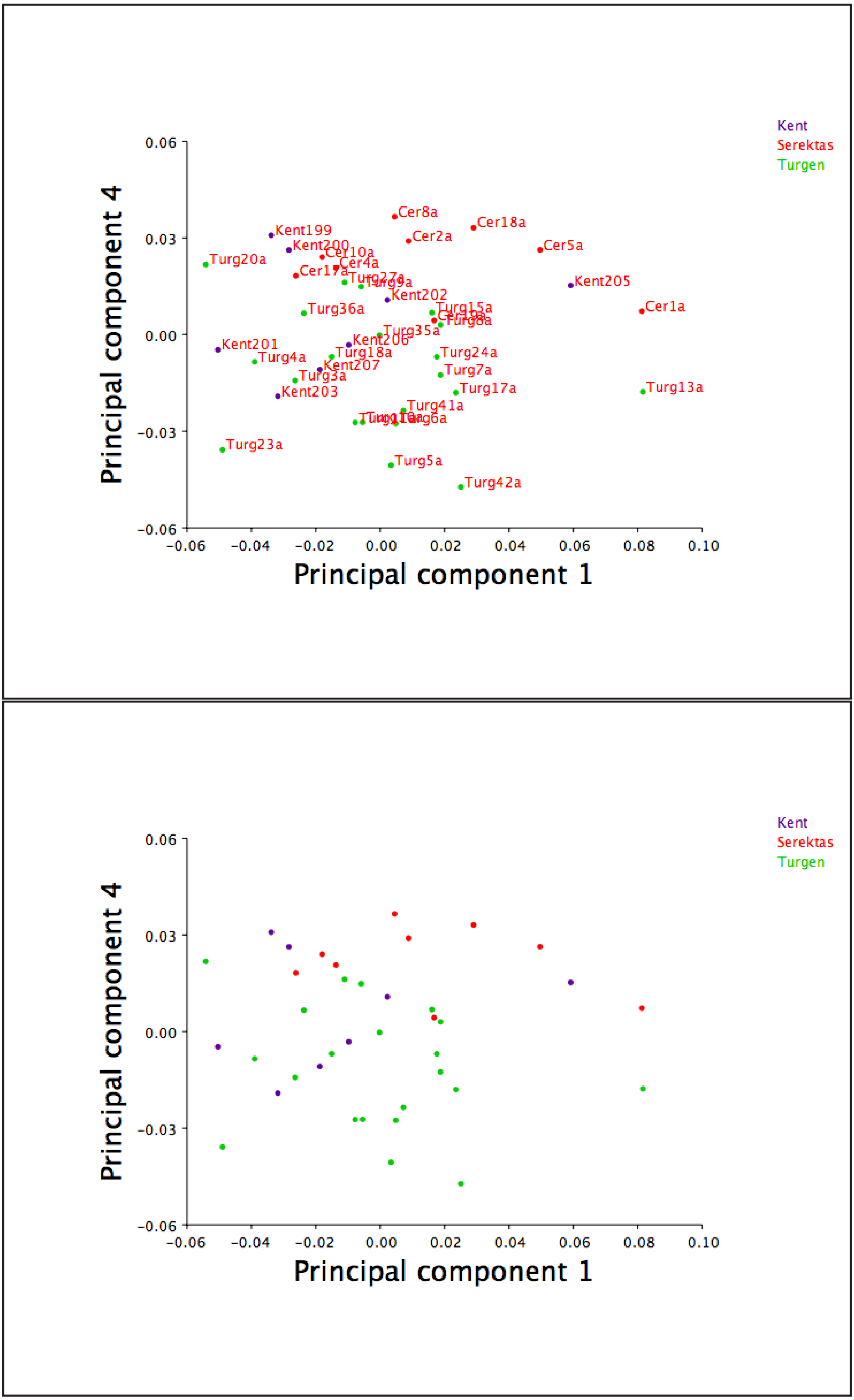


Figure 5.48: Principal Component Scores PC1 and PC4 plotted for all *Ovis aries* specimens from all sites with colour coding for sites with and without labels.

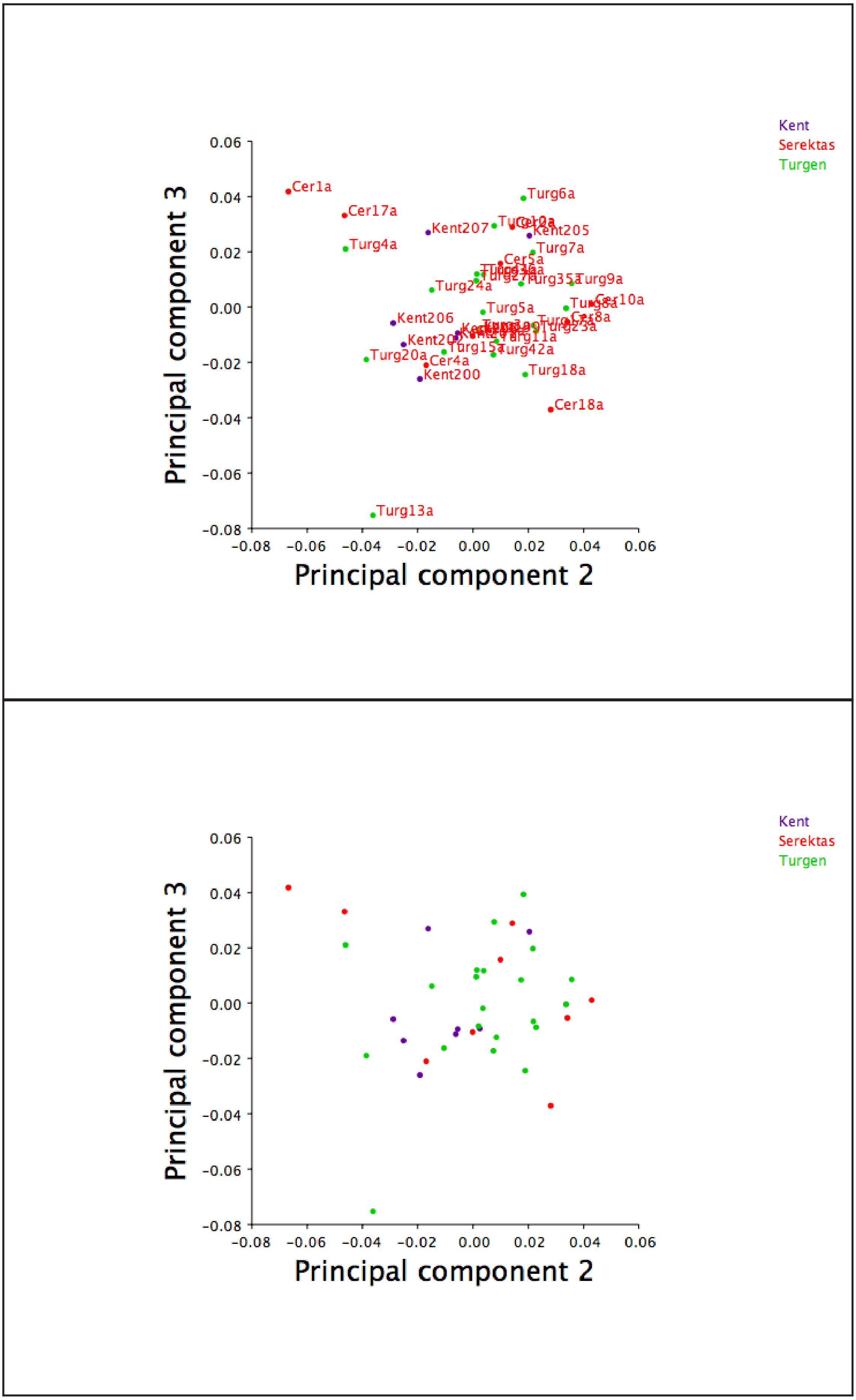


Figure 5.49: Principal Component Scores PC2 and PC3 plotted for all *Ovis aries* specimens from all sites with colour coding for sites with and without labels.

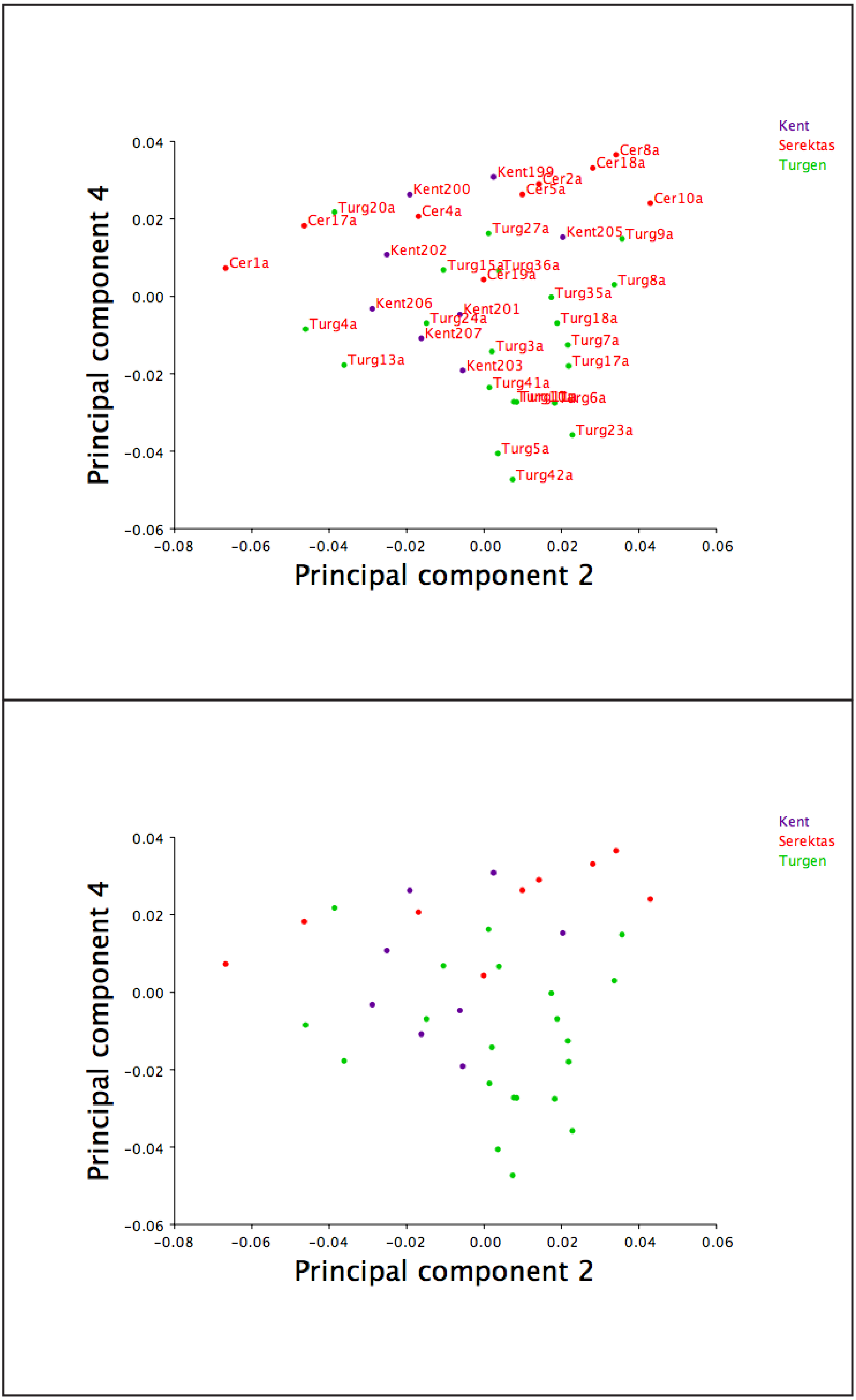


Figure 5.50: Principal Component Scores PC2 and PC4 plotted for all *Ovis aries* specimens from all sites with colour coding for sites with and without labels.

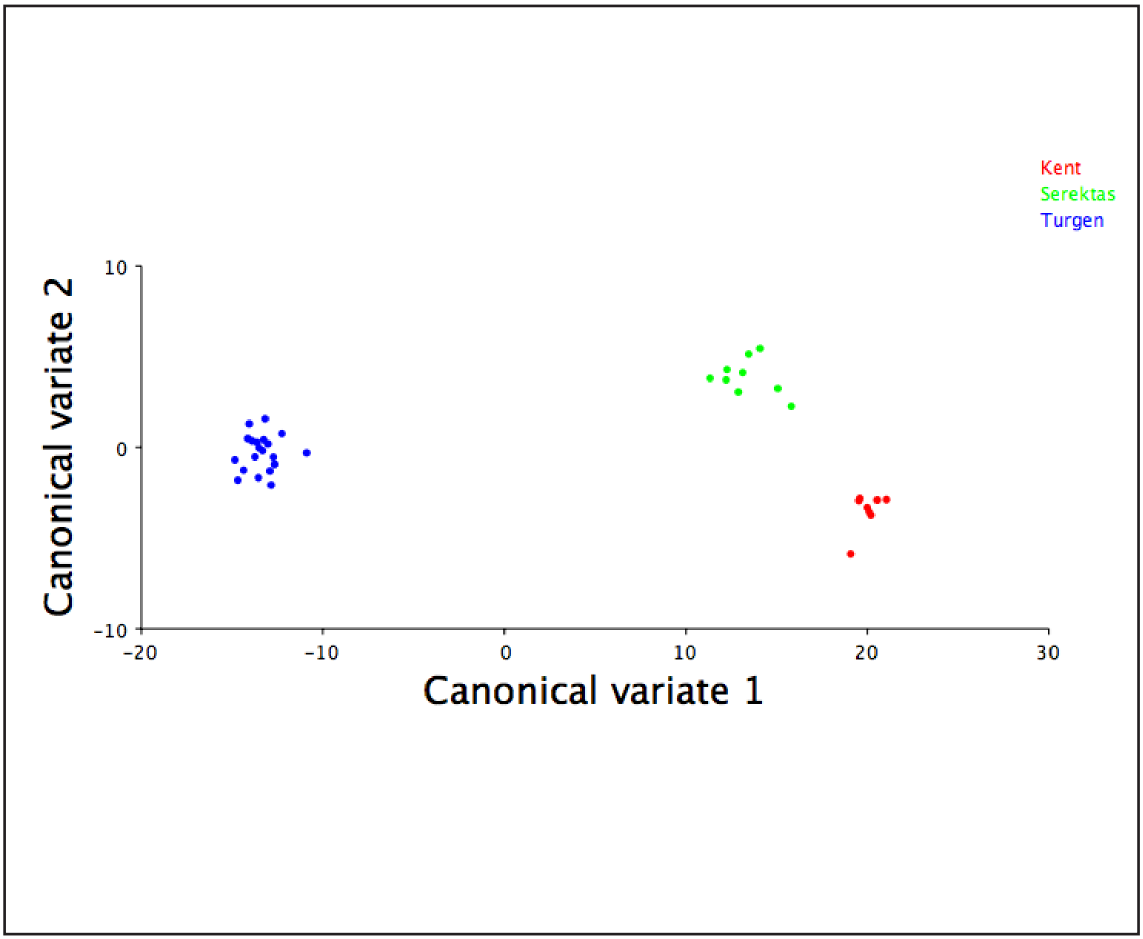


Figure 5.51:Canonical Variate 1 plotted against Canonical Variate 2 for all *Ovis aries* specimens from all sites.

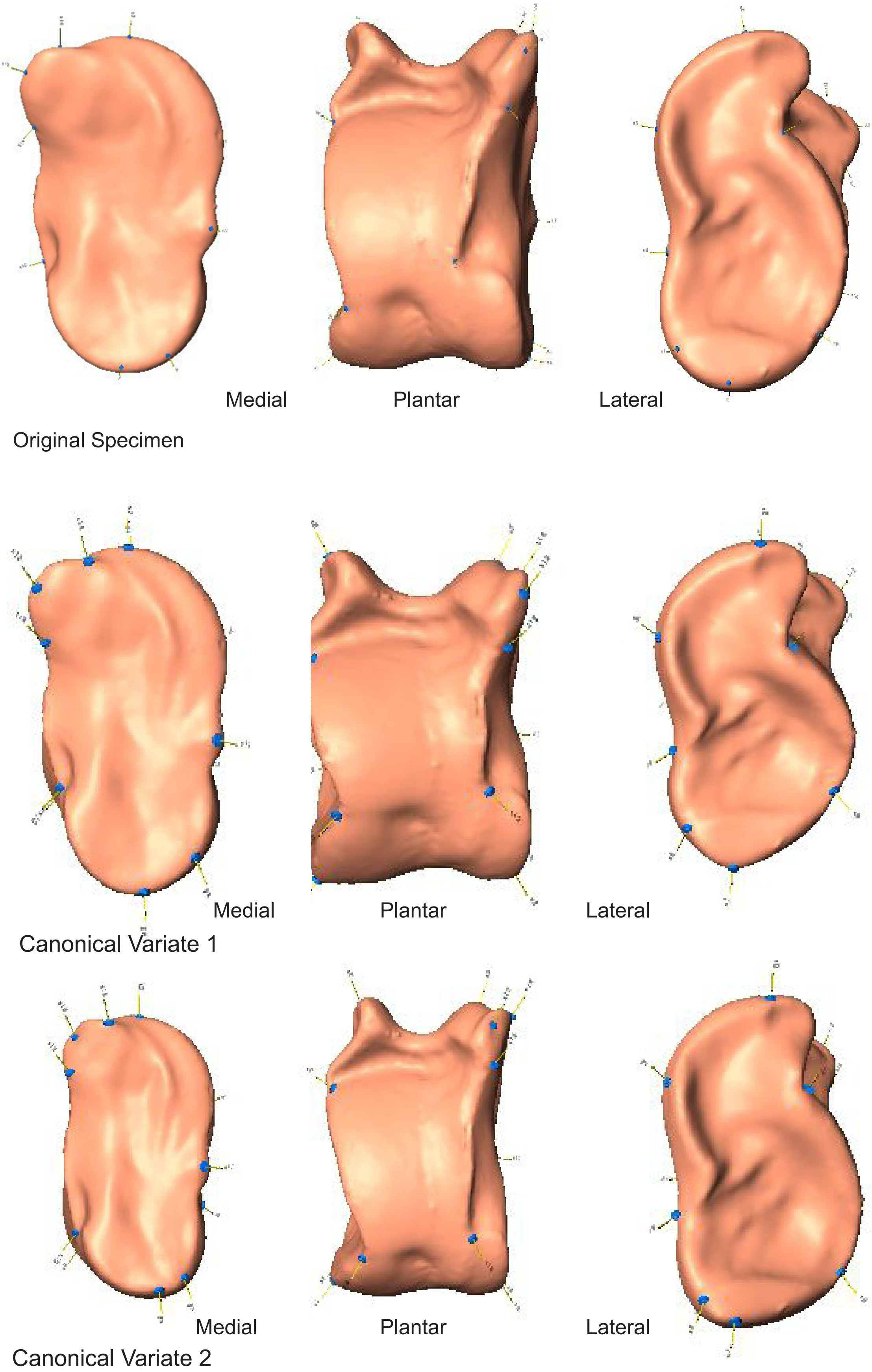


Figure 5.52: Canonical Variate 1 and 2 on left astragalus three dimensional model Cer19a, using a scale factor of 20 to enhance shape differences.

and Kent exhibited the shape changes such as the change in the orientation of the plantar ridge, only Serektas exhibited the shape changes such as the more actue angle between the proximal condyles.

5.5 Conclusion

Principal components analysis and canonical variate analysis are exploratory multivariate statistical techniques. The results displayed above are suggestive not only of a morphological difference between species, but also a clear morphological difference between *Ovis aries* specimens from different sites. The small sample sizes do not preclude the ability of these ordinance techniques to describe the shape differences and amount of variation both within and between sites. These statistical techniques were successful in revealing significant variation between sites which other methods, such as ratio indices, were unable to achieve.

Chapter 6: Discussion

Geometric morphometric methods and zooarchaeological anlayses have been employed to understand the degree of localisation of the pastoral subsistence economy of steppe peoples and the degree of animal exchange in the Late and Final Bronze Age. The complexity of the geometric morphometric results belies the descriptive nature of the shape difference that is depicted. While there are some considerations and caveats when using GMM (see below) it is clear that this descriptive analysis found clear evidence for the separation of sheep specimens from different sites.

The zooarchaeological analysis is discussed in full below. While the results suggest that the same domestic animals were exploited in nearly the same manner, there are differences that suggest localised subsistence strategies. In comparision with each other and other sites in the region, the specific nature of these subsistence strategies becomes clear in their ecological and archaeological context.

6.1 Geometric Morphometric Variation

Key to the interpretation of the geometric morphometric results is the statistical significance of the analysis. As explored in Chapter 4, principal component analysis (PCA) is a descriptive multivariate statistical method, which looks for variation among uncorrelated principal components. As PCA is descriptive, statistical significance is not a concern. PCA does not operate under the premise of a hypothesis and group membership is not predetermined. As shown in the analyses above (Chapter 5) there is some group membership revealed in the PCA analysis, such as between species, but a separation between specimens from sites is not clear.

Canonical variate analysis (CVA) is an analytical method to measure variation between groups based on a predetermined group membership. Unlike discriminant functions, which seek to produce rules to determine group membership, canonical variance is an ordinate function to display as much variation between the means of groups in as few dimensions as possible (Kovarovic *et al.* 2011). Specimens subjected to CVA are plotted in a shape space that is measured not by Procrustes distance, an absolute measurement, but rather by Mahalanobis distance, which measures distance relative to variation. Canonical variates are uncorrelated between and within groups and

Table 6.1: P-vales from CVA anlaysis of all specimens from all sites. Note that #1 refers to the specimen *C. hircus,* Kent.

P-values from permutation tests (10000 permutation rounds) for Mahalanobis distances among groups:					
	1	2	3	4	5
2. C. hircus, Serektas	<.0001				
3. C. hircus, Turgen	0.0001	0.0021			
4. O. aries, Kent	0.1162	0.0057	<.0001		
5. O. aries, Serektas	0.0419	0.0028	<.0001	<.0001	
6. O. aries, Turgen	0.0214	0.0007	<.0001	<.0001	<.0001

Table 6.2: P-vales from CVA Analysis of all *Ovis aries* specimens from all sites

P-values from permutation tests (10000 permutation rounds) for Mahalanobis distances among groups:		
	Kent	Serektas
Serektas	.0001	
Turgen	<.0001	<.0001

Table 6.3: P-vales from CVA Analysis of all *Capra hircus* specimens from all sites

P-values from permutation tests (10000 permutation rounds) for Mahalanobis distances among groups:		
	Kent	Serektas
Serektas	0.5581	
Turgen	0.9527	0.0111

ordered according to the amount of variation they display.

A permutation test with 1000 permutations based on the Mahalanobis distances between the groups results was performed alongside the CVA. The CVA returns p-values between pairs. The results of the CVA All Specimens All Sites returned a diverse set of p-values. *Capra hircus,* Kent is not listed as a row but instead forms the first comparative column as 1 (Table 6.1). The p-values returned for comparisions with this group were not significant in comparision with the *Ovis aries,* Kent specimens (p=0.0777), while a p-value of p ≤.05 was returned for the other *Ovis aries* specimens. A p-value of p ≤.05 was also returned in comparision with the *Capra hircus* specimens. As the group *C. hircus* is comprised of only one specimen, it is likely that this small sample size affected the p-values. All other p-values rejected a null hypothesis at p ≤.05, indicating that there are differences between sites and species. P-values for *O. aries* comparisions all returned p ≤.0001 indicating that there are significant differences between sheep specimens from different sites.

The results of the *Ovis aries* CVA reject the null hypothesis that there are no differences between groups as all pairs return a result of p <.0001 (Table 6.2). This supports the rejection of a null hypothesis for sheep results in the All Speciens All Site CVA. The variation between the morphology of the sheep astragalus clearly varies between sites in a significant manner (Figure 5.51).

The *Capra hircus* CVA returned only one p-value which rejected a null hypothesis for the Serektas/Turgen comparision. The p-values for the other comparisions were p > 0.5 indicating a failure to reject the null hypothesis, which indicates that there are no differences between the *Capra hircus* specimens from different sites (Table 6.3). These p-values for *Capra hircus* is not surprising given the low numbers of samples.

The p-values from the analysis of *Capra hircus* specimens suggest that the hypothesis that all goats are morphologically similar across sites cannot be rejected. The p-values returned from CVA All Sites All Species (Table 6.1) suggest that only *Capra hircus*, Kent is problematic and other issues with speciation (see chapter 5) indicate that the number of specimens for this species is not adequate to draw further conclusions.

6.1.1 Controlling for Biological Variables

A key aspect of conducting GMM on the ovicaprid astragalus was the elimination of biological variables which would cloud the detection of phenotypes. As discussed above (Chapter 3), phenotypic expression of morphological form can be blurred by ontogenetic variables. The effect of protein intake dramatically and permanently changes axial morphology in ovicaprids. Hence, it was necessary to select an element for which reduced protein would not have a noticeable effect. The research conducted by Popkin (*et al.* 2012) on flocks from a controlled feed experiment supported the choice of the astragalus. They found that the astragalus was not affected by reduced feed intake as much as other elements and only varied for females in breadth (Bd), while other elements were affected significantly, particularly for length. This is supported by earlier experimental work by Sykes (1983, Sykes and Poppi 1983).

Hormonal morphological change is also a variable that must be eliminated or controlled in the research design. Once again, the astragalus is an excellent choice to minimise morphological variation between the sexes. It is only variation in breadth (Bd) which distinguishes between sexes (Popkin *et al.* 2012, Davis 2000). Yet these same studies found that hormone driven morphological variation was significant between males, females, and castrates in nearly all elements except for the astragalus in which it was so minimal even in breadth as to preclude the use of this element to determine sex. Finally, continued bone growth post-fusion, which in long bones occurs around the diaphysis, has been recorded for the astragalus. Interestingly, this again varies only along breadth (Bd) (Popkin *et al.* 2012, Davis 2000). Indeed, the length of the astragalus (GLl) was found to be one of the most stable measurements and least subject to variation out of all of the post-cranial elements (Davis 2000). The breadth of the distal articulation appears to be the only variable measurement for age, sex and growth for the astragalus.

The landmarked equivalent of the Bd measurement, landmarks s4 and s5, varies along with other morphological features. In the PCA of *Ovis aries* for Kent, a reduction in the breadth of the distal articulation is clearly visible on PC1 and PC4. The specimen which exhibits the most positive association with these principal components is Kent206 (Figure 5.11). This reduction in breadth is actually a reduced prominence of the lateral distal articular surface towards the lateral side (Figure 5.7).

The PCA for all specimens for all sites appears to show an increase in the breadth of the distal articulation on PC 2 in relation to the rest of the specimen, which becomes more squat and square (Figure 5.22, 5.25, 5.26, 5.27). Specimens that exhibit positive values along PC2 are *Ovis aries* specimens, rather than a mixture of members from both species as would be suggested by previous research. Individual biological variation around the tuberculum talus, plantar articular surface, and plantar ridge appear to control for more variation than the breadth of the distal articulation. It is likely that as the Bd measurement is a linear measurement of size, such variation was removed from the landmark configuration during the generalised Procrustes analysis (GPA). Any small linear changes in size were less significant than other variation, for example, around the tuberculum talus. The minimisation of the variability of this feature due to the high variability of other features reduced age and sex related variability within the samples.

The elimination of ontogenetic variables, which includes adaptive remodelling, was accomplished by selecting the astragalus as the focus of study. The removal of size using GPA removed ontogenetic size variation along the breadth of the distal articulation. As these ontogenetic variables are controlled for and removed, biological variation is then largely phenotypic. Explanations for shape should be directed towards inherited genotypes.

6.1.2 Controlling for Speciation

The GMM results suggest that some of the qualitative characteristics for separating sheep and goat may be accurate for Central Asian specimens (see Chapter 5, Boessneck 1969, Fernandez 2001, Prummel and Frisch 1986, Zeder and Lapham 2010). While the variation of the tuberculum talus dominated shape change in all Principal Components in all analyses, it is interesting to note that a change in the orientation of the distal lateral articular surface was associated with PCs from the analysis of all specimens from all sites that controlled for species clustering (Figure 5.40). Boessneck (1969) and Prummel and Frisch (1986) suggest using this small qualitative characteristic to speciate the astragalus. In a review of qualitative characteristics, this characteristic was found to be the most reliable for species differentiation (Fernandez 2001). While the numbers of *Capra hircus* specimens are few, this suggests that removing the landmarks from the tuberculum talus and instead locating more landmarks around this articular surface may be a fruitful avenue of enquiry to resolve speciation issues in the future.

Traditional morphometrical methods were not as successful in separating *Ovis aries* and *Capra hircus.* Ratio methods which were effective in European contexts, such as those used by Davis (in press), were not successful for speciating the specimens in this study. As GMM quantitatively assesses small but significant amounts of variation that is difficult to measure using traditional data collection techniques, further evaluations of sheep and goat elements should prove useful in re-evaluating qualitative characteristics that differentiate these very similar species.

While the majority of the specimens analysed here are classified correctly, it is prudent to refrain from drawing conclusions about speciation based on morphological variation between the two species groups that have been identified in this study. As such, while results involving the combination of *Ovis aries* and *Capra hircus* are useful descriptive measures for directing future study they should not be taken as significant delineation of speciation. The very small number of *Capra hircus* specimens and the high p-values for *Capra hircus* CVA (Table 6.3) indicates that the morphological analyses have revealed largely descriptive features. Hence the *Capra hircus* specimens are not included for further analysis of the divergence of phenotypes.

6.1.3 Sheep Breed Interpretation

Variation between *Ovis aries* specimens that were originally identified in Tables 5.3, 5.6, and 5.9 show a high degree of morphological variability between individuals. Within site analyses showed no clear clustering. Principal component analysis of all *Ovis aries* specimens from all sites was suggestive of some site clustering, but this was not clear. The principal component analysis of sheep from all sites (Figure 5.41-5.45) shows that there is some group differentiation, particularly visible in Figure 5.43. PC1 pulls apart Kent and

Turgen, while Serektas trends across PC1 and is pulled out along PC4. Other principal component plots are not as clear. Principal Component 2 and 3 do not appear to control for shape variation that distinguishes between sites.

The canonical variate analysis of sheep specimens however shows clear separation between sheep specimens from all sites. CV1 clearly controls for variation between the specimens from Turgen (mountain) and Serektas and Kent (steppe and plain). Canonical variate 1 describes an extension of the plantar ridge along the parasagittal axis: the plantar articulation is squarer. The tuberculum talus changes only slightly from the origin specimens, largely in orientation as it meets the plantar ridge. The lateral distal side is more pointed while the proximal condyles have a shallower groove between them.

The variation between Serektas and Kent is controlled by CV2, and is not as great in magnitude as that between Turgen and the steppe and plain sites. CV2 controls for a more dramatic shape change than CV1. The plantar ridge extends further along proximal-dorsal axis, but the plantar articulation narrows into a trapezoid shape. The tuberculum talus reduces in prominence, which can be seen from the lateral view. The proximal articular groove is more acute and the proximal medial condyle is located closer to the midline that runs proximally-dorsally. This deeper grove in the proximal articulation would form a more tightly interlocking joint with restricted lateral twisting and movement. This restriction would be advantageous for cursorial animals which are adapted for movement over long distances (Plummer *et al.* 2008).

A more prominent plantar ridge, as expressed along CV1 and CV2 would also contribute to a more tightly locking joint. As the medial facet of the calcaneus slides along the plantar surface of the astragalus, it follows the prominence of the plantar ridge and is stopped at full extension by the tuberculum talus. The distal tibia lies on the proximal condyles and moves across these condyles dorsally towards the midline medial-laterally. The tuberculum talus acts as a stop for the distal tibia at the top of this motion, preventing overextension. Finally, the navicular-cuboid articulates with the distal articular surface. It is stopped the divot on the distal half of the plantar surface that only is sometimes present (Figure 5.55). Morphological characteristics on the plantar surface control for overextension, while characteristics on the dorsal surface control for flexion. Any reduction in the prominence of features such as the plantar ridge would result in a less stiff joint.

Similar morphological research into the shape change of bovid astragali across a variety of habitats in Africa showed an overall change in shape dependent upon habitat. Ecomorphological investigations into the efficacy of utilising postcranial elements to predict habitat for African bovids and antelope suggests that the astragalus is one of the most reliable predictors (DeGusta and Vrba 2005a). The astragalus has a 95% accuracy rate in determining palaeohabitat based upon a set of morphometric measures. Measurements used by DeGusta and Vrba (2005a) were similar to those defined by von den Driesch (1976) but do not correspond exactly; additional measurements are included and some are not perpendicular to the three main anatomical axes (DeGusta and Vrba 2003, Plummer *et al.* 2008).

A majority of the variation (74%) from a sample of African bovid species controlled for a more acute angle between the proximal articular condyles for open habitat species. This deeper groove would support a more tightly locked joint with less lateral movement (Plummer *et al.* 2008). CV2 in this study controls for a deeper grove as well. Specimens from the semi-arid site of Serektas trend along this CV positively.

Recent research by Curran (2012) has applied GMM to study the small amount of shape variation on the cervid calcaneus in closed and open habitats from a variety of Pleistocene sites across Eurasia. Once size was excluded, shape was proven to be a significant indicator of palaeohabitat for the calcaneus (Curran 2012) and astragalus (Curran 2013, Thomson and Curran 2013). Using similar landmark based GMM methods to this study, Curran found that cervids from closed habitats exhibited morphological features on the calcaneus that changed the physics of the lever in the ankle joint. The calcaneus from closed habitat cervids had inferiorly oriented cubonavicular articulations, which indicated that the calcaneus was more oblique while the ankle joint was in rest, which provided a slower but more powerful movement, ideal for rapid-changes in direction and bounding leaps. Cervids from open environments possess calcanei with a more vertical resting position due to an anteriorly oriented cubionavicular articulation, which is more responsive, but ultimately less powerful.

The sustentaculum talus of the calcaneus slides along the plantar articular surface of the astragalus. The medial edge of this talus is guided by the plantar ridge on the astragalus. The sustentaculum talus is more trapezoidal in shape from cervids that live in closed habitats than in open specimens, which are triangular. The increased interface with the astragalus' plantar surface would allow for more rotation between the astragalus and calcaneus without risk of dislocation. This results in more flexibility in the joint, ideal for moving through complex environments such as forests in Curran's work (2012, 2013) or vertiginous environments in this case.

The work by Curran (2012, 2013) supports the selection of sites from multiple ecozones within the steppe along a north to south gradient. The vertiginous environment of Turgen is very different from the flat sites of Kent and Serektas in the semi-arid and alluvial plain of the Semirech'ye, respectively. The research on significant shape variation in bones which guide cursorial movement clearly demonstrate that significant inherited differences between populations from the same species in different environments is plausible and likely.

The palimpsest nature of zooarchaeological assemblages, as animal bones remains from hundreds of years are compressed into one site is an advantage in this situation. Any individuals that were not native to the region would clearly be visible as outliers against the mean shape for each site. The introduction of breeding animals, such as rams with different phenotypes would change the mean shape, resulting in a large amount of variance within a site. The amount of this within group variance would be clearly visible in the CVA analysis or even as a cluster within the PCA. Such within group clusters are clearly absent in this study.

The flexibility of the ankle joint as evidenced by the astragalus morphology, supports an interpretation of phenotypic expression of traits that are favoured by an ecozone. As this research study excluded ontogenetic variation, including adaptive remodeling, this specific astragalus morphotype is inherited. The significant difference between astragalus morphotypes confirms a reading of flock isolation and different landraces. Phenotypic traits that are caused by attrition are significant and there is no overlap of morphotypes between sites. This supports an interpretation of little sheep exchange across eastern Kazakhstan in the Late and Final Bronze Age as well as negates assumptions about long distance migrations of animals alongside material culture.

6.1.4 Conclusion

As an ordination analysis, the CVA reveals that *Ovis aries* specimens from different sites, located in the different ecozones, had statistically significant morphological differences in the astragalus. These differences relate to the stability of the joint, with positive expressions along both canonical variates controlling for a stiffer, more efficient ankle joint. The two sites which have positive values along these canonical variates are sites which are located in flatter, more arid ecozones than the lush foothills of Turgen. As biological ontogenetic influences have been excluded, this morphological difference must be due to phenotypic expression of inherited traits. It appears that attrition of individuals from each of these sites was driving selection for morphology which was advantageous for each ecozone, resulting in separate landraces at each site.

6.2 Pastoral Subsistence Economies

All sites in this study reveal similar percentages of the same suite of domesticated animals (Chapter 3). Variation between the proportions of this group of *Bos taurus, Equus caballus,* and ovicaprids reveal trends that correlate with precipiation rates and material culture. Exploitation of animals besides the main three domesticates reveal interesting details about each site which further refine the specificity of each subsistance strategy.

6.5.1 Kent Interpretation

The subsistence economy at Kent was based upon the meat of ovicaprids and the secondary products of cattle and horses. The cull profiles for ovicaprids clearly show the exploitation of these animals as meat (Figure 3.16), while the cull profiles for cattle and horse indicate an emphasis on secondary products

(Figure 3.22, 3.26)

Wild animals were exploited, from both the surrounding light woodland (*Cervus elaphus, Capreolus pygargus, Alces alces, Castor* sp., *Sciuridae* sp.) and from the steppe (*Saiga tartarica, Equus hemionus,* Gazelle, *Marmot* spp.). Marmots prefer open habitats such as steppes and forest edges to locate their family burrows and are active only during the long hours of daylight in the summer, hibernating for up to nine months to avoid harsh weather (Nowak 1999).

In addition to being hunted for their thick fur pelts, marmots are consumed by pastoralists in Mongolia as a delicacy called *bodog*. The marmot is roasted simultaneously from the interior using hot rocks and from the exterior using a blowtorch or a spit to singe off fur and the associated bubonic plague carrying fleas (Clark, pers. comm.; Winston 2006). Marmots are hunted in the autumn, just before the animals enter hibernation before the first snows (Winston 2006).

At Kent, the first snows fall in October, and cover the ground until the end of April, giving the marmot nearly six active months. Therefore, it is likely that the marmots in this assemblage were hunted between April and October. It is conceivable that the Mongolian tradition of hunting before the first snows for the most succulent specimens was practiced at Kent, when the marmot would have had a thick winter pelt and high percentage of fat.

The marmot specimens from Kent are likely *Marmota baibacina*, which is specifically located in eastern Kazakhstan, southwestern Siberia, and Mongolia. This species designation is contested and prior to 1993 was a subspecies of the *Marmota bobek,* which today is limited to the western steppe in the Ukraine. In this prior designation*, M. bobek* also included marmots from two other subspecies (*M. himalayana, M. sibirica*) which includes specimens from northern India, Tibet, Nepal, Mongolia, and western China (Nowak 1999). Earlier zooarchaeological reports often identify marmot remains as the *Marmota* *bobek* but it is likely that these designations need reviewing in light of the reclassification of this species.

Despite this very wide range of wild animals from both sylvan and steppe environments, the majority of animals consumed at Kent were domesticated. Wild animals comprise less than 2% of the total NISP from Kent. As not all animal bone had contextual information that gave depth below surface and some were labelled by feature alone and lacked level, the NISP calculation for each level is less than the NISP for the entire assemblage (Table 6.5). The variation of wild animal exploitation at Kent varies through different levels. The percentage of wild animal exploitation decreases slightly at levels 3 and 4 after an increase at level 5. For all levels, the wild animal exploitation is low, and too few animals are deposited to indicate that these wild specimens could have supported the population at Kent. Earlier excavations at Kent have found a similar percentage of wild animal exploitation (3%, Outram and Kasparov, 2007). None of these levels have been dates or further assessed for stratigraphic relationships. Therefore, this assessment is descriptive of the overall diachronic trends but cannot be tied to specific periods of occupation.

Zooarchaeological studies of animal bone from earlier excavations at Kent (Outram and Kasparov 2007, Outram *et al*. 2012) utilised metric measurements of cattle metapodia. Using this technique, it was determined that there was a mix of aurochs and domestic cattle at the site. Additionally, the ratio of female to male cattle was 2.9 to 1.9, suggestive of a dairy herd. Outram *et al.* (2012) found similar cull patterns for horse and ovicaprids as those presented here, and suggested that ovicaprids were exploited for meat, while horses were utilised for transportation. Lipid residue analyses of ceramic fragments from Kent further support the interpretation of cattle being exploited extensively for dairy products. The majority of ceramic fragments studied from Kent contained ruminant dairy and adipose fat (Outram *et al.* 2012). These earlier reports

Table 6.5: Percentage of wild animals by level (NISP), Kent.

Percentage of Wild Animals by Level								
	1 (0-20cm)	2 (20-40cm)	3 (40-60cm)	4 (60-80cm)	5 (80-100cm)	6 (100-120cm)	7 (120-140cm)	TOTAL
TOTAL NISP by Level (Wild + Domestic)	697	1043	802	343	271	494	40	3690
% Wild by Level	2.58%	1.92%	0.75%	0.87%	3.32%	1.62%	2.50%	1.76%

found higher levels of cattle and horse remains. As this report is limited to one complex, as opposed to an amalgamation of excavation across the entire site, it is likely that earlier work in an average across the site while these data are specific to the building and platform of Excavation 11 (Figure 1.2).

Kuzmina (2008) notes that all Andronovo sites had a small amount of camel present. She postulates that this was likely for transportation. The tradition of camel clearly continues at Kent, as camel is present although in small amounts. Horses, also indicative of mobility, are also present at Kent, with a NISP of 14.46%. Taphonomic indicators, specifically fragmentation type, suggest that marrow may have been exploited (Section 3.3.4).

The evidence for metallurgy, combined with the intensity of settlement, supports the interpretation of a regional centre, if not a proto-urban site (Varfolomeev, pers. comm.). The consumption of many prime age ovicaprids would indicate consumption patterns of an urban population. In contrast, animals which had secondary value, such as horses and cattle, were consumed usually after they had reached full maturity, and likely after they had contributed towards a secondary product economy including dairying and riding.

6.5.2.Serektas Interpretation

The high percentage of equids in the NISP of Serektas is suggestive of high-status consumption patterns. The presence of 6% of *Equus hemionus* was most likely as a horse replacement- as a smaller version of a horse, when no horse was forthcoming or available. While it is clear that domesticated horse was the preferred food, *Equus hemionus* and small amounts of deer and gazelle in conjunction with the usual ovicaprids and cattle were also eaten.

The exploitation of the two other main domesticates, the ovicaprids and cattle, indicate that while they were not consumed in as large numbers as at other sites, their consumption formed the basis of the subsistence economy. The survivorship graphs support an interpretation of secondary products utilisation for cattle and ovicaprids. Small sample sizes and taphonomic issues have created some problems with these survivorship graphs (Section 3.4.4). In the final age stage some members of the population appear to have returned however, this increase in survival at this final stage is an artefact of the small sample size. This issue does not invalidate the usefulness of these particular cull profiles, but should be considered in their interpretation. Nearly 67% of ovicaprids survived past 36 months of age while 75% of cattle survived past 48 months (Figure 3.24, 3.16). It is clear that older animals from both of these species were consumed, as opposed to younger individuals from the equid populations.

The 6% of *Equus hemionus* in the assemblage at Serektas is unusual and deserves further investigation. A look into the elements that are present indicates a dominance of bones below the ankles. Interestingly, there are no bones from the rump or shoulder (pelvis or scapula) or from the head or jaw

(Figure 3.20). A mortality profile of the few elements which fuse indicate a small dip in survivorship between 19 and 24 months but it appears that most animals were consumed after full fusion at 42 months (Figure 3.21). . One unfused tibia skews the 19 to 24 month survival range to 50%. The amount of bones (62) is small, and this does create sampling problems, as seen in the jump in the final fusion stage of the survivorship graph.

Although the data from the survivorship graph for *Equus hemionus* does not support an interpretation for secondary product exploitation, it does not refute it. The skeletal part abundance could represent transportation of limbs from hunting as girdle bones are not present or it could be evidence of density-mediate attrition.

The wild kulan (*Equus hemionus kulan*) is native to Kazakhstan and graze on flat ground (Nowak 1999). Wild kulan populations have been known to compete with domesticated stock for pastoral resources. Herds of hundreds were known to congregate after the autumn rains, but due to hunting, the Central Asian wild population is now reduced to 1500 individuals in a nature reserve in Turkmenistan (Feh *et al.* 2002).

There is no evidence to suggest the domestication of this equid species had occurred in the Late and Final Bronze Age on the steppe. Modern domesticated donkeys all originate from the African wild ass, *Equus africanus asinus*. Domesticated donkeys have been found in Egypt and Mesopotamia dating back to 3000 BCE (Beja-Pereira *et al.* 2004, Kimura *et al.* 2011, 2013, Rossel *et al.* 2008, Nowak 1999). Domestic donkeys have been found in Syria, Iran, and Iraq dating from 2800-2100 BCE (Rossel *et al.* 2008). DNA work indicates that all modern donkeys originate from African stock. Hence, this research suggests that there was no separate domestication event in Central Asia, and there are no domestic descendants of the kulan.

As few other *E. hemionus* remains are found at other Bronze Age sites in Kazakhstan, and there is no positive supporting evidence for the domestic use of these animals, it is likely that these bones are from wild kulan which were hunted. It may well be that there is preferential transport of limbs, as evidenced by lack of scapulae and pelves. The largely adult composition suggests selection for mature individuals.

Wild kulan can gather in larger herds at specific times of the year, but they are not herd animals. Their social structure is fluid, unlike horses. They may form harems or bachelor groups but have been observed living in small mixed groups or even as solitary individuals (Nowak 1999). Hence, it is unclear what type of hunting strategy would have been utilised.

What is clear is that horse consumption is a known marker of high-status sites (Anthony 2007), as is clear from the presence of equid lipids in funerary ceramics associated with kurgan burials that contain high-status material culture (Outram *et al.* 2011). Of the *E. hemionus* remains at Serektas, 56% of the elements were dry fragmented, while only 32% had helical fractures which are evidence of marrow exploitation. This does not seem indicative of marrow extraction. When only meat bearing and marrow rich long bones are analysed, 88% have helical fractures and only 4% have dry fractures (the remaining 8% had modern damage). This suggests these culturally significant elements were processed for marrow.

The presence of equid remains in funerary contexts diminishes through the Andronovo as does the presence of equid remains at settlement sites. Yet the decrease in horse remains does not negate the relative proportions of domesticate consumption at funerary and settlement sites (Outram *et al.* 2011). Serektas is unusual as a Late and Final Bronze Age site with a high concentration of equids, suggesting an association with the local ritual site of Tamgaly, located only 24 kilometres to the southwest. Tamgaly has been classified by UNESCO as a ritual and sacred archaeological landscape that includes the petroglyphs along the Tamgaly River, as well as a hinterland of settlements and burial mounds (Davis-Kimball 2000, Frachetti 2009, Rogozhinskii 1999). Frachetti suggests that as Tamgaly is located in the semi-arid steppe, which would have been untenable for year-round pastoralism, that it was instead occupied or visited only at particular times of the year for celebrations or rituals (Frachetti 2008). It may be possible that the influence of Tamgaly would have reached beyond its' small hinterland to other settlements located on the other watercourses in this region.

A single rider on a fresh horse can cover up to approximately 40 kilometres in the spring, and down to 12 kilometres in the dark and dangerous conditions in winter (Cope 2013). Watering places were historically located approximately every 20 kilometres along migratory routes (Cope 2013). Hence Serektas, located near a seasonal water source and only a good half-day ride from Tamgaly would be an ideal stopping point to and from this ritual space. As people travelled to or from Tamgaly, they may have interacted with the local population at Serektas, and may well have participated in host/guest feasts which could have centred around the consumption of high value animals such as horse and kulan.

Serektas was a small settlement that would have seen many travellers, whether as a stopping place for a large encampment on migration, or for individuals travelling back and forth. Ritual feasts of wild or domesticated equids would have formed a critical source of meat that was also appropriate to the ritualised landscape of this region.

6.5.3 Turgen Interpretation

Turgen is just one of a number of settlements found at various altitudes throughout the foothills of the Tien Shan. These settlements were inhabited seasonally as local people practiced vertical transhumance. As they followed their animals to green summer pastures in the mountains, they would stop at various encampments up and down ravines. Turgen would be at its best for pasturage during the high summer and as such was likely as the terminus of vertical transhumance, as evidenced by the presence of the highest set of kurgans in the ravine nearby (Goriachev 2004).

In comparison with other sites, Turgen presents similar animal bone proportions to the Final Bronze Age site of Kent as well as other sites in central Kazakhstan such as Temirkash and Alat (see below). This is indicative of a pattern of pastoralism in which ovicaprids played a very large role. Nearly a third of the domestic animal remains at Turgen are from adult cattle, animals which would have provided a large amount of meat once slaughtered. While there are no data to indicate whether these are male or female, the cull pattern suggests that these were fully adult animals. It is likely that they were exploited for secondary products such as milk as was practised at numerous other sites across the steppe (Outram *et al.* 2012), but this is not conclusive due to the likely transhumant nature of the people settled at Turgen. Animals from different fusion stages may have been slaughtered at settlements located at different altitudes. Therefore, the survivorship curves only represent the consumption of animals for part of the year and hence are not reliable for identifying secondary product exploitation.

The majority of domestic animals are Turgen are ovicaprids. From the speciated ovicaprid remains, it is clear that *Ovis aries* dominates and there are few *Capra hircus* specimens. The combined ovicaprids account for over half of the NISP at Turgen (Table 3.16). The survivorship data from bone fusion indicates that few older animals were consumed at Turgen. Instead, most of the ovicaprid specimens are from young animals just over a year in age (Figure 3.35).

As ovicaprids typically give birth between March and April, a slaughter of animals which had just passed a year in age supports the idea that Turgen was used as a stopping place for pasture in May and June. Seasonal celebrations would like have not taken place at Turgen. Ethnohistorical evidence suggests that celebrations took place before movement to the summer pastures (Shayakhmetov 2006). It is unclear why there is such a large drop in survival after one year of age. To overwinter a young animal is difficult – requiring cut fodder and shelter. It would make more economic sense to slaughter young animals in the autumn, at approximately six to eight months of age. The lack of younger animals at Turgen could be attributed to taphonomy as new lambs would be recently born during peak grazing season.. As Turgen is at such a high altitude it was likely not inhabited in the autumn or winter and was used as a summer terminus and consumption of year old animals represents meat consumption. Any secondary product exploitation patterns in the survivorship pattern are not evident, likely as older specimens were not consumed at Turgen except in cases of culling or need.

It is clear that ovicaprids were utilised as a source of meat at Turgen. The horses and cattle specimens at Turgen are from older individuals that were likely prized for their secondary products such as riding and milk. The presence of grinding stones indicates that grains were also a part of the subsistence at Turgen, as well as the occasional opportunistic hunting of *Cervus elaphus* (4.4% of NISP).

The large mix of ceramic and metalworking traditions that are in evidence in the ravines that line the eastern Tien Shan and indeed, most of the Semirech'ye region, have led to the inference of high degrees of mobility. As many of the ceramic forms are similar to those from the eastern steppe, it has been assumed that the people of the Tien Shan were in active contact with people from the eastern steppe or may have even migrated from that region (Kuzmina 2008). However, the lack of a unique funerary signature and zooarchaeological signature of these foothill people at any cemeteries or settlements on the semi-arid steppe between these two regions confounds the notion of regular long-distance migration or mobility of entire family groups or populations. Indeed, the specificity of the funerary and zooarchaeological assemblage that seems to follow ravines up into the higher mountain pastures suggests a transcribed migratory pathway that was dependent upon altitude, rather than distance. Furthermore, one of the only passes through the Altai and Tien Shan mountain ranges to the western Chinese steppe is a route which follows the foothills of the Tien Shan east through the Ili river canyons. Historical evidence from the Iron Age (c 200 BC) (Barfield 1989) suggests that it was through this corridor that Chinese ambassadors trekked to negotiate treaties with the people of the Semirech'ye (Book of Han in Torday 1997). The proximity of this easy route was likely a major contributory factor towards the variety of material culture that these people possessed rather than long distance migration patterns.

6.5.4 Regional Interpretation

For these three sites, it is clear that secondary products such as milk and wool/ hair would have been amply provided by the ovicaprids and cattle, with the addition of horses for herding and transportation purposes. The presence of camel at all of these sites is a sign of the need for additional transportation provision regardless of the degree of mobility of their subsistence pattern (Table 3.7, 3.12, 3.16).

The presence of small amounts of camel is consistent with findings at Andronovo sites (Koryakova and Hanks 2006, Kuzmina 2008). Kuzmina postulates that these small numbers of camel were from a few individuals that were kept at each site for long-distance transportation needs. Ethnographically, camel pastoralists have been able to exploit the camel for all types of secondary products, including milk and hair. In very arid regions, such as western Kazakhstan near the Aral Sea in the Betpak Dala (the Starving Steppe) and in Mongolia near the edge of the Gobi desert, raising camels, often in combination with sheep and goats, has proven to be an effective means of subsistence. Camel in the semi-arid steppe and Semirech'ye sites in such small numbers clearly indicate that these animals were valuable in small numbers but not the foundation of the subsistence economy as was the case to the east.

Trimodal plots of the percentages of the three main domesticated animals reveal interesting trends. The sites included on these plots include sites from Outram *et al.* (2012) and earlier work by the author (Haruda 2007). Cultural affiliations range from the Andronovo culture of the Middle Bronze Age (2400-1700 BCE) through to the early Iron Age (200 BCE- 400 CE). The sites are also located in a wide swathe from the forest-steppe of northern Kazakhstan and southern Siberia, through the semi-arid steppe of central Kazakhstan, to the alluvial plain of the Semirech'ye region in southeastern Kazakhstan.

When the sites are colour coded by ecozone (Figure 6.3) the forest-steppe sites cluster together with high levels of cattle. These findings, noted in Outram *et al.* (2012) as well as Bendrey (2011a) correlate with the higher amounts of rainfall in the forest-steppe zone. The semi-arid sites and the Semirech'ye sites have a much lower percentage of cattle and group together. Of interest are the sites which have a high percentage of horse. Studies of lipids in funerary and ceramic assemblages found a higher percentage of horse lipids in funerary ceramics rather than in settlement ceramics (Outram *et al.* 2011). Historic ethnographic evidence has shown the symbolic location of the horse in steppe cultures and the high importance attached to the consumption of this animal (Koryakova and Hanks 2006). The sites of Dongal and Bugully are interpreted as high-status sites as horse lipid residues and the proportion of horse are both high (Outram *et al.* 2011, Figure 6.3). Serektas can be included with these high-status sites. Even without the contribution of wild equids, Serektas groups with Dongal and Bugully on the trimodal graph and shows a high level of horse remains (Figure 6.3, 6.4). It is clear that the consumption of a high level of equids makes these sites unique and trend apart from their ecozone and material cultural cohort.

Kent New refers to the zooarchaeological assemblage analysed for this research which is from an excavation of a platform and building at the centre of the site. Kent Old is a collection of zooarchaeological material from across the site, which was analysed and published in abbreviated form (Outram and Kasparov 2007, Outram *et al.* 2012). The results were broadly comparable, but there are higher proportions of cattle and horse in Kent Old. The semi-arid steppe sites of Kent, Temirkash, Alat, and Karalinskoe roughly group together, although they are interspersed by the Semirech'ye sites of Turgen and Tuzusai/Taldy-Bulak 2.

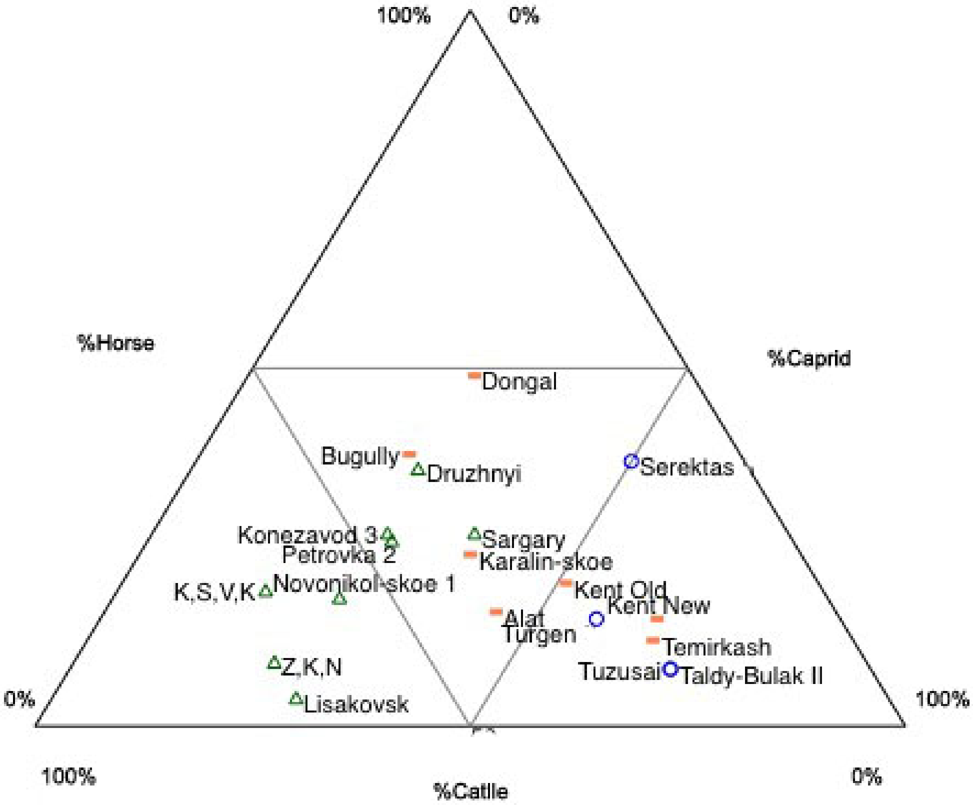


Figure 6.3: Trimodal distribution of the three main domesticate species for sites from Outram *et al.* 2012 and this study. Colour coded according to ecozone.. Green triangle is forest-steppe, orange dash is semi-arid steppe, and blue circle is Semirech'ye.

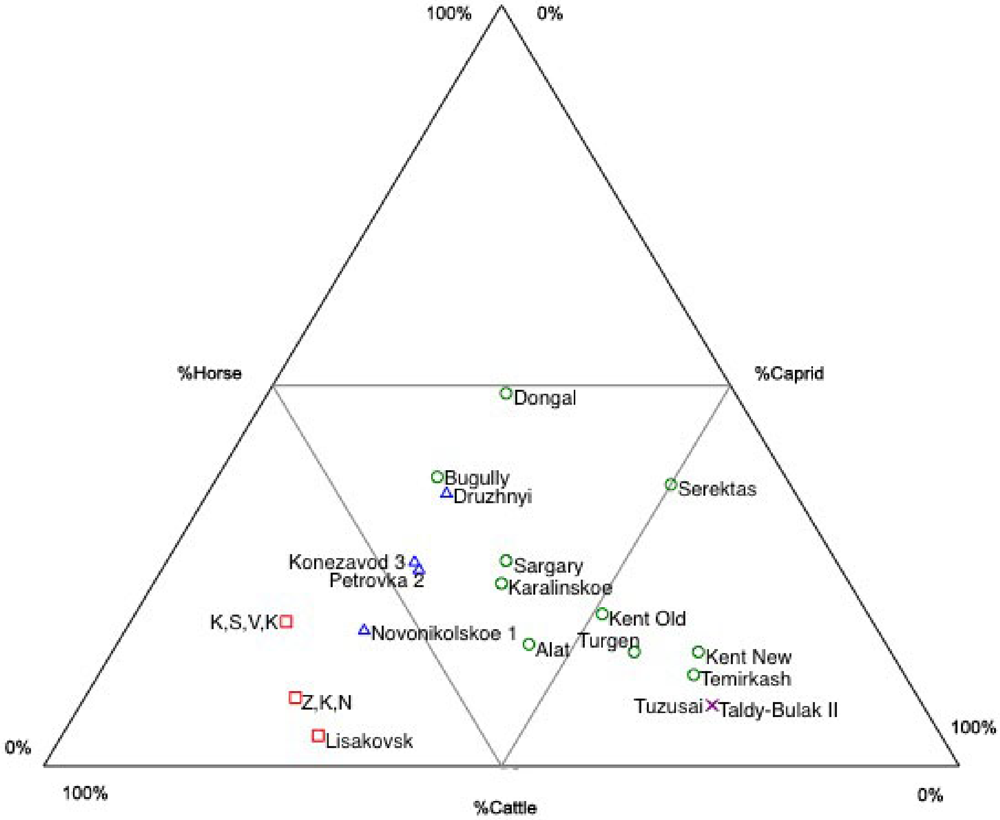


Figure 6.4: Trimodal distribution of the three main domesticate species for sites from Outram *et al.* 2012 and this study. Colour coded according to culture and era. Andronovo sites are red squares, Androvo-Late Bronze Age sites are blue triangles, Final Bronze Age are green circles and Iron Ages sites are purple crosses.

When the sites are coloured according to archaeological cultures, there are similar trends. Many of the forest-steppe sites are also from the Middle Bronze Age Andronovo and transition into the Final Bronze Age. There is an exception: Sargary is located in the forest steppe, but plots not with sites from the forest-steppe ecozones but instead with sites from the Final Bronze Age. Despite the sample bias in the study which has examined largely Andronovo sites nearly exclusively in the forest-steppe, animal proportions do appear to be influenced by culture as well as ecozones.

There is a reduction in the proportion of cattle through the end of the Bronze Age towards the Iron Age. Turgen is located a thousand meters above and 40 kilometres from the Iron Age sites of Tuzusai and Taldy-Bulak 2 in the Semirech'ye. These sites have clearly different proportions of domesticated animals even though they are located in the same ecozone. It is clear that domestic animal proportions are influenced by archaeological culture as well as ecozones in this instance. Likewise, Sargary trends closer to its Final Bronze Age contemporaries rather than with other sites from the Forest-Steppe.

The ceramics from Turgen are similar to the ceramic tradition from Dongal (Goriachev 2004) and it is interesting to note that while the percentage of cattle is very similar between these two sites, the exploitation of horses and ovicaprids are significantly different. The high proportion of horse at Dongal clearly marks it out as a site utilising a different subsistence strategy or consumption pattern. The percentages of cattle however, at 25% and 28% respectively, are remarkably similar despite a difference in precipitation between the two sites. This would suggest that cultural ties do have an influence on animal proportions and subsistence economy.

6.3 Conclusion

The detailed zooarchaeological analysis of these three sites from across the eastern steppe has shown that while they exhibit broadly similar subsistence strategies that employ a uniform suite of domesticated animals, at a detailed level there are differences in exploitation based on ecology and culture.

Serektas has a high amount of wild and domestic equid consumption; Kent is affected by its proto-urban nature, while Turgen is clearly a seasonal settlement site that is habitable at only particular times of the year. Closer inspection of the wild animal exploitation, pathologies and survivorship graphs supports this conclusion.

Broader comparisons across a range of sites continue to support this interpretation of complex subsistence strategy deployment that is responsive to both cultural trends and ecological pressures. High amounts of precipitation appear to favour high proportions of cattle in the forest-steppe ecozone. Cultural trends appear clearly in these comparisons of domesticates and horse consumption appears across a variety of cultures and ecozones as a signal of status. Variation in cattle proportion in the semi-arid and Semirech’ye regions appear to respond to cultural trends, rather than precipitation rates.

Archaeological cultures in Kazakhstan are traditionally defined by funerary assemblages and ceramic typologies. A linkage between sites using these cultures has resulted in links between sites in diverse ecozones, such as between Dongal and Turgen. The difference in cattle proportion at sites such as Sargary suggests that these linkages may hold true for subsistence strategies.

The geometric morphometric results tell a different story. The variation between the astragalus from these sites suggests that landraces were phenotypically distinct and did not intermingle. It is clear that breeding animals were not traded between these sites and that the integration of flocks from one region to another was not occurring in this time period. There appears to be no significant evidence for animal trade, despite the evidence for transportation and trade of material culture, specifically ceramic forms.

The geometric morphometric results and the zooarchaeological analysis suggest that the subsistence economy for each site was localised. The separation of sheep specimens confirms that animals were not traded across the steppe. While the proportions of domestic animals changed with cultures, the local flocks remained isolated. This refutes the migration theory of culture change as suggested by Kuzmina (2003, 2008). Instead of a movement of an entire people and their animals, it is more likely that a suite of cultural practices were embraced by local people who continued to manage their flocks of sheep and exploit their particular local ecology.

Chapter 7: Conclusion

This thesis sought to investigate the variability in morphology between ovicaprid breeds in the Late and Final Bronze Age in order to evaluate the degree of animal exchange and to test the theory of cultural change via migration. Geometric morphometric methods were applied instead of traditional morphometric techniques in order to control for ontogenetic variables and focus on inherited characteristics. Subsistence strategies were explored with a thorough zooarchaeological analysis of the major domesticated specimens from each site, which included horse, cow and ovicaprids (Chapter 3, 6). This exploration of subsistence was found to follow cultural boundaries, while the variability of *Ovis aries* astragalus morphology indicates that flocks were not mixed; phenotypic variation was significantly different between flocks.

Geometric morphometrics have not yet been widely applied to zooarchaeological assemblages. Curran (2012) was the first published instance of GMM on zooarchaeological material. Her methodology and focus on the cervid ankle joint directed the development of the methodology for this project. Other applications to archaeological material have focused on axial elements (e.g. Pionnier-Capitan *et al.* 2010, Seetah *et al.* 2014)

Phenotypic characteristics are inherited morphological traits. This work sought to measure inherited morphology that was related to local environment. Teasing out phenotypic variation from ontogenetic variation required the use of GMM. Biological variables inform ontogenetic variation and range from developmental defects, hormone drive sex differences, pasturage quality, infection, and adaptive remodeling.

Careful and thorough investigation of all of the above biological variables informed recording methodology. The astragalus is the ideal bone for detecting shape change between ecozones. This small bone does not posses fusion zones and hence is not affected by variation in protein intake. Protein reduction due to infection or poor pasturage reduces growth along the parasagittal plane and this is clearly seen in the variability of the greatest length of long bones such as the femur (Popkin *et al.* 2012, Sykes 1983). Hormonal driven morphological variability is present in the astragalus, but is not as significant as in other elements (Popkin *et al.* 2012). Developmental defects result in early death, and hence juvenile specimens are excluded from this study. Age-related bone growth is evident in the astragalus along the breadth of the distal articulation, but there were no patterns in the data returned from the analysis to indicate significant patterns along this measurement.

As the astragalus is located in a tight sheath of tendon and tissue within the ankle joint, the potential for the development of aberrant features from adaptive remodeling is small. Variations in the morphology of the astragalus affect the overall motion of the hind limb. This joint is significant in hind limb rotation, stride, and power (Curran 2012). Curran's work on the calcaneus demonstrated the relationship of functional morphology of the ankle joint to the environment. Variation in the morphology of the astragalus shown here, particularly on the plantar articular surface, clearly relates to local ecozones.

The morphological variability of the astragalus is likely to be largely phenotypic. Variation of the morphotype is driven by the necessity for different types of movement. Curran (2012) investigated the ankle joint in relation the natural open or closed habitats of cervids. Unlike cervids, domestic ovicaprids do not always chose their pasture location and are driven to forage by pastoralists. Choices made by shepherds regarding the annual range of pasture over long periods of time would drive positive evolutionary pressure for movement which was best suited to survival and reproduction in that particular ecozone.

The separation of *Ovis aries* and *Capra hircus* specimens in the field were accomplished using the standard qualitative methods as laid out in Boessneck (1969), Prummel and Frisch (1986) as well as in Zeder and Lapham (2010). The random k-means cluster analysis suggests that qualitative characteristics are more reliable for *Ovis aries* than for *Capra hircus* specimens originating from Central Asia. Descriptive PCA suggested that variation between species controlled for the most amount of shape variation as seen in the PCA when all specimens were analysed together (Section 5.2.4). Morphological variations along the first two principal components describe variation in the prominence of the proximal articulation and the orientation of the lateral distal articular pad.

Results from the GMM analysis were statistically significant in nearly all cases. The null hypothesis could not be rejected significance for *Capra hircus* specimens. This is likely due to the few *Capra hircus* specimens analysed although the unreliability of speciation techniques, as indicated by the k-means cluster analysis, is likely also an underlying issue. It is disappointing that qualitative characteristics for the differentiation between *Ovis aries* and *Capra hircus* could not be elucidated in this study. Future zooarchaeological and GMM research ovicaprid speciation should focus on the lateral distal articulation and the proximal articular condyles. The descriptive GMM analysis here suggests that these two areas as likely to contain the most valuable characteristics for speciation.

For all analyses based on *Ovis aries* specimens, the null hypothesis of a similar morphological phenotype across all sites could be rejected as the p-values were less than 0.001 (Section 5.4). The inherited morphology of *Ovis aries* astragali is significantly different between sites. The variation is not due to ontogenetic developmental variables, but instead describes inherited characteristics which control for hind limb agility and power. This variation in movement is clearly indicative of positive evolutionary pressure for effective movement in different ecozones.

Economic variation between sites was clear in the zooarchaeological analysis. Each site had a specific proportion of the three main domesticated species, *Equus caballus, Bos taurus,* and ovicaprids. While the influence of ecological factors on the proportions of animals is undeniable, particularly for the *Bos taurus* in the forest-steppe, there are interesting links between sites of similar cultures that appear to trend out from the prevailing ecozone.

Turgen is unique in this study as it is a seasonally occupied site (Goriachev 2004). No further settlement or funerary sites are found higher in the Turgen ravine, leading the principal investigator to suggest that this site is the summer terminus of local mobility patterns (Goriachev 2004). Settlements further down the ravine have not yet been studied, and while the transhumant nature of Turgen is assumed, it is not confirmed. Survivorship patterns from ovicaprids support and interpretation of seasonal occupation. The drop in survivorship between 16 to 18 months indicates consumption of ovicaprids in the summer months. While a relative paucity of cattle elements at Turgen may be attributed to site seasonality and skew the proportions of cattle, nearby sites of Tuzusai and Taldy-Bulak 2 have similarly low proportions of cattle, which is not to be expected if the proportions of cattle are controlled by precipitation rates.

The similarity of cattle between Turgen and Dongal appears to support a cultural link noted in the ceramic typologies, despite their locations in different ecozones. Likewise, Iron Age sites near Turgen have a different proportion of domestic animals, suggesting that cultural influence does play a role in the proportions of animals in the domestic suite. This link surprisingly supports evidence for an overarching cultural group that extends beyond material culture.

Survivorship graphs reveal differences in exploitation patterns between the sites. The *Equus caballus* population at Serektas was less likely to survive past 42 months than the populations at Turgen and Kent. Serektas also had a very high percentage of wild equids. The high amount of equid consumption when considered in relation to the ritual landscape of Turgen intimates that Serektas was the scene of ritual or high-status feasting.

Furthermore, the heavy exploitation of wild equids is unique at Serektas. *Equus hemionus* elements are also found at Kent, but form a small part of a diverse suite of exploited wild resources from both the steppe and sylvan ecozones. Indeed, the exploitation of wild resources beyond the typical domestic suite of animals is indicative of subsistence strategies than embraced a multitude of resources. Isotope research conducted on human remains found in kurgans on the periphery of Kent indicates that individuals consumed fish in addition to the species described here (Lightfoot *et al.* 2014). This wide range of species signals that consumption was not culturally proscribed. Individuals had multiple sources of food beyond domestic animal products.

The subsistence economies at each site are clearly local and specific to each particular ecozone. Unexpectedly, domestic animal proportions revealed cultural trends that crossed ecozones when compared regionally. The proportion of cattle south of the forest-steppe appears to be linked to cultural trends, and the seasonal settlement of Turgen may have more than a material culture link with the semi-arid steppe site of Dongal. Serektas is clearly linked to high-status ritual feasting activity. Of the three major domesticated species, only ovicaprids do not appear to be associated with culturally adjusted consumption patterns.

Kuzmina notes that in the Late and Final Bronze Age floodplain settlements from the Andronovo were abandoned (Kuzmina 2008). She postulates that sites such as Turgen are evidence for increased mobility and expansion of seasonal settlements. Increased proportions of ovicaprids at Late and Final Bronze Age sites further support her theory. Others have interpreted changes in settlement patterns during this period as linked to more settled behaviour (Chernyk 2009, Evdokimov and Varfolomeev 2002) and point to the metallurgical focus on the Altai and the central Kazakh steppe at sites such as Kent. Theories of nodal networks in the Late and Final Bronze Age hypothesise that people met on a semi-annual basis at sites of high cultural value, such as at Tamgaly. All of these theories suggest that mobility changes in nature after the Andronovo. Regions exhibit unique changes to settlement patterns and resource exploitation patterns. Trade likely occurred, perhaps at places of high cultural values such as at Tamgaly, or simply as part of nodal networks.

Long-distance trade of valuable livestock did occur in later periods. For example, in the Iron age the early Han emperor Wu sent 40,000 men to the Fergana valley, close to the south western corner of modern-day Kazakhstan, to acquire ‘heavenly’ horses (Mair 2006, Book of Han in Torday 1997). The Chinese knew of these valuable horses from previous exchanges from the Wusun people of the Semirech’ye (Mair 2006). The horses from Central Asia stood taller and were better suited to cavalry warfare, which had replaced chariot warfare in China by the Han dynasty (Torday 1997). Livestock exchange such as this illustrates the high value horses from Central Asia possessed, even in prehistory. Ovicaprids do not figure in such global exchanges. Indeed, ethnographic accounts from pre-collectivised pastoralists in Kazakhstan suggest that ovicaprid trade did not even play a part in marriage dowry payments. Rather than sending a girl to the groom’s family with livestock, instead she was sent with, ‘clothing, bed linen, cooking equipment, household goods, a new yurt, a horse, and a camel… the basic essentials for a nomadic way of life’ (Shayakhmetov 2006, 27-28).

While an account from a Turkic Kazakh pastoralist may not reflect prehistoric traditions and rituals, it does suggest that ovicaprids were not transferred to new ownership. Perhaps they were so ubiquitous that there was no need for long-distance transfer, or conversely they were so valuable as to preclude their trade. The zooarchaeological data from this work indicates that ovicaprids did not have added cultural value, unlike horses.

While the cultural value of ovicaprids in the Late and Final Bronze Age in Kazakhstan may never be recovered, at least the landrace morphologies have been described. Morphological variation between *Ovis aries* is specific to local ecozones, indicative of long periods of persistent local settlement. Limited intrasite variability suggests that long-distance exchange of exotic breeding animals did not occur. Inclusion of exotic phenotypes would have introduced variability within assemblages. Variation among *Ovis aries* specimens at all sites is individual, with no clear clusters indicative of multiple phenotypes (Figures 5.29-5.33, 5.35-5.39, 5.41-5.45).

The evidence presented here refutes cultural historical hypotheses which explains cultural change as migration of animals, material culture, and funerary traditions with ethnic groups. This work also refutes hypotheses of animal exchange at nodal points. Material culture similarities between all sites are not indicative of a uniform landrace of sheep across the eastern steppe in the Late and Final Bronze Age. Despite the similarities in domestic animal proportions at sites linked by material culture, evidence for similar phenotypes is lacking. Even sites located in ritual landscapes such as Serektas, where meetings between groups may have occurred, the local morphological signature is constant.

Mobility was clearly a factor of life on the steppe, but the exchange of sheep was not. Long distance mobility was likely tied to social connections while local mobility was circumscribed by annual routes for forage. Exchange of portable material culture such as ceramics and metal objects clearly occurred but there is no evidence for the exchange of subsistence products or their vectors, the sheep. Economies were localised in the Late and Final Bronze Age with no market for the exchange of sheep.

Future research should focus upon the identification of goat and sheep astragali. By identifying a clear qualitative or morphological signature, the reliability of speciation criteria would be established for Central Asia. This research would further refine investigations of ovicaprid based pastoral activities. It would be possible to research the co-variation of traits with ecology as well as refine investigations into flock mixing and migration by ascertaining the degree of ovicaprid variation and co-variation within and between flocks. Further uses for geometric morphometric methods could be successfully applied to the post-cranial elements of more mobile animals, such as horses or camels, which could help to elucidate landrace morphology for these more mobile species.

This research has shown that both the culture history and nodal network theories must revise assumptions about the nature of domestic animal mobility and exchange across the eastern steppe in the Late and Final Bronze Age. Economies were localised and landraces of sheep were adapted to ecologies; people on the steppe inhabited small ecozones. Subsistence strategies within these small patches were unique and contributed to a heterogeneous pattern of economies rather than a uniform nomadic pastoralist way of life.

Appendix: GMM Results

Table 8.1 Kent specimen measurements in mm (based on von den Driesch 1976).

Specimens	Dm	Dl	GLm	GLl	Bd
Kent199	19.63	18.31	30.8	33.24	21.63
Kent200	22.06	19.15	33.71	34.95	24.1
Kent201	23.65	20.15	35.73	37.42	23.22
Kent202	19.95	19.49	35.06	35.36	22.21
Kent203	22.6	20.96	35.81	39.08	24.82
Kent204	22.84	21.83	38.87	40.35	25.6
Kent206	19.31	18.26	31	32.52	19.81
Kent207	18.59	18.69	31.68	33.45	20.21

Table 8.2: Serektas specimen measurements in mm (based on von den Driesch 1976).

Specimen	Dm	Dl	GLm	GLl	Bd
Cer1	N/A	19.45	33.06	34.76	22.89
Cer2	18.27	18.11	29.62	31.24	20.9
Cer4	19.02	18.57	32.18	33.74	21.61
Cer5	18.17	17.35	29.28	30.5	20.11
Cer6	17.96	17.73	30.32	32.77	19.08
Cer8	19.83	18.96	32.73	33.49	23.34
Cer9	17.64	16	29.94	32.58	20.4
Cer10	21.02	19.36	31.62	32.88	22.39
Cer15	N/A	18.31	31.26	33	20.13
Cer17	21.24	20.03	35.76	36.74	24.03
Cer18	18.9	19.3	32.1	34.6	21.24
Cer19	17.97	16.94	29.42	30.17	19.16

Table 8.3: Turgen specimen measurements in mm (based on von den Driesch 1976).

Specimens	Dm	Dl	GLm	GLl	Bd
Turg1	17.7	17.3	30.28	32.3	20.51
Turg2	16.5	15.13	27	28.07	17.81
Turg3	18.02	17.46	30.78	31.32	20.22
Turg4	19.38	18.7	30.31	31.63	20.67
Turg5	19.51	18	30.33	31.12	19.5
Turg6	18.85	18.08	31.69	32.36	19.79
Turg7	18.34	17.6	31.86	32.86	20.87
Turg8	19.43	20.45	32.91	34.5	21.74
Turg9	17.94	17.58	32.56	33.64	21.24
Turg10	18.86	18.03	31.37	32.42	18.4
Turg11	19.04	17.96	29.71	29.98	19.49
Turg12	17.06	16.98	28.98	29.86	18.74
Turg15	17.31	16.34	29.11	30.38	18.22
Turg16	19.42	18.91	30.84	32.95	20.41
Turg17	19.94	20.12	33.92	35.57	21.71
Turg18	20.06	18.52	31.99	33.12	21.74
Turg19	14.62	13.54	25.03	26.17	17.43
Turg20	19.08	18.24	30.77	32.37	20.86
Turg22	16.02	14.53	27.29	27.67	18.75
Turg23	17.67	16.24	27.95	27.66	18.34
Turg24	18.29	17.72	30.66	32.05	19.49
Turg25	18.05	16.68	28.61	29.23	20.2
Turg26	14.32	14.14	24.59	25.26	16.18
Turg27	20.21	18.98	32.81	34.52	22.57
Turg28	14.22	13.81	24.55	25.83	16.17
Turg29	16.04	14.51	26.16	27.28	17.17
Turg30	17.88	18.11	28.99	30.85	20.04
Turg34	14.67	14.61	26.07	27.91	17.79
Turg35	21.04	19.35	33.42	34.62	23.15
Turg36	30.58	19.65	33.53	34.71	21.64
Turg41	21.75	20.39	35.13	36.08	21.98
Turg42	21.75	20.21	35.11	36.04	22.01

Table 8.4 Eigenvalues for all specimens from Kent.

Principal Component Analysis: CovMatrix, Kent, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00116563	25.597	25.597
2	0.00103885	22.813	48.410
3	0.00072904	16.009	64.419
4	0.00056787	12.470	76.889
5	0.00047608	10.454	87.344
6	0.00036290	7.969	95.313
7	0.00021344	4.687	100.000
Total variance:	0.00455381		

Table 8.5 Eigenvalues for all *Ovis aries* specimens from Kent.

Principal Component Analysis: CovMatrix, Kent *Ovis aries* Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00135395	32.457	32.457
2	0.00085081	20.396	52.852
3	0.00067880	16.272	69.124
4	0.00055552	13.1317	82.441
5	0.00042756	10.249	92.691
6	0.00030491	7.309	100.000
Total variance:	0.00417154		

Table 8.6: Eigenvalues for all specimens from Serektas.

Principal Component Analysis: CovMatrix, Serektas, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00177499	25.206	25.206
2	0.00144436	20.511	45.717
3	0.00116175	16.498	62.215
4	0.00082698	11.744	73.959
5	0.0005303	7.531	81.49
6	0.00033976	4.825	86.315
7	0.00030519	4.334	90.649
8	0.00025856	3.672	94.32
9	0.0001718	2.44	96.76
10	0.00012763	1.812	98.572
11	0.00010053	1.428	100
Total variance:	0.00704184		

Table 8.7: Eigenvalues for all *Ovis aries* specimens from Serektas.

Principal Component Analysis: CovMatrix, Serektas *Ovis aries*, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00225165	37.431	37.431
2	0.00142016	23.609	61.04
3	0.00079881	13.279	74.319
4	0.00044681	7.428	81.747
5	0.00027245	6.707	88.454
6	0.00027245	4.529	92.983
7	0.00023963	3.984	96.967
8	0.00018246	3.033	100
Total variance:	0.00601543		

Table 8.8: Eigenvalues for for all Turgen *Ovis aries* specimens.

Principal Component Analysis: CovMatrix, Turgen *Ovis aries*, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00076515	17.803	17.803
2	0.00062606	14.566	32.369
3	0.00054386	12.654	45.023
4	0.0004296	9.995	55.018
5	0.00034181	7.953	62.971
6	0.00028983	6.743	69.715
7	0.00026989	6.279	75.994
8	0.00019987	4.65	80.644
9	0.0001706	3.969	84.614
10	0.00013382	3.114	87.727
11	0.00011216	2.61	90.337
12	0.00009809	2.282	92.619
13	0.00008535	1.986	94.605
14	0.00007388	1.719	96.324
15	0.00005462	1.271	97.595
16	0.00004192	0.975	98.57
17	0.00003546	0.825	99.395
18	0.000026	0.605	100
Total variance:	0.00429798		

Table 8.9: Eigenvalues for all Turgen specimens.

Principal Component Analysis: CovMatrix, Turgen, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative %
1	0.00109651	19.55	19.55
2	0.00085188	15.189	34.739
3	0.00050612	9.024	43.762
4	0.00044883	8.002	51.765
5	0.00043074	7.68	59.445
6	0.00029866	5.325	64.77
7	0.00026868	4.79	69.56
8	0.00023193	4.135	73.695
9	0.00021082	3.759	77.454
10	0.00018792	3.351	80.805
11	0.00015217	2.713	83.518
12	0.00013515	2.41	85.927
13	0.00011451	2.042	87.969
14	0.00010906	1.944	89.914
15	0.000087	1.551	91.465
16	0.00008065	1.438	92.903
17	0.0000691	1.232	94.135
18	0.00005661	1.009	95.144
19	0.00005282	0.942	96.086
20	0.00004485	0.8	96.886
21	0.0000417	0.743	97.629
22	0.00003565	0.636	98.265
23	0.0000275	0.49	98.755
24	0.00002069	0.369	99.124
25	0.00001539	0.274	99.398
26	0.00001255	0.224	99.622
27	0.00000817	0.146	99.767
28	0.00000539	0.096	99.864
29	0.00000456	0.081	99.945
30	0.00000291	0.052	99.997
31	0.00000018	0.003	100
Total variance:	0.0056087		

Table 8.10: Eigenvalues for all specimens from all sites.

Principal Component Analysis: CovMatrix, All Sites, Procrustes coordinates			
	Eigenvalues	% Variance	Cumulative 5
1.	0.00090612	15.317	15.317
2.	0.00078331	13.241	28.557
3.	0.00055227	9.335	37.892
4.	0.00051423	8.692	46.585
5.	0.00040737	6.886	53.471
6.	0.00031951	5.401	58.872
7.	0.00027816	4.702	63.574
8.	0.00025322	4.280	67.854
9.	0.00021556	3.644	71.498
10.	0.00019377	3.275	74.773
11.	0.00016608	2.807	77.580
12.	0.00015843	2.678	80.258
13.	0.00015083	2.550	82.808
14.	0.00013551	2.291	85.098
15.	0.00010683	1.806	86.904
16.	0.00009768	1.651	88.556
17.	0.00008727	1.475	90.031
18.	0.00008034	1.358	91.389
19.	0.00007274	1.230	92.618
20.	0.00006458	1.092	93.710
21.	0.00005280	0.892	94.602
22.	0.00004413	0.746	95.348
23.	0.00004085	0.691	96.039
24.	0.00003990	0.674	96.713
25.	0.00003473	0.587	97.301
26.	0.00002791	0.472	97.772
27.	0.00002598	0.439	98.211
28.	0.00002141	0.362	98.573
29.	0.00001812	0.306	98.880
30.	0.00001747	0.295	99.175
31.	0.00001382	0.234	99.409
32.	0.00000940	0.159	99.567
33.	0.00000841	0.142	99.710
34.	0.00000681	0.115	99.825
35.	0.00000363	0.061	99.886
36.	0.00000269	0.046	99.932
37.	0.00000224	0.038	99.969
38.	0.00000182	0.031	100
Total variance: 0.00591592			

Table 8.11: Eigenvalues for PCA of all sheep specimens.

```
Principal Component Analysis: PCA: CovMatrix, AllSheep, Procrustes coordinates

      Eigenvalues        % Variance   Cumulative %
 1.    0.00104692        18.963       18.963
 2.    0.00064674        11.715       30.678
 3.    0.00053473        9.686        40.364
 4.    0.00048875        8.853        49.217
 5.    0.00035561        6.441        55.658
 6.    0.00032576        5.901        61.559
 7.    0.00029134        5.277        66.836
 8.    0.00025414        4.603        71.440
 9.    0.00021988        3.983        75.422
10.    0.00017911        3.244        78.667
11.    0.00014511        2.629        81.295
12.    0.00013470        2.440        83.735
13.    0.00011815        2.140        85.875
14.    0.00010716        1.941        87.816
15.    0.00009351        1.694        89.510
16.    0.00008542        1.547        91.057
17.    0.00007233        1.310        92.367
18.    0.00007030        1.273        93.641
19.    0.00005885        1.066        94.707
20.    0.00005364        0.972        95.678
21.    0.00004465        0.809        96.487
22.    0.00003935        0.713        97.200
23.    0.00003424        0.620        97.820
24.    0.00002647        0.479        98.300
25.    0.00002378        0.431        98.730
26.    0.00001899        0.344        99.074
27.    0.00001364        0.247        99.321
28.    0.00001166        0.211        99.533
29.    0.00001033        0.187        99.720
30.    0.00000454        0.082        99.802
31.    0.00000362        0.066        99.868
32.    0.00000272        0.049        99.917
33.    0.00000201        0.036        99.953
34.    0.00000121        0.022        99.975
35.    0.00000073        0.013        99.988
36.    0.00000063        0.011        100.000
37.    0.00000001        0.000        100.000

Total variance:  0.00552075
```

Table 8.11: Eigenvalues for PCA of all goat specimens.

```
Principal Component Analysis: PCA: CovMatrix, AllGoats, Procrustes coordinates

        Eigenvalues        % Variance    Cumulative %
  1.     0.00295217        32.083        32.083
  2.     0.00142443        15.480        47.563
  3.     0.00119434        12.980        60.543
  4.     0.00079418        8.631         69.174
  5.     0.00062192        6.759         75.932
  6.     0.00051700        5.619         81.551
  7.     0.00035951        3.907         85.458
  8.     0.00028822        3.132         88.590
  9.     0.00024049        2.614         91.204
 10.     0.00020284        2.204         93.408
 11.     0.00019211        2.088         95.496
 12.     0.00014515        1.577         97.073
 13.     0.00009847        1.070         98.143
 14.     0.00007280         0.791        98.935
 15.     0.00006276         0.682        99.617
 16.     0.00003528         0.383        100.000

Total variance:  0.00920169
```

Canonical Variate Analysis: CVA ...SpeciesSites

Dataset: AllSites, averaged
Classification criterion: Species, Sites

Groups		Observations
1.	C. hircus, Kent	1
2.	C. hircus, Serektas	4
3.	C. hircus, Turgen	11
4.	O. aries, Kent	8
5.	O. aries, Serektas	9
6.	O. aries, Turgen	21

Variation among groups, scaled by the inverse of the within-group variation

	Eigenvalues	% Variance	Cumulative %
1.	9.54790515	33.806	33.806
2.	7.85567169	27.815	61.621
3.	5.33073346	18.874	80.495
4.	3.74249186	13.251	93.746
5.	1.76626805	6.254	100.000

Mahalanobis distances among groups:

	1.	2.	3.	4.	5.
2. C. hircus, Serektas	17.7227				
3. C. hircus, Turgen	16.1900	9.1766			
4. O. aries, Kent	16.3950	10.5076	7.7486		
5. O. aries, Serektas	17.7784	11.0428	8.1160	5.0830	
6. O. aries, Turgen	16.3975	8.2289	7.1570	5.8640	7.2134

P-values from permutation tests (10000 permutation rounds) for Mahalanobis distances among groups:

	1.	2.	3.	4.	5.
2. C. hircus, Serektas	<.0001				
3. C. hircus, Turgen	0.0156	0.0004			
4. O. aries, Kent	0.0777	0.0004	0.0001		
5. O. aries, Serektas	0.0323	0.0006	<.0001	<.0001	
6. O. aries, Turgen	0.0288	0.0001	<.0001	<.0001	<.0001

```
Canonical Variate Analysis: CVA ...Sites

Dataset: AllSheep
Classification criterion: Sites

Groups       Observations
1.           Kent   8
2.           Serektas     9
3.           Turgen       21



Variation among groups, scaled by the inverse of the within-group variation

       Eigenvalues          % Variance    Cumulative %
 1.    244.20865557           97.299         97.299
 2.    6.77979690             2.701         100.000



Mahalanobis distances among groups:

             Kent          Serektas
Serektas       9.9495
Turgen         33.5010       27.0350



P-values from permutation tests (10000 permutation rounds) for Mahalanobis
distances among groups:

             Kent          Serektas
Serektas     <.0001
Turgen       <.0001        <.0001
```

```
Canonical Variate Analysis: CVA ...Sites

Dataset: AllGoats
Classification criterion: Sites

Groups        Observations
1.            Kent   1
2.            Serektas    4
3.            Turgen      12



Variation among groups, scaled by the inverse of the within-group variation

       Eigenvalues         % Variance     Cumulative %
 1.    1.47974939          62.691          62.691
 2.    0.88063090          37.309         100.000



Mahalanobis distances among groups:

              Kent         Serektas
Serektas        4.0339
Turgen          3.7277       2.6218



P-values from permutation tests (10000 permutation rounds) for Mahalanobis
distances among groups:

              Kent         Serektas
Serektas      0.5776
Turgen        0.9445       0.0117
```

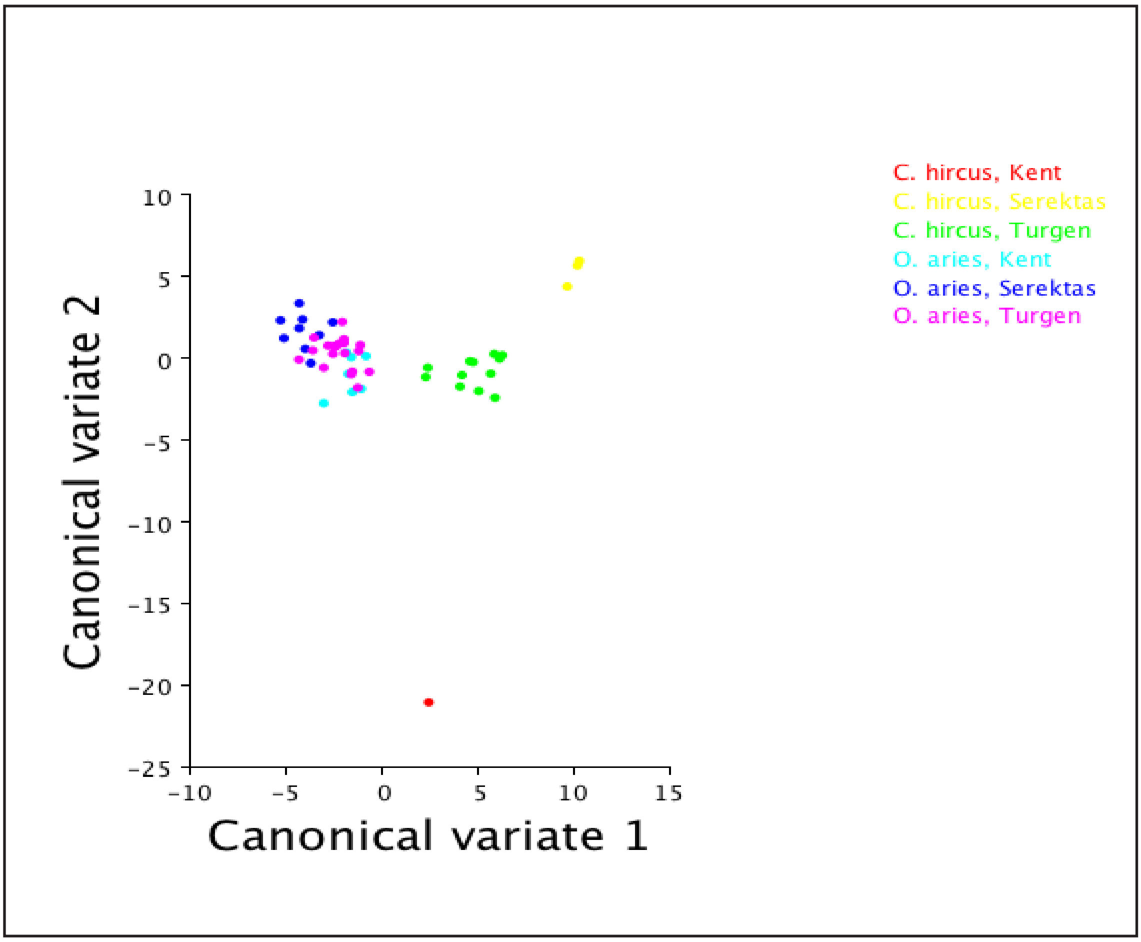


Figure 5.51:Canonical Variate 1 plotted against Canonical Variate 2 for all specimens and all sites.

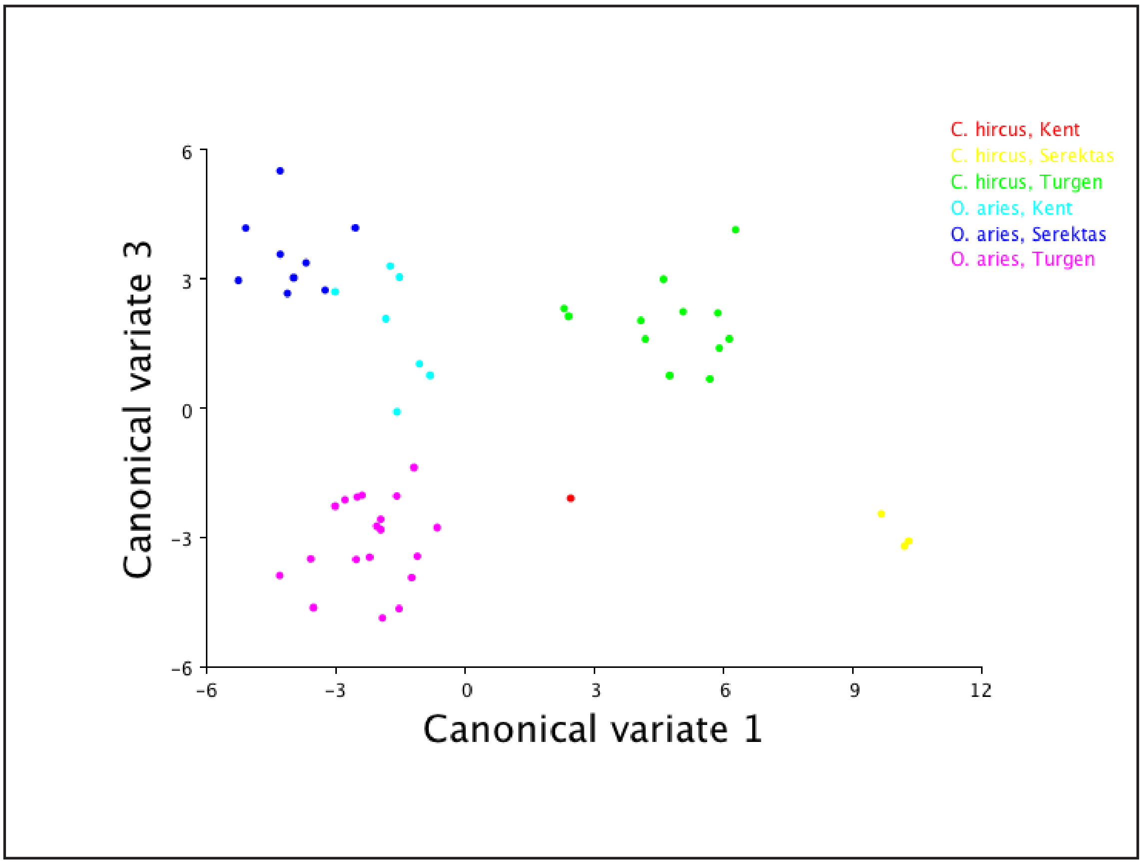


Figure 8.1:Canonical Variate 1 plotted against Canonical Variate 3 for all specimens and all sites.

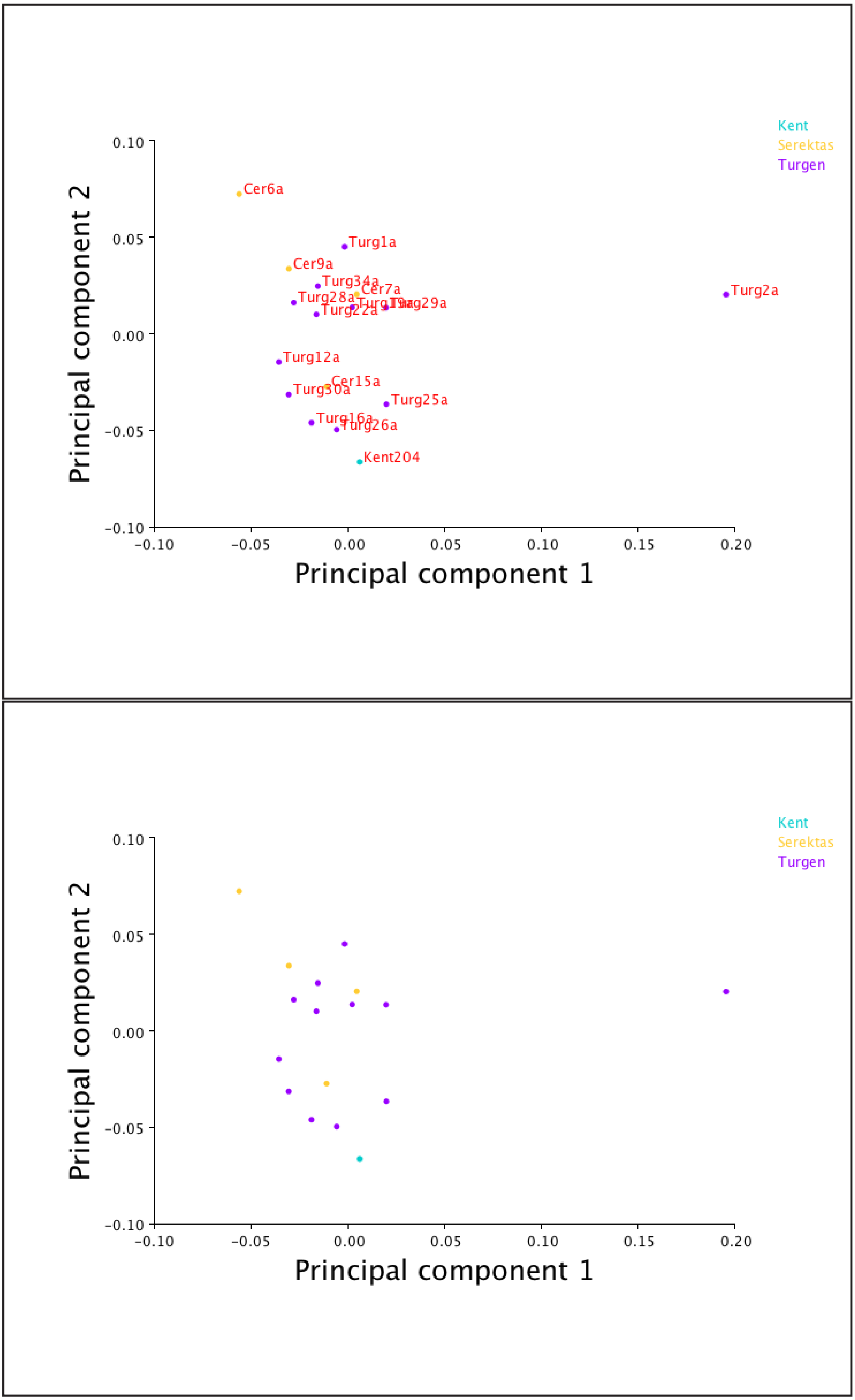


Figure 8.2: Principal Component Scores PC1 and PC2 plotted for all *Capra hircus* specimens from all sites with colour coding for sites with and without labels.

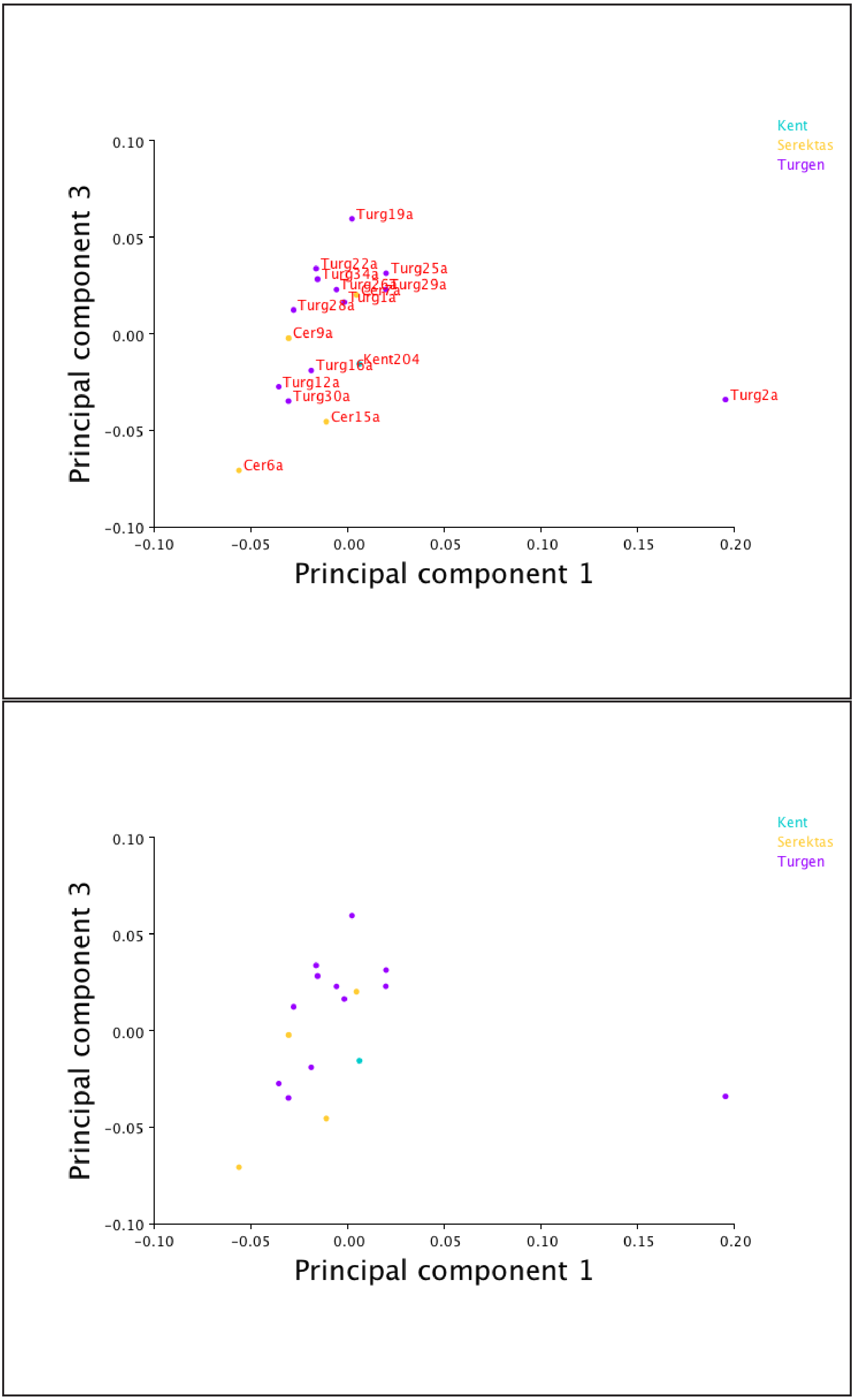


Figure 8.3: Principal Component Scores PC1 and PC3 plotted for all *Capra hircus* specimens from all sites with colour coding for sites with and without labels.

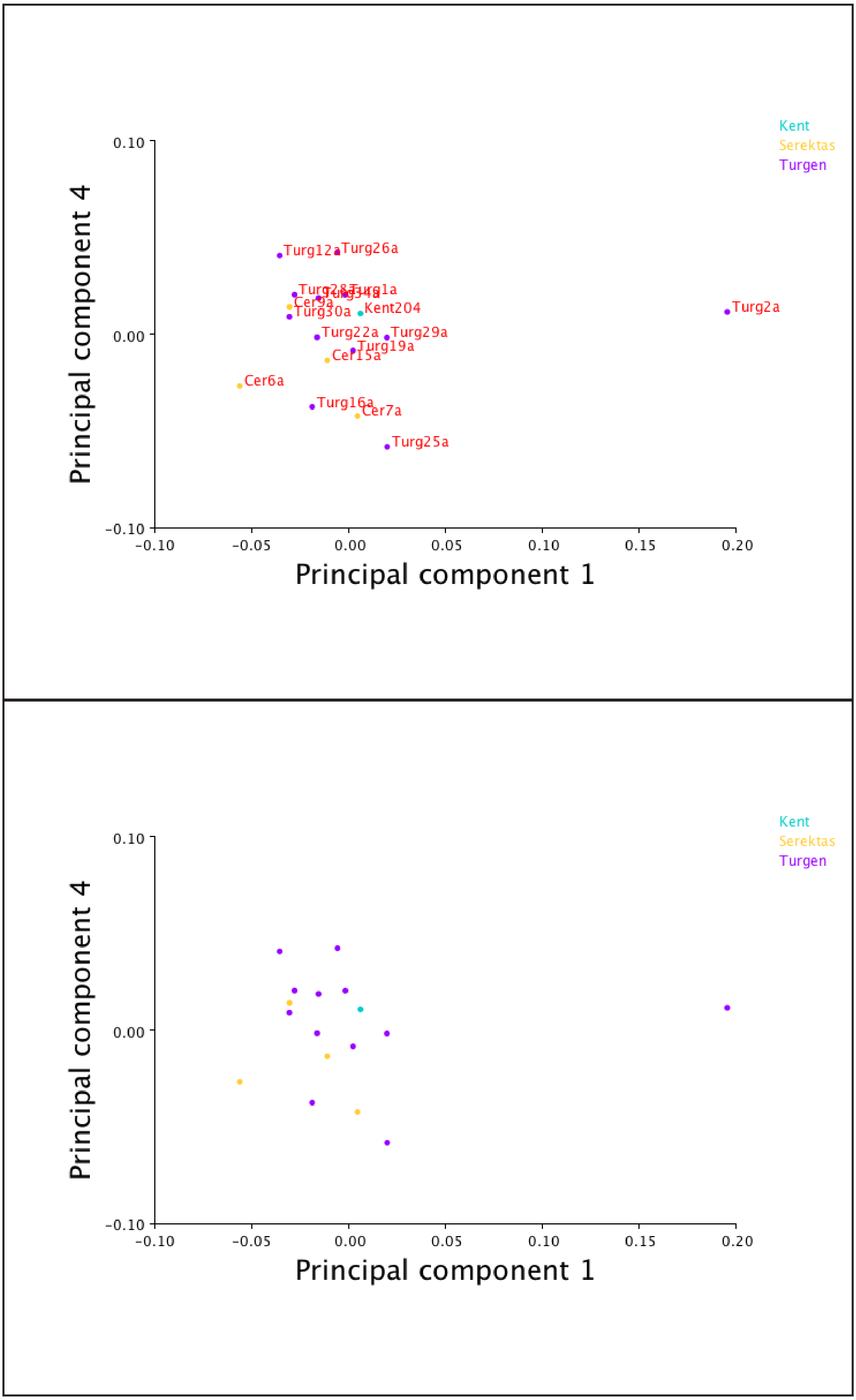


Figure 8.4: Principal Component Scores PC1 and PC4 plotted for all *Capra hircus* specimens from all sites with colour coding for sites with and without labels.

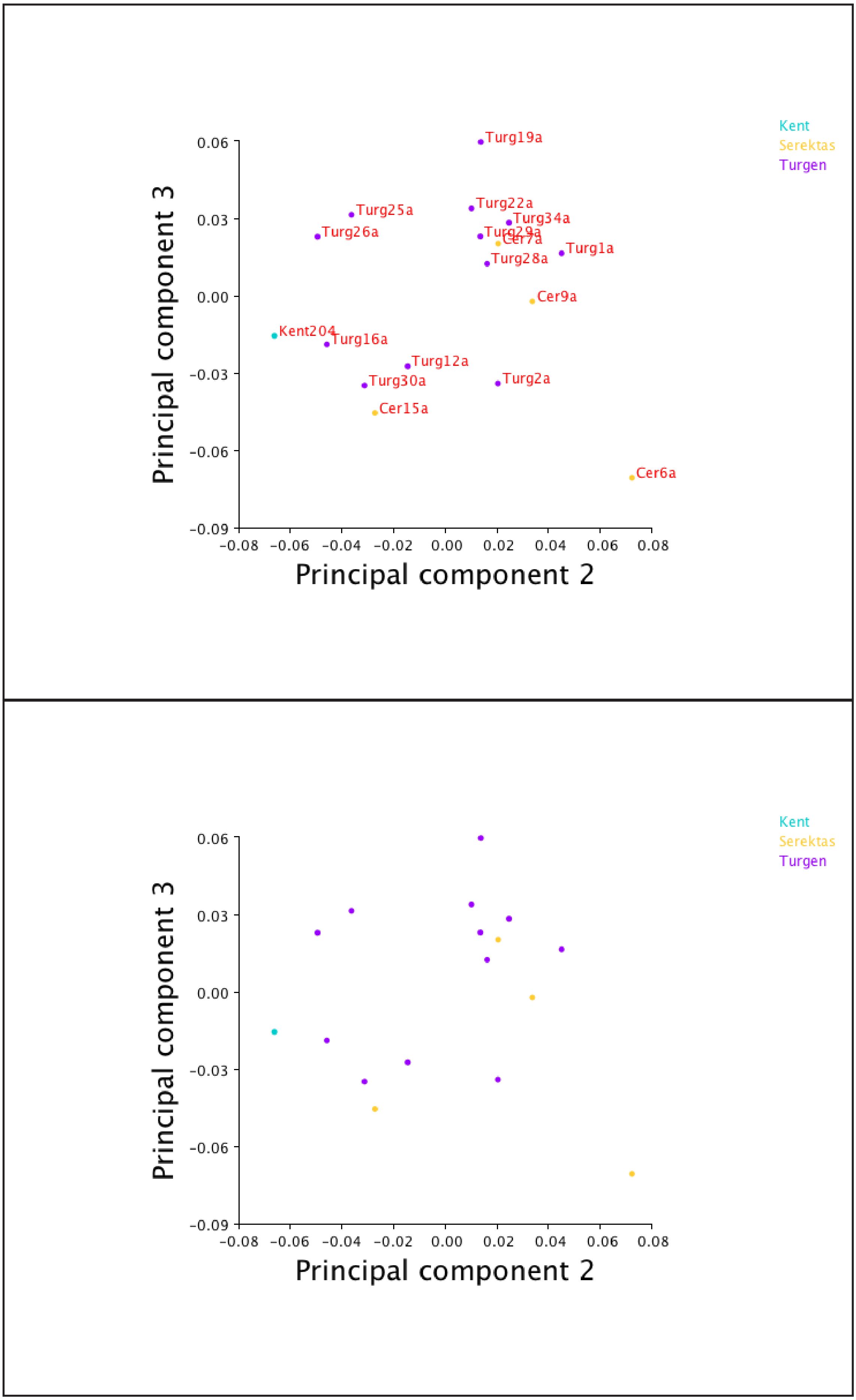


Figure 8.5: Principal Component Scores PC2 and PC3 plotted for all *Capra hircus* specimens from all sites with colour coding for sites with and without labels.

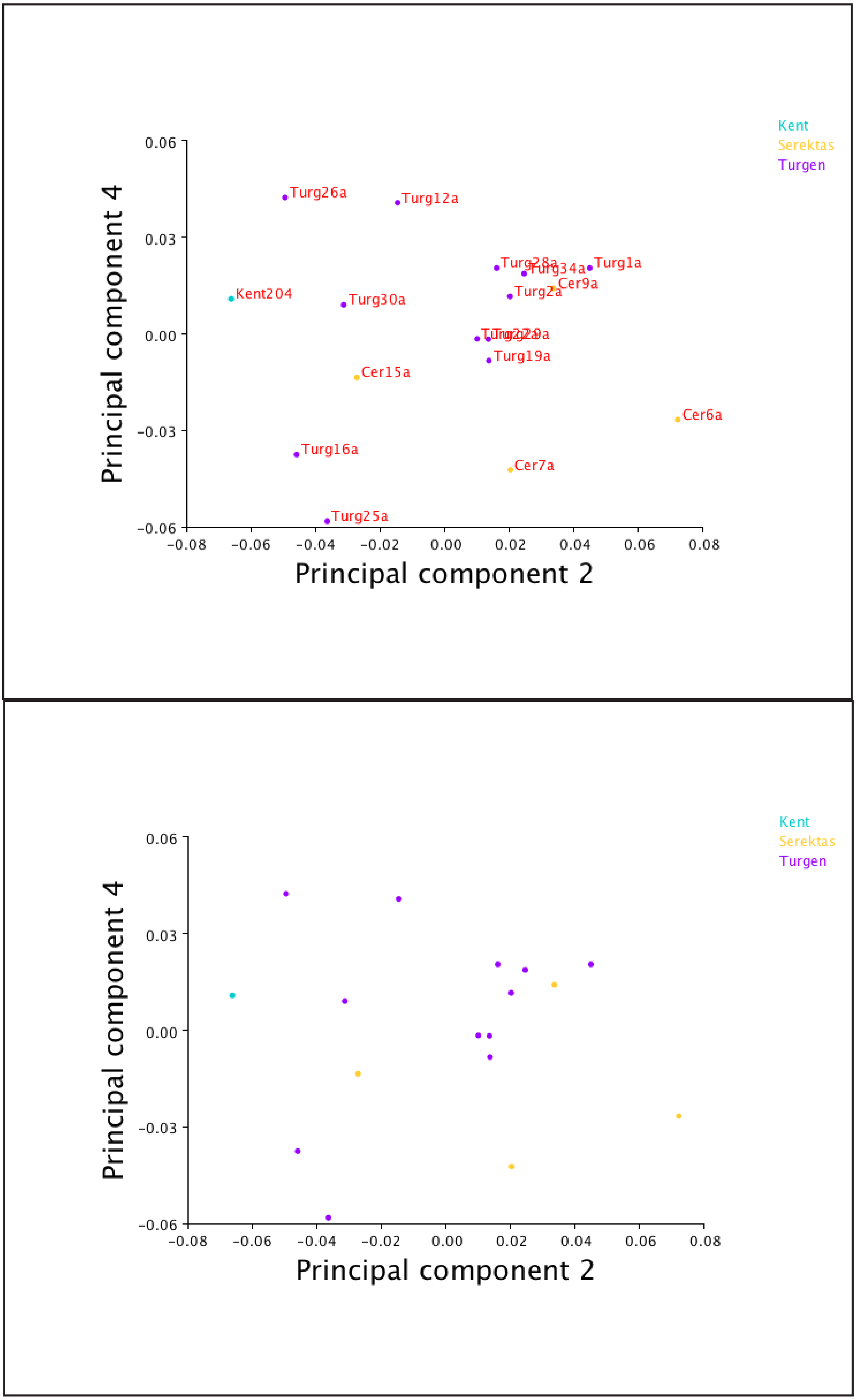


Figure 8.6: Principal Component Scores PC2 and PC4 plotted for all *Capra hircus* specimens from all sites with colour coding for sites with and without labels.

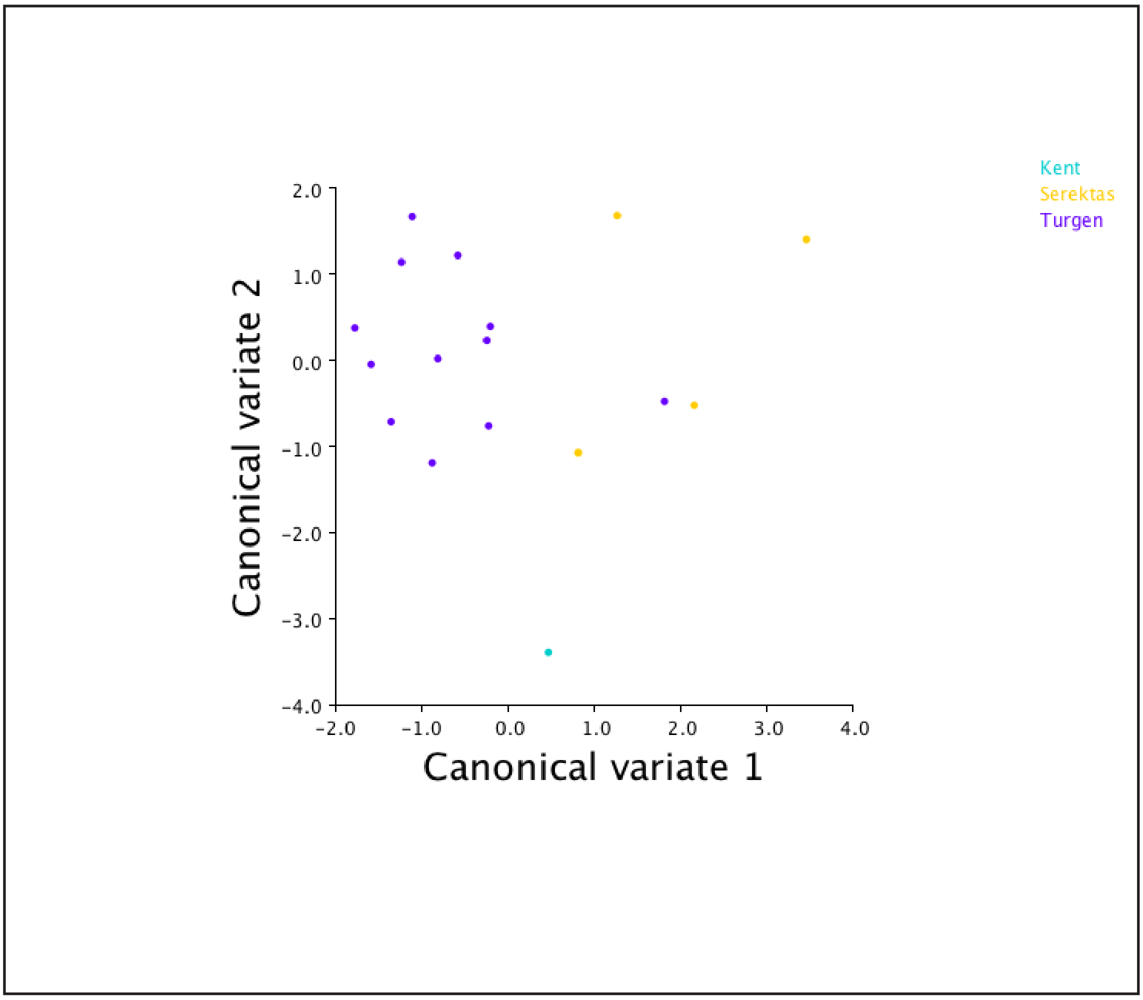


Figure 8.7: Canonical Variate 1 plotted against Canonical Variate 2 for all *Capra hircus* specimens from all sites.

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