University of Reading

Animal Management during the Transition from Mobile Hunting and Gathering to Sedentary Agriculture in the Eastern Fertile Crescent and the Caspian Sea Littoral

Doctor of Philosophy

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Declaration: I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Statement on author contribution per article

This thesis is written as a collection of papers. All papers in this thesis are co-authored works. I am the lead author on each article and I have been the main content writer for each article. The first article 'Pigs in the Neolithic of the Eastern Fertile Crescent: New evidence from Pre-pottery Neolithic Bestansur and Shimshara, Iraqi Kurdistan (7800 – 7100 BC)', published in *International Journal of Osteoarchaeology* is co-authored by Robin Bendrey and Roger Matthews. As stated in the article, zooarchaeological data collected by Robin Bendrey (second author) are included in the article and he has proofread the article. Roger Matthews (last author) is the supervisor of the project and edited the article.

The second article 'Sheep and goat management in the Early Neolithic in the Zagros region (8000-5500 BC): new zooarchaeological and isotopic evidence from Ganj Dareh, Bestansur and Jarmo', is co-authored by Robin Bendrey, Gundula Müldner, Alex Coogan and Roger Matthews. As in the first article, I used zooarchaeological data collected by Robin Bendrey (mentioned in the article) and he has proofread the article. Gundula Müldner helped me with the isotopic analysis, both in the lab as with the interpretation of the data. Alex Coogan collected some isotopic data for his master thesis, these are included in the isotopic dataset, this is stated in the article, but I interpret these data. Roger Matthews is the supervisor of the project and helped me to construct the article.

The third article 'The Epipalaeolithic-Neolithic Transition in northeastern Iran: new zooarchaeological evidence from the southern shores of the Caspian Sea', is co-authored by Hassan Fazeli Nashli and Roger Matthews. Hassan Fazeli Nashli conducted the excavations in Hotu Cave, helped interpret the stratigraphical layers of the site, supplied the zooarchaeological material and proofread the article. Roger Matthews supervised the project on the zooarchaeological material.

Covid Impact Statement

This research has unfortunately been conducted over the time of the global Covid-19 pandemic. The pandemic has severely impacted my research in several different ways.
First of all the University was completely closed from March 2020 until August 2020, a period in which I had planned to conduct lab work. More severely, my research visit for data collection and sampling specimens for isotopic analysis at the Smithsonian National Museum for Natural History (Washington DC) (March 2020), had to be cut short halfway through my time there, since the Smithsonian Research Centre closed. I had planned to sample 20 molars of Ganj Dareh and was able to sample 18 molars from Ganj Dareh for isotopic analysis. However, I had also planned and had been given permission to sample 70 bones from Ganj Dareh and 20 bones of the Epipalaeolithic site Zawi Chemi Shanidar for stable carbon and nitrogen isotopic analysis. Due to the sudden closure of the Smithsonian Research Centre I was not able to sample these specimens.

In November 2019 I sampled bones and molars from the Pottery Neolithic archaeological site Sarab and Early Neolithic site Asiab for stable carbon, nitrogen and oxygen analysis. These samples need a license to be exported, since they are from Iranian sites, and Iran is a sanctioned country. There was a major delay in the granting of the export license and the postage of those samples due to Covid-19, since the museum closed and no export licenses were granted and no samples were posted. Also there was a delay by the legal institution granting export licenses. Because of these circumstances the samples were not posted in time to be included in this thesis.

The MENTICA project was meant to conduct a seven-week field season at Bestansur and possibly at Zarzi in spring 2020 and 2021, which both had to be cancelled. I was unable to obtain more zooarchaeological and isotopic data for my PhD research from Bestansur and Zarzi. I did receive some new zooarchaeological data from the field season in autumn 2021, but I could not use these data for isotopic analysis as it was too late in the course of my PhD project.

Abstract

The Neolithic transition is one of the most significant changes in the history of humankind. Recent research indicates this transition from mobile hunter gathering to sedentary farming and herding was a long and slow process, which happened over several millennia. Relatively little is known about the first steps in this transition and the development of animal husbandry practices in the Eastern Fertile Crescent and its possible spread eastwards from the Zagros region into Iran. In order to obtain a clearer understanding of the first steps towards animal domestication and the possible spread eastwards, this research investigates zooarchaeological and stable isotopic data of five key sites in these regions, Ganj Dareh (ca. 8000 cal BC), Bestansur (ca. 7700-7000 cal BC), Shimshara (ca. 7500-7200 cal BC), Jarmo (ca. 7500-5000 cal BC) and Hotu Cave (ca. 12000- 3000 cal BC).

This research has shown that it remains essential to study each site in its own right to further our understanding of the transition from hunting to herding. At Ganj Dareh goat were closely managed and isotopic evidence indicates that goats were likely kept close to the site by humans. At Bestansur goat were likely managed, and evidence has been found for the possible earliest pig management in the Zagros region. At Jarmo evidence is found for goat management in the Early Neolithic, as well as for the introduction of sheep management in the Ceramic Neolithic. This research has also given new insights in the development of the Neolithic in Iran beyond the Zagros. Evidence from Hotu Cave has shown that caprines may have been domesticated independently in the region of the Caspian Coast littoral.

Chapter 1: Introduction

1.1 Research context

The transition from mobile gathering and hunting to sedentary farming and herding is one of the most significant changes in the history of humankind (Childe 1928; Braidwood 1960; Zeder 2012). Recent research indicates this transition was a long and slow process, which happened over several millennia rather than a sudden 'agricultural revolution' in a single 'core zone' (Fuller *et al.* 2012; Zeder 2012; Bogaard *et al.* 2021). All over Southwest Asia from around 9500 cal BC, management, domestication, and the adoption of the different species was a highly localized process, influenced by both cultural and environmental factors (Arbuckle and Atici 2013; Arbuckle 2014; Ibáñez *et al.* 2018). In the Levant, Anatolia and the Eastern Fertile Crescent (hereafter EFC; eastern Iraq and western Iran) the Neolithic ways of life seems to have developed in regionally specific ways at approximately the same time in the Early Holocene (Arbuckle 2014). Yet, little is known what the first steps of animal domestication and animal husbandry exactly involved and how this differs per region (Zeder 2012), especially regarding the EFC. The archaeological importance of the EFC region, mainly comprising the Zagros Mountains was first identified in the last century (Garrod 1930; Braidwood 1960; Braidwood *et al.* 1983). Multiple fieldwork projects were conducted in the area (e.g., Braidwood and Howe 1960; Mortensen 1970; Smith 1976; Braidwood *et al.* 1983), establishing the EFC as an important region for the transition to the Neolithic.

However, due to political conditions in Iran and Iraq since 1979, fieldwork was hampered and only started again in the early 21st century (Matthews *et al.* 2020). Since the focus of research has mainly been on the Levant and Anatolia, less is known about the beginnings of agriculture in the EFC. Recently, research has started again in this area and assemblages from early excavations have been restudied (e.g. Zeder and Hesse 2000; Zeder 2008), sites have been re-excavated (e.g. Darabi *et al.* 2019a; Darabi *et al.* 2019b) and excavations haven been started at formerly unexcavated sites (e.g. Conard *et al.* 2013; Matthews *et al.* 2013; Matthews *et al.* 2020). My research both relies on newly excavated material of the sites Bestansur and Shimshara in Iraqi Kurdistan (Figure 1.1) as well as the zooarchaeological collections of Jarmo and Ganj Dareh (Figure 1.1) held by museums and research institutes from earlier excavations. This PhD addresses the first steps towards animal domestication, and therefore provides a case study for the new types of knowledge and information that can be gained by applying new techniques to archived zooarchaeological collections integrated with newly recovered material from ongoing excavations.

Because the EFC has been understudied compared to the Western Fertile Crescent (WFC), and because of challenges of working in Iran, more is known on the spread of agriculture out of the fertile crescent westwards, than of the spread of agriculture eastwards. Farming is argued by many scholars to have spread from the Zagros region along the two major east-west routes of Iran, the Great Khorasan Road skirting the northern edge of the Dasht-e Kavir into Turkmenistan and Central Asia, and the major southern route across south and southeastern Iran into South Asia (Matthews and Fazeli Nashli 2022). By contrast, it has been argued that the Neolithic way of life, including animal herding, could have developed independently on the Caspian Littoral (Coon 1951, 1952; Leroy *et al.* 2019, 360) and possibly in other areas of Iran (Matthews and Fazeli Nashli 2022). The Caspian Sea littoral of northeastern Iran is an ecologically diverse area, with climatic conditions supporting a broad variety of plant and animal food resources (Leroy *et al.* 2019), which could have been favourable for a local transition from hunter-gathering to farming. The idea of local domestication of animals in this region was first suggested by Coon (1951, 1952) based on excavations at the cave site, Hotu, on the Caspian southern shore (Figure 1.1). The cave yielded a long sequence of occupation with Epipalaeolithic and Neolithic layers. Coon claimed to identify an increase in young goat in the late Epipalaeolithic horizons, which he interpreted as evidence for the start of goat husbandry in this period (Coon 1951, 50). He also suggested that domesticated sheep, pig, dog and cattle were present in the Neolithic layers of the site (Coon 1951, 1957). No analysis has been published to verify these statements (Harris and Coolidge 2010, 57) and only a selection of the zooarchaeological assemblage was published. Hotu cave has recently been re-excavated (de Groene *et al.*, accepted subject to minor corrections) and the zooarchaeological material of this re-excavation will be investigated in this thesis in order to learn more regarding the Epipalaeolithic-Neolithic transition in this region. In this research it will be investigated whether animals were managed in the Early Neolithic and whether animal management was introduced or if it was an independent development.

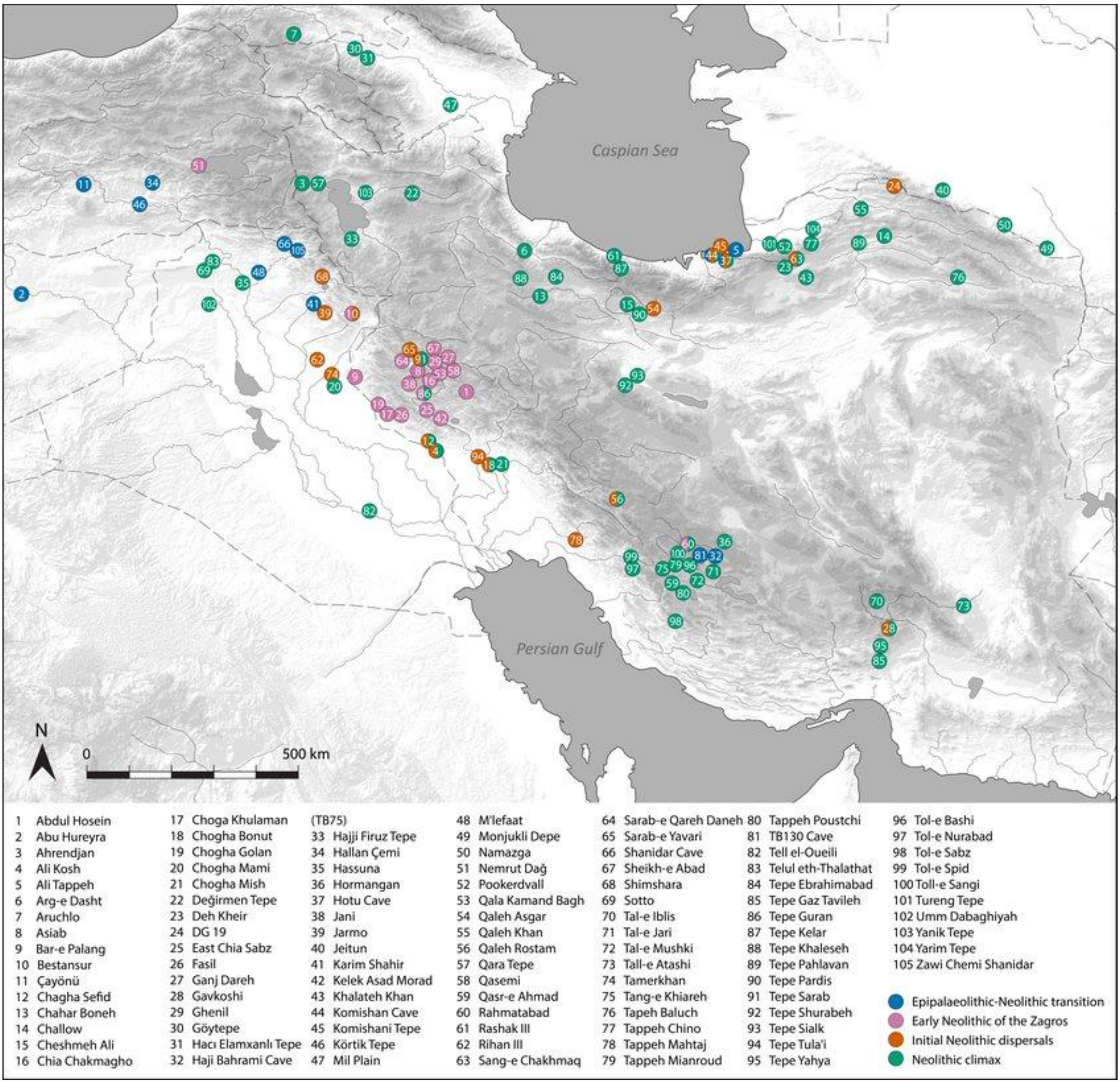

Figure 1.1: Epipalaeolithic and Neolithic sites in the Zagros region (Matthews and Fazeli Nashli 2022: Fig. 5.1. Map created by Amy Richardson).

1.2 Research aims and objectives

The first aim of this research is to obtain a fuller understanding of the initial steps towards animal management and how they led to animal domestication in the EFC. Thus in order to achieve this aim I will study the zooarchaeological material of the sites Ganj Dareh (ca. 8000 cal BC), Bestansur (ca. 7700-7000 cal BC), Jarmo (ca. 75000- 5000 cal BC) and Shimshara (ca. 7500-7200 cal BC) (Figure 1.1; 1.2). These sites cover a time span from the Early Neolithic into the Ceramic Neolithic, and therefore allow to research changes in animal management leading to animal husbandry over centuries. In addition, studying these four sites in the Zagros also enables to research local diversity in animal management in the Early Neolithic in relation to the human niche construction theory (Chapter 2.3). My objectives are to establish species abundancy, to conduct biometry, to establish kill-off patterns and to conduct stable isotopic analysis on zooarchaeological materials. I will conduct carbon and nitrogen stable isotopic analysis on bone collagen to study the diet of animals, as well as stable oxygen and carbon isotopic analysis on teeth enamel of caprines to study diet and mobility of caprines. This integrated methodological approach enables us to characterise early animal management leading to domestication with greater accuracy, using the framework of human niche construction.

The second aim of this research is to investigate whether and how animal management practices spread from the EFC eastwards to the Caspian littoral and beyond, or whether there was an autochthonous development of animal herding in this region, in particular of caprines. This aim will be achieved by studying the zooarchaeological assemblage of the Epiapaleolithic and Neolithic layers of Hotu cave (ca. 12000-3000 cal BC) (Figure 1.2). This site has occupation phases dating from the Epipalaeolithic, Early Neolithic and Ceramic Neolithic, so this site enables to study changes in animal exploitation over time. My objective is to identify changing species abundancy, conduct biometry and establish mortality patterns, which will enable to characterise initial husbandry practices and changes in husbandry over time. Species abundancy needs to be studied to understand which animals were important for the food economy, to obtain insights into the environment and to investigate local variations in animal exploitation practices. Size of sheep, goat and pigs is studied to obtain further insights into human management practices, so the size of the animals can give insight into sex distribution of the slaughtered animals. Kill-off patterns will be studied since they are crucial to understand the first steps towards domestication. The switch from targeting prime adults to herd maintenance, by culling young males and keeping females is attested at various sites in the Zagros region. Stable isotopic analysis on bone collagen is used to obtain insight into the diet of the animals. Human foddering could be one of the early steps of animal management in the Neolithic. Sequential isotopic analysis on tooth enamel will give further insight into the diet of animals and changes in their diet, and their location throughout the year. Therefore, sequential oxygen and carbon analysis can give insights into foddering practices of and human influence on animal movement such as possible transhumance (see also Chapter 3).

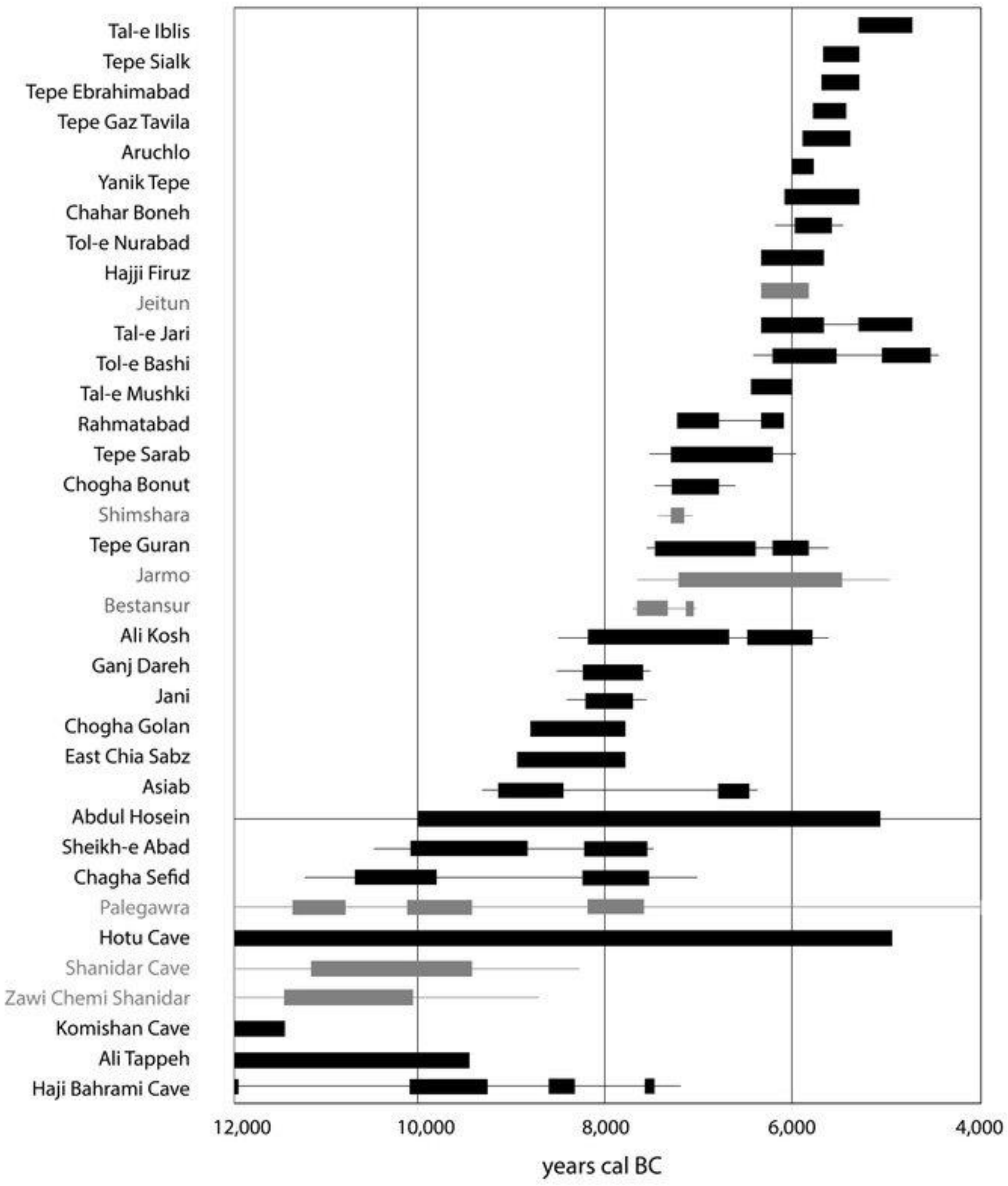

Figure 1.2: Chronology of Epipalaeolithic Neolithic and Chalcolithic sites in the Eastern Fertile Crescent and Iran, sites in Iran in black and sites in Iraq in grey (Matthews and Fazeli Nashli 2022: Fig. 5.2).

1.3 Structure of the thesis

This thesis is written as a collection of papers, which form Chapters 4, 5 and 6. In Chapter 2 I will critically review previous research on domestication and animal management, as well as assessing the state of current state of knowledge of the Neolithic transition in the regions investigated. In Chapter 3 I provide a reflexive evaluation of the methods used in this thesis. The first aim of this research will be addressed in Chapter 4 and 5. Chapter 4 takes the form of an article entitled ‘Pigs in the Neolithic of the Eastern Fertile Crescent: New evidence from Pre-pottery Neolithic Bestansur and Shimshara, Iraqi Kurdistan (7800 – 7100 BC)’ published in *International Journal of Osteoarchaeology* (de Groene *et al.* 2021). In this article, human-pig interrelations early in the Neolithic in the EFC are discussed, with a focus on Bestansur and Shimshara in the low Zagros. Chapter 5 focusses on caprine management in the Early Neolithic in the Zagros region and is an article entitled ‘Sheep and goat management in the Early Neolithic in the Zagros region (8000-5500 BC): new zooarchaeological and isotopic evidence from Ganj Dareh, Bestansur and Jarmo’ submitted to *Journal of Archaeological Science Reports* (de Groene *et al.* in review). In this Chapter human-caprine interrelationships are investigated, including new zooarchaeological evidence from Bestansur as well as new sequential isotopic analysis of molars of sheep/goat of Bestansur, Jarmo and Ganj Dareh. In Chapter 6 the second aim will be discussed. Chapter 6 is an article submitted to *Antiquity* (accepted subject to minor corrections) entitled ‘The Epipalaeolithic-Neolithic Transition in northeastern Iran: new zooarchaeological evidence from the southern shores of the Caspian Sea’ (de Groene *et al* accepted subject to minor corrections). This article focusses on sheep/goat management at Hotu cave in the Early Neolithic. Chapter 7 gives a broader contextualisation of the implications of the findings of Chapters 4, 5 and 6 and addresses the research aims by reviewing how these findings improve our understanding of the first steps of animal management and domestication in the Neolithic in the EFC and the development of animal management at the Caspian littoral. This Chapter concludes with recommendations for further research in order to advance future understanding of these important issues.

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Chapter 2: Zooarchaeology of the Neolithic Eastern Fertile Crescent and the Caspian Sea Littoral: Research Framework and Key Issues

In this Chapter I investigate the zooarchaeological context and the processes of animal domestication in the Early Neolithic in the EFC and Iran beyond the Zagros. First, I will review the geography and ecology of the relevant regions of Iran, critical to understanding the Neolithic transition, before proceeding to evaluate the nature of the archaeological evidence (section 2.1). To understand how the domestication of animals in the EFC proceeded, domestication as a concept and the nature of the first of domesticates will be reviewed (section 2.2, 2.3). These sections will be followed by a consideration of the current state of knowledge of the transition from hunting to herding animals in the EFC (section 2.4). Finally, our current understanding of how animal husbandry spread or developed across Iran beyond the Zagros Mountains will be discussed (section 2.5). This chapter will then give a short overview of the use of stable isotopes in domestication studies in Southwest Asia as well as new insights in animal management and domestication from aDNA research (section 2.6, 2.7).

2.1 Context of the environment and ecology of the studied region

The climate of Iraqi Kurdistan and Iran is very varied because of topographic conditions with a variety of highlands and lowlands where extreme conditions meet more temperate conditions (Mashkour and Tengberg 2013, 189). Overall Iran has very diverse landscapes, but is composed of multiple high mountain ranges which enclose elevated plateaux and basins, and there are relatively few areas of low-lying plains (Makki 2017) (Figure 2.1). Another factor influencing the environmental conditions in Iran, and to a lesser extent, Iraqi Kurdistan, is aridity. The western, higher reaches of Iran are wetter, receiving precipitation from the Mediterranean, while the eastern, lower regions of Iran are hotter and more arid (Vidale 2018). In addition, Iran has few high-quality soils capable of intensive agricultural exploitation (Ehlers 1980). The Zagros Mountains are a long mountain range stretching up to 2000km, ranging from southeastern Turkey to the Gulf of Oman. The range varies in width from 200-600km (Potts 1999, 12) and the highest peak is over 45000m, but more commonly high ridges are *c*. 2000-3500m (Matthews and Fazeli Nashli 2022, 14) (Figure 2.1). The foothills of the Zagros Mountains stretch until Iraqi Kurdistan, but most of the mountain range forms a natural border of Iran. The mountain range is ecologically diverse and nowadays consists of forest and forest steppe with a semi-arid climate. Lake core pollen evidence from lake Zeribar indicates that at the start of the Holocene open woodland of pistachio trees developed over the Zagros slopes (Van Zeist 2008, 81-4), but this forest steppe belt has largely disappeared because of human interference (Van Zeist and Bottema 1978, 24). Above this pistachio-steppe forest at altitudes from 700/800- 2000 metres altitude, oak steppe forest appears (Van Zeist and Bottema 1978, 24) Oak forests were possibly not abundant during the Early Holocene, and it is likely this region was all grass-dominated steppe at that time period (Van Zeist and Bottema 1978, 81; Van Zeist 2008 81-86). Calcareous sediments from Lake Zerzibar have been sampled for stable isotopic analysis. Lower $\delta^{18}O$ values in the lake than today have been argued to indicate that the distribution of moisture was highly seasonal. Almost all rain would have been fallen in winter, with spring rains being rare and prolonging the period of summer drought (Stevens *et al.* 2001), which would not have sustained an oak forest since the oak species of the Zagros Mountains, particularly Quercus brantii Lindl., are strongly dependent on spring precipitation for regeneration and are sensitive to a long dry season (Djamali *et al.* 2010). Jones and Roberts (2008), however have argued that these lower $\delta^{18}O$ sources could be related to rain from more westerly sources rather than longer periods of drought. Djamali *et al.* (2010) have argued that Indian Summer Monsoon variations could have caused dryer summers and springs in this period, which would have caused the area to become more grass-dominated steppe. At altitudes above 2000 metres grassy steppe occurs again, which would have been the environment in the region in the Early Holocene (Van Zeist and Bottema 1978). Climate in the Zagros Mountains today is highly seasonal, with arid hot summers, and significant snow cover during winters (Kehl 2009).

The Alborz Mountains in the north of Iran are more modest in range and width than the Zagros Mountains, covering 800 km and 70-120 km wide, but they are extremely high, reaching up to 5610 m (Matthews and Fazeli Nashli 2022, 16) (Figure 2.1). On the northern side of the Alborz Mountains Iran is bordered by the Caspian Sea. The Alborz Mountains receive heavy rainfall and the region is generally wet year round, in contrast to other areas of Iran (Homami Totmaj *et al.* 2021, 613). Vegetation in the lower mountains consists of forest, while above 2500 metres the region contains only steppe vegetation (Homami Totmaj *et al.* 2021). At the high ranges there are narrow plains with fertile soils suitable for small-scale agriculture and orchards (Bowen-Jones 1968, 570). The eastern area of Iran is an irregular complex of highland massifs, elevated plains and basins. The mountains on the border with Turkmenistan, Afghanistan and Pakistan are very arid (Matthews and Fazeli Nashli 2022, 17-18). The Iranian plateau in between the Zagros Mountains, Alborz Mountains and the eastern highlands is extremely arid nowadays and the soils are highly saline (Fisher 1968). Various trees and shrubs do grow in this area, but plant cover is lower than 5 %, so the region is essentially a desert (Van Zeist and Bottema 1978, 26). The topography, climate and hydrology of the studied region is very diverse and strongly influences the course and nature of routes of communication across the country as well as settlement patterns (Figure 2.1; see section 2.4, 2.5).

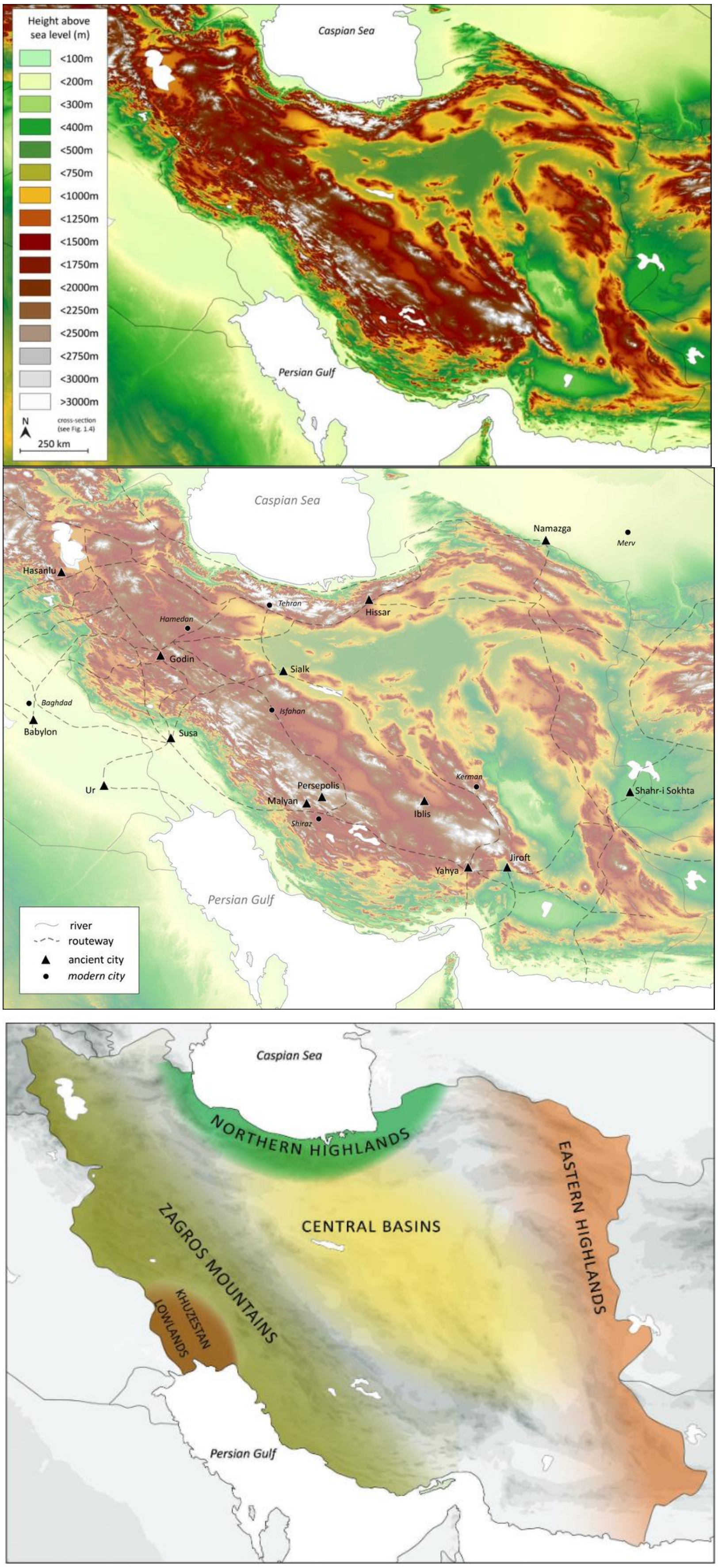

Figure 2.1: Maps showing the altitudes of the studied regions and ancient and modern route ways shaped by Iran's geology, the two desert in Iran are the green lowlands in the centre,

the Dast-e Kavir desert towards the northwest and the Dash-e Lut desert in the southeast (Matthews and Fazeli Nashli 2022: Figs 2.3, 2.7 and 2.12. Maps created by Amy Richardson).

2.2 Theories on the early stages of the Neolithic: Broad Spectrum Revolution, Optimal Foraging Theory and Niche Construction Theory

How and why the transition from mobile hunter-gathering to sedentary farming happened has been a subject of debate for over a century (Childe 1928; Braidwood 1960; Braidwood and Howe 1960; Flannery 1969; Zeder 2011). The crucial difference between the different theories on the start of the Neolithic is whether agriculture was developed out of food scarcity so essentially out of necessity or as the result of favourable conditions. The current leading explanatory frameworks, the ‘Optimal Foraging Theory’ and the ‘Human Niche Construction Theory’ differ in this aspect too. However, both theories use the ‘Broad Spectrum Revolution’ theory as a starting point. This section will first give an overview of these concepts and theories and then relate them to the research aims of this thesis.

Flannery (1969) observed a trend of broadening of diet before the start of farming in the Epipalaeolithic (20,000-10,000 cal BC) in the Zagros Mountains. During this time more small game species were included in the human diet, especially easily collectable species such as land snail, fish, crabs, and turtles. He suggested that the addition of smaller easily catchable prey would give people an extra secure source of nutrients throughout the year. While he did not have access to archaeobotanical data, he assumed that during this period humans would also start to make use of a broader set of plant materials, such as nuts. Flannery argued that this trend of diet broadening raised the carrying capacity of an increasingly human managed environment and that this was the first necessary step of specialised food production, eventually leading to crop rearing and animal husbandry. He called this phenomenon the Broad Spectrum Revolution (hereafter BSR). Flannery’s paper has been highly influential and many archaeologists and anthropologists have used it, sometimes in combination with Optimal Foraging Theory (hereafter OFT) (Stiner 2001; Zeder 2012c). The OFT model assumes that a forager moves through an environment in which prey types are homogenously distributed, encountered at random, and the decision whether to pursue a particular prey item is based on its return in energy or nutrients (Stiner *et al.* 2000; Zeder 2012c). This model has been used to explain the BSR and the subsequent shift to farming. It is argued that the BSR took place because pressure on high ranked resources; large game such as deer, bovids and caprids made people rely on lower ranked resources; smaller game such as hare, birds, turtles and tortoises (Piperno 2011; Stiner *et al.*

2000). After this first expansion in diet, people would continue and eventually domesticate resources (Piperno 2011). So, food scarcity would lead to the domestication of plants and animals resources (Smith 2011).

The core principles of the OFT have been extensively criticized (Smith 2011; Zeder 2012). First, it has been argued that there is no empirical evidence for the OFT, neither in the archaeological record (Zeder 2012c) nor in current day hunter-gathering societies (Smith 2011). One of the most important assumptions in this theory is that the abundance of lower ranked resources is not taken into account when making the decision whether to include them in the diet (Smith 2011; Zeder 2012c). However, it seems that if lower ranked resources become more abundant the decrease in search cost makes them an easier investment. Also, if it is possible to collect lower ranked resources on a high scale, like mass collection of densely distributed sources, such as a cluster of oyster shells, it is a less costly investment (Zeder 2012c, 250).

The model also assumes that the foragers encounter food sources at random in the same proportions over the foraging area (Smith 2011, 263). However, human foragers tend to occupy settlements seasonally according to food availability in the specific environment per season (Zeder 2012c, 251). It is possible to correct for this aspect in the model, but the model would have to be adjusted to account for abundancy of resources. Another possibility is that the theory is wrong, and that foragers’ choices are not shaped by energy maximising goals (Smith 2011; Zeder 2012c).

Zeder (2012c) has highlighted some major issues with this basic principle. The OFT implies that mobility is only given up whenever there is no other option, usually due to population increase (Stiner 2001). However, according to other models tested on current day hunter-gathering societies, mobility and travel distances of foragers increases with resource scarcity and/or unpredictability. When resources are abundant and predictable, foragers can afford to become sedentary (Dyson-Hudson and Smith 1978; Zeder 2012c). Population pressure has not been found to be a factor for people to become sedentary at all (Zeder 2012c, 253). Also, one of the key points of the OFT is that the resource intensification is the result of food scarcity. Foragers then start to make use of lower ranked resources, which lowers the foraging efficiency (Munro and Atici 2009). No evidence exists that this is indeed true (Zeder 2012c). Thus, it remains questionable that foraging decisions are made based on the greatest net return of calories or nutrients (Zeder 2012c, 256).

Another main criticism on the OFT as an explanation for the early development of farming is that the relationship between humans and the environment is unidirectional (Smith

2011). However, multiple species, including humans, do shape their surrounding environments (Smith 2011; Zeder 2016). Studies of current foragers (Hawkes *et al.* 2001; Anderson 2005) showed that people have well-defined resource areas, but keep on continuing to update their knowledge of the local ecosystems. Also, they establish ownership over their local resources. In general, foragers establish control over specific resource locations with high value return. They transfer their knowledge about the environment in the resource catchment area, and the ownership of the resources to next generations. Furthermore, foragers also engineer the ecosystems within their resource catchment area, which is called niche construction (Smith 2011). This is not an exclusive trait of humans; multiple species shape the environment around them to their benefit. Niche construction is seen as a second major influence on evolution (Odling-Smee *et al.* 2003; Smith 2011). The efforts of shaping the environment provides an evolutionary advantage for both individuals as well as populations. Niche construction typically consists of sustained repetitive activities, not of short-term one-time efforts (Smith 2011, 265). Therefore, it does not only provide the current population an evolutionary advantage, but also the descendants of the population. In contrast to many other species, humans communicate these niche construction activities through cultural inheritance (Odling-Smee *et al.* 2003, 242-6). Human-niche construction involves alterations of the physical environment and the management of other species.

Human niche construction theory (hereafter NCT) has also been used to explain the start of farming (Smith 2011). Smith (2011) argues that the onset of warmer conditions in the Early Holocene resulted in more productive ecosystems around the world. In resource rich environments humans established resource catchment zones, with a more varied utilization of plant and animal species. Communities establish ownership over resources and resource-catchment territories. After the establishment of ownership over these areas communities gain increased control over the environment and pass on the knowledge on the areas through social learning to subsequent generations. The increased control over certain species in time resulted in management over wild populations. Co-evolutionary relationships in niche construction activities do not necessarily lead to domestication (Smith 2011; Zeder 2016). For niche construction to result in domestication a multi-generational relationship must develop. The maintenance of this relationship over the long term requires that both partners undergo modifications (Zeder 2016, 328). However, little is known regarding what the first steps towards increased control exactly entail and how this may vary by site, region and wider area. In this thesis, I will study Epipalaeolithic and Neolithic animal remains to further our understanding of the co-evolutionary relationships leading to domestication. In order to investigate how this long-term relationship between animals and humans started and was maintained I will use zooarchaeological analysis, to establish species abundancy, kill-off patterns, sex patterns and changes in size. I will also conduct stable isotopic analysis, to establish animal movements and diet to obtain a closer understanding of human control over reproduction, movement and diet (see also Chapter 3).

2.3 What is animal management and domestication?

No universally accepted definition of the word ‘domestication’ exists. Domestication involves a relationship between a domesticator and a domesticate. However, there is a lack of consensus about what this relationship should involve (Zeder 2015). It has been argued that a domesticated species should differ both in phenotype and genotype from its wild progenitor (Jensen and Wright 2013, 43). This argument implies that the domesticate has a different appearance and that this is defined by its genes. However, changes in animals under the domestication process are not restricted to their morphology. Overall characterises of a domesticated animal are reduced wariness and less aggressive behaviour paired with a reduced brain size, fewer developmental stages and an early onset of sexual maturity (Zeder 2012a). Behavioural changes precede the changes in body morphology. Therefore, the first steps of animal domestication are hard to trace in the archaeological record and it is difficult to determine where in this process an animal should be considered a domesticated species (Zeder 2011). There is a clear dichotomy between the terms ‘wild’ and ‘domestic’ (Bogaard *et al.* 2021). However, domestication is a process (Zeder 2012a; Bogaard *et al.* 2021), and the terms ‘domesticate’ and ‘wild’ ignore intermediate forms or taxa/communities that do not meet the wild/domestic criteria.

In the past century, however, researchers focused on the overall decrease of body size as a marker of domestication in all the four key domesticates (goat, sheep, cattle, pig). However, overall body size reduction does not appear to be a good marker of domestication. Body size of animals is dependent on multiple factors apart from domestication, namely environment, sex and age (Zeder 2008). Another issue with the use of morphological markers to define initial domestication is that animals that are not (completely) morphologically domesticated, may have relations with humans other than a hunter-prey relationship (Zeder 2008, 2012a). Domestication is a long process in which relationships gradually changed. Body morphology of domesticated animals is not an indicator for subtle initial changes in human-animal interrelationships. Human animal management basically includes every way human can take control over animals practices, such as restricting movement, introduction to new environments, controlled breeding, controlled diet. Human management of animals does not equal domestication, but might be the first necessary step towards domestication (Zeder 2012). In this thesis the term animal management will be used to describe practices in the domestication process. Zeder (2012a) has discerned three pathways of animal domestication, the prey-pathway, the commensal pathway and the directed pathway.

Most livestock species were probably domesticated through the prey-pathway. The prey-pathway began when humans started to develop specialised game management strategies. Under certain circumstances those strategies developed into a closer control over the herd which eventually led into controlled breeding. Sheep, goat and cattle were probably all domesticated through this pathway (Zeder 2012a; see also chapter 2 section 2.2 and 2.3). Change in mortality profiles and different mortality profiles of the different sexes could indicate these first step towards domestication (Zeder 2008; Zeder 2012b). A typical hunted ungulate and equid zooarchaeological mortality profile will consist mostly of prime adults (Stiner 1990), while in a managed population it is expected that female animals are being kept alive until after reproduction age and excess young males would be culled (Zeder 1999; Zeder and Hesse 2000; Zeder 2008).

The commensal pathway differs from the prey-pathway in the respect that the domesticate is attracted to humans, either feeding on human waste, or other animals associated with human settlements. Some of these animals developed a new, closer relationship with humans that brought them into a domestic partnership. Dogs, the first domesticated animals, domesticated at least 13000 years ago, are likely to have become domesticated through this pathway (Zeder 2012a, 240-1). Pigs differ from the other livestock animals (sheep, goat and cattle) in the fact that they are omnivorous. Therefore, pigs could have had a different range of relationships with humans and might have been domesticated through the commensal pathway (Zeder 2012a, 240-2; see section 2.2.3). The domestication process of the different key-domesticates in the Neolithic of Southwest Asia will be discussed below.

2.3.1 Goat

The wild progenitor of the domestic goat (*Capra hircus*) is the bezoar goat (*Capra aegagrus*). Its current day habitat ranges from the Taurus Mountains of Turkey into Pakistan (Zeder 2006b, 181). The bezoar goats preferred habitats are mountainous areas with a mix of rocky outcrops and vegetation. Bezoar goat can very well survive in relatively arid areas, but does live in forests too (Weinberg *et al.* 2008). The bezoar goat is herbivorous; they both browse and graze, although they prefer browsing over grazing (Dwyer 2017, 203). They are non-obligate drinkers, meaning they can survive longer periods without drinking water (Dwyer 2017, 204). Both wild and domestic goat are social animals that live in groups which can range in size from two to a few hundred. The herds are usually sexually segregated, apart from areas with mild climate where breeding happens throughout the entire year (Houpt 2011, 33). The home range of goats is defined by predation risks and food availability (Houpt 2011, 33; Dwyer 2017, 204-205;). The total home range is between 10-40 ha which may vary per season (Dwyer 2017, 205). Breeding of goats is seasonal, except for goat living in mild climatic areas. Their reproductive behaviour is driven by sexual activity of the female, which is influenced by day-length and amount of rainfall. Mating usually occurs in autumn, and in spring the young are born. Usually goats give birth to twins, while single and triplet births occur but are less common (Dwyer 2017, 207). Weaning in wild goats occurs at 6 months, while domestic goats are sometimes already weaned between 8 and 12 weeks (Dwyer 2017, 208). Pre-weaning mortality in wild goats is high (Dwyer 2017, 208).

The bezoar goat was abundant in the Zagros Mountains during the Palaeolithic and heavily exploited (see section 2.3). In the Epipalaeolithic bezoar goat was one of the most hunted animals by humans, while communities broadened their overall diet (see section 2.1 and 2.3). In the Neolithic, goat was the earliest domesticated livestock animal in the Zagros region (Zeder 2008). In the past century, most researchers relied solely on morphological markers to establish whether animals, including goat, were domesticated. One of these morphological markers in goat is a change in horn size. The horns of the bezoar goat are more quadrangular, while the cross section of the horns of domestic goat are flatter, also the horns of domestic goat are significantly smaller than those of bezoar goat (Zeder 2006b, 181). This difference is especially pronounced in male domestic and non-domestic goat. A major difference in horn size between male and female wild bezoar goats occurs, while in the domesticated species this difference in size decreases, although the horns of the domestic male goat are still larger than those of both domestic and wild female goats (Zeder 2006b, 181-3). Horn size reduction can be linked to human selection, but the exact reason for it is unknown. It has been argued that large horns were not needed as defence against predators because of new human protection (Zohary *et al.* 1998, 131). Reduced mating competition has been suggested as another explanation, since mating would be controlled by humans. In addition to this, humans could have selected against big horns (Zeder 2006b, 181-3). Although the reduction in horn size is clearly linked to human impact, it is not a useful marker for initial domestication. First, it is hard to detect subtle changes in horn morphology because no objective distinction between horns of wild, transitional and domesticated animals can be made. In addition, the change in horn size happened at a very slow pace, so during the first stages of domestication a clear reduction in horn size would be hard to determine. Another complicating factor is that horns in archaeological assemblages are often fragmented and the recovery of complete skulls is rare (Zeder 2006b, 183).

Another morphological marker often used to determine the domestic status of goat is overall body size reduction. In the 1970's Uerpmann (1978) was the first to propose size reduction in all body parts as a marker of domestication. He found that bones from sheep and goat from Near Eastern assemblages generally became smaller around 8000 B.C. and concluded that this was the effect of domestication (Uerpmann 1978). However, he did not specify why he argued domestication was the cause of this change. Nevertheless, overall body size reduction was used as a predominant criterion for domestication for almost all livestock species ever since (Zeder 2006b, 184).

This approach is not without issues. Firstly, the measure of size reduction before a goat should be considered as 'domesticated' is not established (Zeder 2006b). Second and more important, it is not clear whether overall body size-reduction in animals can be linked to human impact and domestication at all. Zeder (2002, 2008) researched the influence of sex, age, geography and domestic status on the overall size of modern wild and domestic goats from the Zagros. Sex was found to be the most important factor to influence the size of goat. All skeletal elements of both domestic and wild male goats were larger than both domestic and wild female goats. While domestic and wild females were usually about the same size, high variation in size was observed between wild and domesticated males (Zeder 2006b; Zeder 2008). Apart from sex, geography also influenced body size, as goat generally became smaller in areas with higher temperatures and increased aridity. Age did not play a significant role in the overall size of their bones, especially not in breadth of the bones. Also, the domestic status of the animals did not have a major impact on the body size. Although a difference in size could be observed between wild male goat and domesticated male goat, domesticated male goat were still larger than the largest wild female goat. So, decreased sexual dimorphism can be seen as a marker of domestication, but overall body size reduction is not a marker of domestication in goats (Zeder 2006, 184-6).

The general decrease in size of goats observed in the archaeological record (Uerpmann 1978) can be explained by changing human-animal relationships. Hunter-gatherers started to develop new hunting strategies in order to maximize the availability of the prey (Zeder 2012). When people first became more sedentary, they started to develop a different relationship with the hunted herd because they had to rely on the same herd for a longer period of time (Larson and Fuller 2014). During the Epipalaeolithic mostly male prime-adults were hunted, because these would provide the largest calorific return. Whenever a herd should be maintained, humans would shift towards a strategy to kill-off most males at a young age and maintain the female population to live longer so they could reproduce (Zeder 2006b). This change in management strategies cannot be called domestication, although it might be a first step towards domestication. It is difficult to assess at which point in the domestication process a specimen should be called 'domesticated' rather than 'wild'. The first real change in goats under the process of domestication is likely to have been on the behaviour of goats, which is not directly detectable in the archaeological record (Zeder 2006b). Except for differences in culling patterns in the Zagros it is not clear what the first stages of animal domestication involve (Makarewicz and Tuross 2012, 495). At developed phases of the domestication process humans exercise control over movement, breeding, and diet of goats, but it might have been that humans only exercised limited amount of control over these factors in the early stages of domestication. The influence of people on goats in the early stages of management and domestication in the Zagros region will be a subject of further investigation in this thesis.

Evidence of animal coprolites and dung on site has been used as a potential indicator of animal proximity and therefore possible management practices like penning (Matthews *et al.* 2013; Matthews *et al.* 2014). This has been done by the use of GC-MS and micromorphological analysis and dung sperulite analysis (e.g. García-Suárez et al. 2018; Matthews *et al.* 2014; Matthews 2020). Herbivore dung can be separated from omnivore dung (Shilito *et al.* 2011).

A relatively new method under development to assess domestic status is the use of aDNA (Larson *et al.* 2014; Daly *et al.* 2018). No clear mutations or genetic variants which could be assigned to early stages in the domestication process have been found for any animal so far, probably due to the fact that is harder to find the genes which influence behavior, than genes which influence morphology. Apart from that, the domestication process may have consisted of small shifts in multiple different loci of genes, and therefore these changes in the genotype are hard to trace (Zeder 2006a, 171-2). Genetic research on mtDNA and whole-genome data combined indicates that multiple populations have contributed to the first domestic goats. A multilocus process of domestication happened and there was not a single place of origin where goats were domesticated (Daley *et al.* 2018) (see also Chapter 2.6).

2.3.2 Sheep

Just like goat, the wild ancestor of domestic sheep, wild sheep/ mouflon (*Ovis orientalis)* is widely abundant in the Zagros region since the Palaeolithic (Zeder 2006b). The habitat ranges of bezoar goat and wild sheep overlap, but generally wild sheep live in the lower mountains and foothills of the mountains (Zeder 2006b, 186). Just as wild goat, wild sheep both browse and graze (Valdez and DeForge 1985). In contrast to goat though, sheep are more adapted to grazing. Also, they cannot cope with longer periods without drinking water (Dwyer 2017, 204). Sheep usually dwell in hills or on elevated ground and move to lower regions during the day to graze (Dwyer 2017, 204). They live in groups and move together with the entire group. Groups either consist of females and their juvenile female offspring or solely of rams (Dwyer 2017, 201). Female flocks consist of about 20 members, while ram flocks are smaller, consisting of about 6 animals, and they are less stable (Houpt 2011, 32). Rams tend to forage more in open areas than ewes since they have reduced predation risk. Both males and females reduce their home range during the winter and decrease their activity (Dwyer 2017, 205). Birth in wild lambs take place in spring and in contrast to goat, twins and singles are both common. Weaning takes places after 6 months, but this process can be shortened by humans (Houpt 2011, 141).

To investigate possible domesticated status of sheep, changes in body morphology have been used as the main criteria. Horn size can provide information about the domestic status of sheep, although the changes in horn size under the influence of domestication in sheep are less pronounced than in goats (Zeder 2006b, 182-3). Under the influence of domestication horns of the male sheep become smaller, and some of the females become hornless (Zohary *et al.* 1998, 130-1; Zeder 2009). Overall body-size reduction has been used as a marker for domestication in sheep too, but although slightly less pronounced than in goats, sexual dimorphism turned to be the most prominent factor affecting body size in both wild and domestic sheep, not domestic status (Zeder 2008). As is the case in goat, domestic status has less impact on body size than environmental conditions in sheep (Zeder 2008). The first impact of domestication on sheep was most likely on behaviour (Zeder 2006b), and therefore changing management strategies are the best indicator of the first step towards domestication (Zeder 2006b). In the Zagros region wild sheep are abundant, but they seem to be domesticated later than goat (see also Chapter 2.6).

2.2.3 Pig

Wild boar *Sus scrofa*, the wild progenitor of pig, is native in Eurasia (Albarella *et al.* 2006;

Leaper *et al.* 1999). The habitat range of the wild boar is determined by food availability, shelter, and weather conditions. Wild boar generally have a large ecological tolerance, but they avoid areas where snow cover hampers movement and large stretches of open land (Singer *et al.* 1981). Wild boar lack sweat glands, so in hot areas they thermoregulate by wallowing and resting in cool places (Leaper *et al.* 1999, 242). The ideal habitats for wild boar are woodlands or dense marshlands. However, wild boar inhabit steppe, Mediterranean shrubland and farmland as long as there is some tree cover and wallowing opportunities (Spitz 1989). Estimates of the annual home range of the wild boar are between 4 to 26 km^2 (Leaper *et al.* 1999, 242-3). The home range becomes wider however, when humans actively hunt wild boar or when food availability decreases (Leaper *et al.* 1999, 242-3). Wild boar, in contrast to domesticated pigs, are primarily nocturnal animals (Leaper *et al.* 1999). During the night wild boar generally travel between 2 -15 km (Spitz 1986). Wild boar migrate seasonally on occasion, from higher to lower evaluations. This elevation shift may be up to 1500 metres (Singer *et al.* 1981) over distances up to 250 kilometres (Andrzejewski and Jezierski 1978). Wild boar feed opportunistically; they are omnivorous but in general more than 90 percent of their diet consists of plant material (Leaper *et al.* 1999, 241). Acorns and beechnuts are preferred over green plant material and roots and bulbs often make up a large part of the diet (Genov 1981). Occasionally wild boar feed on invertebrates, carrion and juvenile birds (Genov 1981, 202; Leaper et al 1999, 241). Nowadays, wild boar also feed on cultivated plants and are considered pests in that regard. In some cases, 75 percent of the diet consists of crops cultivated by humans (Genov 1981). Wild boar tend to make more use of agricultural crops in places where the boundary between field and woodland is not clearly defined (Genov 1981, 185-6). The wild boar female/male ratio is 1:1. Female wild boar live in groups together with their most recent young, while adult males operate solitarily (Leaper *et al.* 1999, 241-2). The farrowing season is early spring, and in exceptional cases, a second farrowing occurs in autumn (Grigson 1982, 298). Usually the litter consists of 5-6 piglets. The gestation period is about four months; pigs reach puberty around 9 months. They do not tend to breed before the age of two years (Grigson 1982, 298). Female wild boar tend to stay with the group while males are driven away from the group when they reach puberty (Rowley-Conwy *et al.* 2012, 23-9). Wild boar can live up to 11 years, but they have a lower life expectancy (Leaper *et al.* 1999, 241-2). Sexual dimorphism is very pronounced in wild boar, maleon average 1.3-1.4 times larger than females (Zeder and Lemoine 2020, 7).

It is unknown whether wild boar was domesticated through the prey-pathway, like sheep and goat, or though the commensal pathway, like dogs (Zeder 2012a), or both. Male

wild boar are substantially larger than wolves and arguably more dangerous for humans. Therefore, a commensal relationship between human and wild boar, leading to domestication seems less likely to develop than between humans and wolves. Domestication could have started with the management of solely female wild boar and/or piglets. In current day New Guinea communities, only female 'domesticated' pigs are kept at the settlement and encouraged to interbreed with male wild boar (Rowley-Conwy *et al.* 2012, 12-3).
The first impact of human management of wild boar is hard to trace in the archaeological record. Just as for sheep and goat, morphological markers have been used to assess the domesticated status of pigs. The postcranial bones of pigs change and decrease in size under the influence of domestication. This stage is a continuous development, which occurs over millennia. So, in the first stages of domestication, domesticated pigs are not expected to be significantly smaller than their wild counterparts (Price and Evin 2017). Overall size reduction coincides with morphological changes (Albarella *et al.* 2006, 212). Research has indicated that pigs probably undergo the largest brain size reduction of all domesticated animals (Zeder 2012, 167), changing the skull shape completely. Furthermore, the snout is shortened, probably related to the fact that rooting for food becomes less necessary. Complete skulls are not often found in the archaeological record, so it is hard to use the changing dimensions of the total skull as a marker for domestication. However, the teeth in the jaw are affected by this skull change as well. Teeth farther back in the jaw seem to be most affected by this size reduction in the first stages of domestication. Interestingly, at some Neolithic sites the M3 is already smaller than those of wild boar, while the M1 did not undergo any size reduction yet (Albarella *et al.* 2006, 213-5). In domesticated pigs often both the width and the length of the M3 decreases. In Neolithic Italy, pigs are found with large postcranial bones but small teeth. Since brain size reduction is thought to be one of the earliest changes, smaller teeth may precede postcranial diminution (Albarella *et al.* 2006, 210-217).

Changing kill-off patterns would also be an indication of human management. In an assemblage of hunted animals, a focus on prime adults would be expected. Domesticated pigs are often slaughtered immediately once they reach full size or slightly before, since pigs are pre-dominantly meat-producers. However, this idea is mainly based on present-day pig farming, where farmers have big herds and only a few older female pigs need to be kept alive to maintain the herd. In the past this might have been different since the population of managed pigs would have been smaller, so possibly a larger percentage of the herd would have been kept alive for reproduction (Rowley-Conwy *et al.* 2012, 24-9). Another complicating factor is that wild boar and pigs have larger litters than most other large vertebrates, and intensified hunting strategies can result in many young individuals in the assemblage (Rowley-Conwy *et al.* 2012, 24-9). Furthermore, seasonal hunting strategies could result in a high percentage of juveniles in an assemblage. Besides, juveniles may well have been easier targets. This is especially true for male juveniles since they are driven away from their mothers earlier than their female counterparts (Rowley-Conwy *et al.* 2012, 23-9). To conclude, ageing has proven to be a useful tool to identify management, but a higher ratio of juveniles does not necessarily indicate humans were herding the population.

Another indication for human management could be change in diet. Wild boar are omnivorous, but most of their diet consists of plant material (Leaper *et al.* 1999, 241). Since they are omnivorous and non-critical eaters, humans can easily adjust their diet. When pigs are kept in the settlement and are fed on domestic waste, which might include animal products, they could become more carnivorous. On the contrary, it is also possible that pigs are mostly or only fed on agricultural waste, or that pigs are led through forests, where they can forage for themselves. In that case, the diet does not differ largely from their wild counterparts (Albarella *et al.* 2006; Hadjikoumos 2012; Rowley-Conwy *et al.* 2012).

As in ruminants, pig coprolites on site could indicate that they were being kept on sites by humans and possibly managed. Omnivore coprolites can be identified by micromorphological analysis of thin sections (Matthews *et al.* 2014, 256-7). Using GC-MS analysis of spot samples omnivore coprolites can be further identified to species level (Shillito *et al.* 2001; Matthews *et al.* 2012)

2.4 Regional overview: The Neolithic transition of the Eastern Fertile Crescent

As discussed in section 2.1, the Zagros region of Iran and Iraq is a large mountainous area. The mountains comprise a series of parallel mainly Cretaceous and Tertiary limestone stretches, reaching up to 4500 metres (Matthews and Fazeli Nashli 2022, 14). In the high Zagros zone has karstic features and Paleozoic rocks can be found (Hessami *et al.* 2006). There is considerable climatic diversity in the Zagros, the higher cooler parts receiving less rainfall than the lower, warmer foothills. Natural vegetation of the region is dominated by oak, pistachio and deciduous trees but pulses, grains and cereals are also abundant (Van Zeist 2008; Chapter 2.1). Climate in the region is extremely diverse, with mean January temperatures ranging from an average of 2 degrees Celsius to 27 degrees in July, but much higher and lower values frequently occur. The plains of the Zagros are nowadays covered in snow for long winter periods (Matthews *et al.* 2013, 15: Chapter 2.1).

Bezoar goat, wild sheep, wild boar and deer have been abundant in the region at least from the Middle Palaeolithic until nowadays (Bökönyi 1977; Firouz 2005). They are frequently locale-specific within zones of the Zagros, with altitude and seasonal temperature the main determining factors in their distribution (Bökönyi 1977; Firouz 2005). In the Middle Palaeolithic goat was the most hunted species by Neanderthal communities, making up the majority of the faunal remains at the sites Hazard Merd Cave, Shanidar level D, Tamtama, Kobeh and Kunji (Zeder 2008; Matthews *et al.* 2013, 15-6). In the Upper Palaeolithic, climatic conditions might have been more severe. Lake core evidence from Zeribar and Meribad shows a lack of tree pollen for the period 35000-12000 cal BC, indicative of an environment of tundra, steppe and scrub-steppe (Van Zeist and Bottema 1977). It is unclear if there was any form of human occupation in the region during this period (Matthews *et al.* 2013, 16). In the Epipalaeolithic, the region became warmer again and cave-sites reappear. In the Epipalaeolithic levels of Shanidar and the close by site Zawi Chemi Shanidar bezoar goat was very still abundant (Zeder 2008). During this period evidence for an overall broadening of the diet is found at several archaeological sites. At Zarzi cave evidence can be found for the hunting of gazelle, wild sheep and goat, but the inhabitants of the cave were also consuming the land shell *Helix salmonica* and fishing (Matthews 2000, 15-6). This trend of dietary broadening is also visible at the Late Upper-Palaeolithic site Palegawra (Matthews *et al.* 2013, 15-6; Asouti *et al.* 2020, 47-60). Onager is the most abundant animal in the zooarchaeological assemblage, but tortoise is very abundant too, and fox and hares were also exploited (Asouti *et al.* 2020, 47-60).

In the Upper Palaeolithic in the Iranian Zagros the main source of meat provision varied highly per site. At Warwasi there was a high emphasis on hunting of onager. At Ghar-i Kar, in contrast sheep and goat were the most abundant animal in the zooarchaeological assemblage. It is hard to draw conclusions from this assemblage because of its small size (N=53) (Hesse 1989). At the cave site Eshkaft-e Gavi, gazelle was the most abundant animal in the zooarchaeological assemblage (Rosenberg 1985). The recently discovered cave site Tutan has a relatively well preserved faunal assemblage dating from the Upper Palaeolithic. The remains include aurochs, onager, wild goat and hare (Heydari-Guran and Ghasidian 2017). No radiocarbon dates are available from these sites, so the reliance of different animals could be the result of the different availability of resources in different time periods, local adaptions to local environment, seasonal differences or a difference in hunting strategies and preferences between different groups of people.

During the climatic event the Younger Dryas (11,000-9600 cal BC) climatic conditions changed over the whole world. Southwest Asia would have been very affected by this climatic event and conditions seem to have become more arid. This change in climatic conditions, however, did not lead to an overall abandonment of the region. Shanidar cave was reoccupied during this period and the open air site Karim Shahir shows strong similarities in material culture with Shanidar so is argued to date from the same period (Matthews *et al.* 2013). At Karim Shahir sheep/goat dominate the assemblage, sheep outnumbering goat (Bendrey *et al.* 2013). Wild boar, deer, gazelle and aurochs were also hunted, but also evidence for consumption of land snail and freshwater mussels has been found (Matthews *et al.* 2013, 16-7). At the B2 levels of Shanidar there is evidence for diet broadening too. Land snail and crab were exploited alongside the hunting of wild goat and sheep (Matthews *et al.* 2013, 16). The late Epipalaeolithic site Zawi Chemi Shanidar is situated in the valley of Shanidar cave and shows trends for diet broadening as well. The faunal assemblage is dominated by wild sheep, juvenile sheep being very abundant (Zeder 1999; Matthews *et al.* 2013). Wild goat is found in smaller frequencies at the sites and relatively more bones derived from adults (Zeder 1999). Based on the sudden increase in frequency and the high number of juveniles it has been argued that these sheep were the first managed population (Perkins 1973). This interpretation has been contested and it is argued that the increase of sheep in the region had to do with changing environmental conditions (Zeder 2008). The increase in juvenile sheep, compared to the older is likely the effect of differential seasonal movement of wild sheep and wild goat (Matthews *et al.* 2013). Apart from this increase in sheep, a possible cultic deposit has been found at Zawi Chemi Shanidar. Close to a circular building a deposit of reddened earth was found, containing at least 15 skulls of wild goat and possibly wild sheep and wing bones of at least 17 different birds, all raptors, including at least 7 white-tailed eagled, 4 smaller eagles, one griffin vulture and one great bustard (Russell 2012). The deposition of caprine skulls, sometimes in association with red ochre and bird bones is a form of ritualistic behaviour more often seen in the Neolithic in Southwest Asia (Russell 2012; Matthews *et al.* 2013).

In the Western Zagros foothills, the same trends of diet broadening are visible in the Late Epipalaeolithic. The zooarchaeological assemblage from the Early Neolithic site M’lefaat is very small, but contains sheep/goat, wild boar, deer and gazelle, as well as both land snail and freshwater shell (Turnbull 1983). Sheep highly outnumber goat in the zooarchaeological assemblage. The adaption of hunting sheep and gazelle shows that adaptions were made to the resources available in the lowland foothills (Matthews 2000, 89-90). The overall trend of diet broadening in the late Palaeolithic has not just been observed in the eastern Fertile Crescent but in various parts of the world (Binford 1968; Flannery 1969; Stiner *et al.* 2000). As reviewed above, Flannery (1969) suggested that this trend of diet broadening raised the carrying capacity of an increasingly human managed environment. So, he argues that this trend is the first necessary step of specialised food production eventually leading to crop rearing and animal husbandry. Stiner *et al.* (2000) suggested this shift was because of the overexploitation of lower ranked resources (Chapter 2.2). In Stiners *et al.* (2000) research at the Mediterranean basin, mainly higher ranked resources such as turtle were heavily exploited in the Middle Palaeolithic, while in the Upper Palaeolithic there was focus on exploitation of small game which would be harder to catch such as birds and hare. It seems that in the Epipalaeolithic in the Zagros both the so-called ‘lower rank’ and ‘higher rank’ small game were exploited so there is no direct evidence for this hypothesis.

During the Younger Dryas there was a hiatus in occupation above altitudes of 1000 metres in the Zagros Mountains (Matthews *et al.* 2013, 17). At the end of the Younger Dryas occupation can be found in the Highland Zagros again. The earliest known occupation found above 1000 metres is at Sheikh-e Abad (1425 m). The radiocarbon dates from the recently excavated highland site range from ca. 9800-9200 cal BC (Matthews *et al.* 2013, 20). The zooarchaeological assemblage is dominated by sheep/goat, goat outnumbering sheep, red deer, large canid, fox and hare are found too (Bendrey *et al.* 2013). The most striking zooarchaeological finds were four goat skulls and one sheep skull deposited in a room together with the wing bone of a large bird (Bendrey *et al.* 2013). The skulls all belong to morphologically wild specimens, but it is unsure whether this population was managed (Bendrey *et al.* 2013). Evidence for ruminant dung has been found on the site, indicating that sheep/goat were possibly kept in captivity at the site (Shillito *et al.* 2013).

The oldest layers of the lowland site Chogha Golan are approximately contemporary with Sheikh-e Abad, dating from ca. 10000-7800 cal BC (Riehl *et al.* 2013). The site may have been inhabited for over 2000 years and is situated in the foothills of the Zagros Mountains (Figure 2.2). Excavations of the site took place recently, and the results are currently subject of further study (Conard *et al.* 2013). Faunal remains document the presence of caprines, wild boar, gazelles, equids, large bovids, rodents, hares, reptiles, birds, fish, mussels, and freshwater crustaceans (Riehl *et al.* 2013). East Chia Sabz is located in the same region as Chogha Golan (Riehl *et al.* 2012) (Figure 2.2), but it is uncertain if the occupation span of the two sites overlaps. Based on material culture, the youngest occupation phases of the site seem to be no older than 7000 cal BC. Sheep/goat are the most abundant animals found on the site, sheep about twice as numerous as goat. The domestic status of both is uncertain, since the bones of both species are all highly fragmented. Therefore, it was not possible to investigate if the animals were morphologically domestic or to reconstruct a kill-off pattern (Darabi *et al.* 2011, 259). Fresh water resources such as fish, freshwater mussels, crab and turtles were also exploited by the inhabitants of Chogha Golan (Darabi *et al.* 2013).

Asiab, Ganj Dareh and Abdul Hosein are all highland sites located close to Sheikh-e Abad and slightly later in date than Sheikh-e Abad (Figure 2.2) (Matthews *et al.* 2013). Asiab was excavated in the 1960's excavated but recently restudied, redated (Zeder 2008) and re-excavated (Bangsgaard *et al.* 2019; Darabi *et al.* 2019a). The site was argued to be contemporary to Shanidar, but is now thought to be dated ca. 8500-8000 cal BC, which makes the site slightly younger than the earliest levels at Sheikh-e Abad. Similar to Sheikh-e Abad, sheep/goat are the most abundant animals in the zooarchaeological assemblage, goat outnumbering sheep (Zeder 2008). The zooarchaeological assemblage showed heavy reliance on hunted wild boar, red deer and aurochs and many clamshells have been found (Zeder 1999; Matthews *et al.* 2013; Bansgaard *et al.* 2019). While the goat at Asiab are morphologically wild, it has been argued that the zooarchaeological assemblage shows the start of herd management. The focus on large wild males was interpreted as killing-off of superfluous males (Bökönyi 1977). This interpretation was not universally accepted, and restudying of the assemblage did not provide any evidence for herd management (Zeder 1999; Zeder 2008). The assemblage mainly consists of both adult males and females (over 4-5) years, so it represents an emphasis on prime age large bodied specimens (Zeder 2008).

Ganj Dareh (8000-7800 cal BC) is the oldest site so far in high Zagros where patterns of animal management are evident (Zeder 2008). The site consists of five levels of occupation (A-E), but overall the site was inhabited for 200 years maximum. The upper four levels contained architecture composed of rectangular structures with thick mud-brick walls, while the lowest, level E, consisted primarly of pits (Darabi *et al.* 2019). Goat are the most abundant animals in all levels, outnumbering sheep on 15:1 ratio (Zeder 1999). Apart from sheep/goat, the zooarchaeological assemblage contains wild boar, hare, deer and aurochs. In addition, there is evidence of crab, crayfish and land snail consumption (Hesse 1978). The presence of house mouse (*Mus musclusus)* has been argued to be evidence for year-round occupation (Hesse 1978, 104). At level E, the oldest level of the site, goat remains are morphologically wild and the ageing profile represents a targeted hunted population. In all the later levels the archaeological assemblage showed focussed kill-off of males between 1-2 years age, while the females were kept alive until after reproducing age (Hesse 1978; Zeder 1999; Zeder 2008). Recent re-excavations and reanalysis showed the presence of foetal goat bones and hoofprints, providing further evidence for the argument that animals were present on site and managed (Darabi *et al.* 2019b, 51; Yeomans *et al.* 2021). The management patterns of goat at Ganj Dareh are a major feature of this thesis (see Chapter 5), since this zooarchaeological assemblage is pivotal to understand the first steps towards goat management.

Bestansur is a mound site in the foothills of the Zagros Mountains (Figure 2.2), which is currently being excavated (Figure 2.3). The site has been radiocarbon dated and gives an age range from ca. 7800-7000 cal BC. The presence of various migratory birds indicates the site may have been occupied year-round (Bendrey *et al.* 2020, 331-2). Excavations of Neolithic levels have revealed mudbrick structures, fire installations, and areas of activities such as lithic working (Matthews et al., 2019). Numerous burial deposits across the site have been encountered, predominantly from two large mudbrick buildings (Matthews *et al.* 2019) Micromorphological analysis has indicated that dung was used as fuel by the inhabitants of Bestansur rather than wood (Matthews 2020).

Sheep/goat are the most abundant animals at the site, sheep outnumbering goat. Wild boar is the third most abundant species (Chapter 4, 5). The zooarchaeology assemblage of Bestansur is investigated in this thesis (Chapter 4, 5), since this site is possibly one of the first lowland sites in the Zagros region where animal management is practiced. Shimshara is a Neolithic site ca. 110 km northeast of Bestansur. Today the region around Shimshara is characterized by mountain forest vegetation and mountain riverine forest vegetation. In phytogeographic terms Bestansur and Shimshara falls into the Kurdo-Zagrossian sub-division of the Irano-Turanian region, which is dominated by climax vegetation mostly in the form of steppe- or park-forests (Elliot *et al.* 2020, 92). Shimshara was previously excavated in 1957 by a Danish-Iraqi team (Mortensen 1970). Both Neolithic and Bronze Age layers were excavated. Since then, the site has been eroded by waters of a dam and a rescue excavation was carried out by the Central Zagros Archaeological Project in 2013. The material excavated has been radiocarbon dated to between 7450 and 7180 cal BC (Matthews *et al.* 2020b, 178-9). Pigs are the most abundant species in the zooarchaeological assemblage from the 2013 excavations, followed by caprines (Bendrey *et al.* 2020). Because of the moderate size of the assemblage it is uncertain if the sheep/goat are managed (Bendrey *et al.* 2020). The faunal remains, specifically the wild boar/ pig remains, will be discussed in detail in this thesis (Chapter 4) since the high abundance of pigs is exceptional in the Zagros region in the Neolithic.

The lowland site Ali Kosh (Figure 2.2) was also excavated in the 1960’s (Hole and

Flannery 1967) and recently restudied by Zeder (2008a), and re-excavated (Darabi *et al.* 2017). The site was occupied from around 7500 cal BC for at least 500 years (Zeder 2008). Unlike sites in the high Zagros wild goat would not have been native to the environment surrounding Ali Kosh, although they would have been abundant in the mountains not far away from the site (Hole and Flannery 1968). Nevertheless, goat is the most abundant animal in the zooarchaeological assemblage (Hole and Flannery 1968). It has been argued that these goats were a domestic population, based on their abundance outside of their native area, combined with their smaller size and the kill-off patterns (Hole and Flannery 1968). Based on the presence of a few hornless individuals they argued that sheep at this site were domesticated too (Hole and Flannery 1968). Zeder's reanalysis of the assemblage supported the claim that the goats were managed based on the kill-off patterns (Zeder 1999, 2008). This supports the idea that goat domestication was developed in the heartland of wild goat, the highland Zagros and later adopted in the lower regions (Matthews *et al.* 2013, 27). No supporting evidence for management of sheep at Ali Kosh was found. In the zooarchaeological assemblage there was a clear emphasis on prime age animals, mainly males (Zeder 2008). The presence of a hornless specimen does not support domestication either since hornlessness occurs in wild sheep (Zeder 2008, 264).

The PPNA site Qermez Dere lies on the plains northwest from the Zagros Mountains. The site dates from slightly before 8000 B.C. continuing into the first half of the eighth millennium. The most abundant animal at the site is gazelle, but there is evidence for fox and hare consumption as well. A variety of birds was found, and wild sheep, onager, and wild cattle were found in smaller frequencies. Wild goat and wild boar were not found at the site. There are no morphologically domestic animals present at the site and no indications for human management of animals have been found (Dobney *et al.* 1999). Clearly this zooarchaeological assemblage differs from the more southern sites in the Zagros, where goat or sheep are the most abundant species in the zooarchaeological assemblages. This could be related to the difference in location as gazelle would be more abundant here on the lowland steppe than in the high Zagros.

No evidence for sheep management has been found at sites in the Zagros until after the introduction of ceramics (Zeder 1999). The site Jarmo is one of the earliest sites in the Zagros region where both domestic goats and domestic sheep are present (Zeder 2008). The exact dating of the Neolithic site Jarmo is problematic, but it contains both Early Neolithic and ceramic Neolithic layers. The site was excavated by Robert Braidwood between 1948 and 1955 (Braidwood and Howe 1960). The site consists of mudbrick buildings and has been interpreted as a permanent, year-round settlement of an early village-farming community. The site reached 1.3 hectares at its greatest extent and the Neolithic inhabitants would have cultivated plants (Braidwood 1982). In both Early Neolithic and ceramic Neolithic periods, goats were the dominant taxon in the zooarchaeological assemblage followed by sheep. However, the sheep population does not seem to be a herded population until the ceramic Neolithic (Zeder 2008). Aurochs, wild boar/pig, gazelle, deer, onager, fox, dog, lion, leopard, lynx, badger and hare remains were also recovered. It has been suggested that wild boar were managed as well (Price and Arbuckle 2015). The animal management patterns of Jarmo will be further discussed in this thesis (Chapter 4, 5), since the sites is relatively long lived and can provide further understanding of the development of management practices from the Early Neolithic into the ceramic Neolithic. The site Guran has both Early Neolithic and ceramic Neolithic occupation phases, with radiocarbon dates ranging from ca. 7000- 5500 cal BC. Domestic goat is present from the earliest levels (Zeder 2008). Sheep increase heavily in abundancy in the ceramic neolithic layers (Zeder 1999). Originally, when the zooarchaeological remains were studied in the 1960’s Flannery argued that the sheep were wild (Zeder 1999). Zeder’s restudy (2008a) of the assemblage found that the kill-off pattern did indicate the sheep population was managed. Sarab is another site excavated in the 1960’s thought to be overlapping in date with the ceramic Neolithic layers of Jarmo and Guran (Zeder 2008). Based on culling profiles, both sheep and goat are managed by humans (Zeder 1999). Also, both sheep and goat are smaller than the earlier ‘wild populations’ but it is uncertain whether this is the direct effect of domestication (Zeder 1999, 16).

It seems that the initial use of domestic sheep in the Zagros is contemporaneous with the initial introduction of domestic goat in the Northern Levant (Zeder 2008). At the site Abu Hureyra the first evidence for goat management is found around 7500 cal BC (Legge and Rowley-Conwy 2000). While in Epipalaeolithic Abu Hureyra the zooarchaeological assemblage was dominated by gazelle, onager, fox and hare were also present, but declined over the Epipalaeolithic. In the Neolithic levels, caprines rapidly become the most abundant animals while the relative abundancy of gazelle drops (Legge and Rowley-Conwy 2000). Domestic cattle reached the EFC very late. There has been no strong tradition of aurochs’ exploitation in the Palaeolithic and Early Neolithic in contrast to the Western Fertile Crescent. It is not until the sixth millennium cal BC that domestic small cattle are first found in the EFC. The small cattle arrived suddenly in the region and there is no slow decrease in size, implying there was no local cattle domestication (Arbuckle *et al.* 2016).

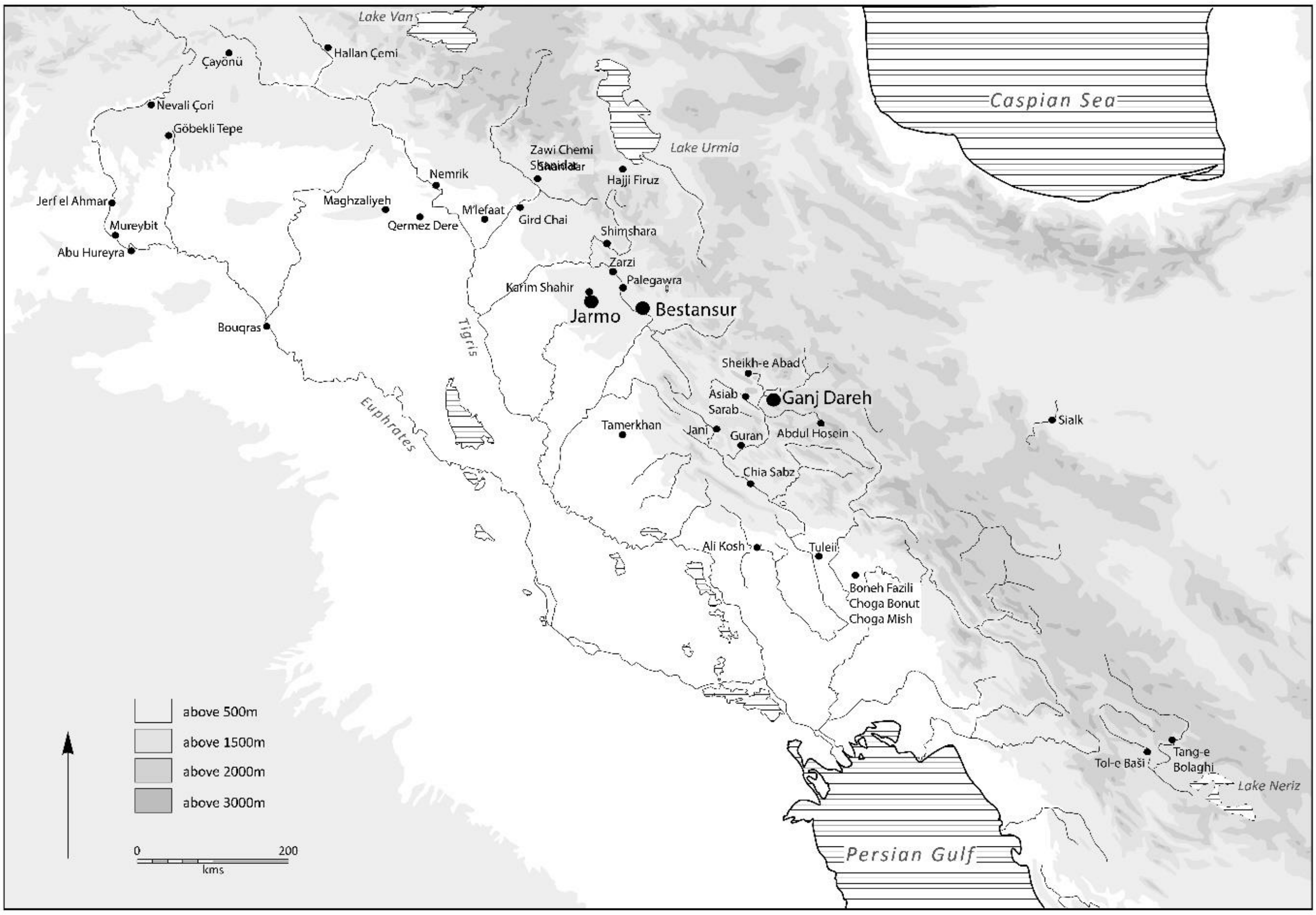

Figure 2.2: Epipalaeolithic and Neolithic sites in the Zagros region (Map created by Amy Richardson).

Figure 2.3:Picture of the end of the 2019 excavation of the Neolithic site Bestansur, trench 10 East side of the mound (picture by Roger Matthews).

2.4.1 The Neolithic transition of the Western Fertile Crescent: a comparative study

The development of agriculture and domestication in the Western Fertile Crescent (hereafter WFC) has been more extensively studied than the EFC. The area has long been regarded as the key area for the development of agriculture. Therefore most of the chronological terminology for the development of agriculture is based on developments in the WFC. Because this area is well studied it provides a valuable comparison to the Eastern Fertile Crescent. The chronological terms Natufian, Pre-Pottery Neolithic A, Pre-Pottery Neolithic B (PPNB, ca. 8700-6800 cal BC), Pre-Pottery Neolithic C, Pre-Pottery Neolithic (PPN, ca. 9,700-6,200 cal BC) and Pottery Neolithic are based on the developments in the WFC, and therefore only applied on sites in the WFC. However, the developments and traditions associated with those time periods are comparable in the EFC (Table 2.1).

Table 2.1: Chronological terminology of the WFC compared to the EFC (after Matthews et al. 2020: Table 1.1).

WFC	Years BC	EFC	Years BC
Late Epipalaeolithic	12000 – 10000	Late Epipalaeolithic	15000 – 10000
PPNA	10000 - 8700	Early Neolithic/ Pre-pottery Neolithic/ Aceramic Neolithic	10000 - 7000
Early PPNB	8700 - 8200		
Middle PPNB	8200 - 7500		
Late PPNB	7500 - 7000		
Pottery Neolithic	7000 - 6000	Pottery Neolithic	7000 - 5200

Most of the Natufian period and settlements are found in the Levant. In the Natufian people were not sedentary, but large semi-permanent occupations with substantial architecture were common. The Natufian is well known for the first large cemeteries, diverse ground stone tool assemblages, long distance travel of goods and numeral personal adornments (Bar-Yosef 1998; Goring-Morris and Belfer-Cohen 2008; Richter *et al.* 2011). Subsistence practices changed as well during this period. Natufian communities heavily relied on gazelle hunting, but also started to exploit small game of all sorts, such as turtle, birds, aquatic resources, including both fish and shellfish, and small mammals (Munro 2004; Munro and Atici 2009; Bar-Yosef Mayer and Zohar 2010). This broadening of the diet seems to be a similar development to the development in the Zagros in the Epipalaeolithic (Chapter 2.2).

In the PPNA most settlements were larger than Natufian settlements and they were occupied year-round (Belfer-Cohen and Bar-Yosef 2002). PPNA sites are characterized by rounded or oval mudbrick houses. Storage of food in large storage facilities are found at most settlements (Bar-Yosef 1989). Subsistence practices were based on wild legumes and hunting of animals (Belfer-Cohen and Bar-Yosef 2002). Experimenting with the cultivation of cereals and legumes possibly started, however there are no clear signals for domesticated cereals. The collection of wild fruits and plants continued (Belfer-Cohen and Goring Morris 2010). The communities did not rely on domesticated animals. Wild game species as gazelle, wild ass and fallow deer are most represented in PPNA zooarchaeological assemblages (Bar-Yosef 1989; Belfer-Cohen and Bar-Yosef 2000). These foragers, however, developed different new relationships with animals, which were different from strict hunter-prey relations. The best example of this is visible at archaeological sites in Cyprus, where several new species, including sheep, goat, aurochs, fallow deer and cat were introduced by humans. Introduction of wild species to new areas by humans is not attested before this event (Vigne *et al.* 2012).

Almost all PPNA villages were abandoned within a few centuries (Bar-Yosef 2011). In the PPNB several PPNA sites were re-occupied but the architecture of the sites changed. Instead of round houses, the PPNB is characterised by square-houses and storage units located within the houses (Bar-Yosef 2001). It was possibly not until the middle PPNB that communities which relied on domestic products appear. Sheep and goat are not morphologically domesticated during the beginning of the PPNB. Changes in culling patterns in sheep, pointing towards human management, are visible from ca. 8500 cal BC in southeastern Anatolia (Zeder 2008). Goat was possibly firstly brought under domestication in the Zagros region, but independently domesticated in other areas in the Fertile Crescent (Zeder 2008). Managed goat spread throughout the region faster than managed sheep (Zeder 2008, 265). In the Euphrates basin caprine management seems to have been practiced, but there is no evidence for culling of young excess males (Arbuckle and Atici 2013). The caprine herds might have been substantially smaller in this region than in the Zagros and that access to wild caprines was limited (Arbuckle and Atici 2013). Because these populations were more isolated, they likely developed phenotypic changes faster than the managed populations in the Zagros region (Arbuckle and Atici 2013, 230). However, even in southeastern Anatolia, where wild sheep was heavily exploited before they were domesticated, young male culling was not a primary step of animal management either (Arbuckle and Atici 2013). Wild sheep are not native to the Southern Levant and are introduced in the Northern part of the Southern Levant around the second half of the 9th millennium BC (Arbuckle 2014). This indicates that in the early Neolithic caprine management strategies are highly localised (Arbuckle 2014). In the WFC a stronger tradition of cattle herding exists too. Aurochs was exploited before domesticated in the Euphrates and

Tigris valley. There is a slow transition over several millennia from larger to smaller bovids at multiple sites, which implies they were domesticated locally at multiple centres (Arbuckle *et al.* 2016).

So, similar developments occurred in the Epipalaeolithic in the WFC and the EFC. In both regions an overall trend of broadening of the diet was visible. In the EFC no clear phase of abandonment of settlements has been found, as has been found at the end of the PPNA in the WFC. Also the first steps to domestication in the WFC seem to have been different from those in the EFC. While in both regions caprines were the earliest domesticated livestock species, in the WFC both sheep and goat were domesticated and young male cull was not a first step of animal management.

2.5 Regional overview: The Neolithic transition of Iran beyond the Zagros

In order to investigate the diffusion of Neolithic lifeways from proposed core regions, such as the central Zagros, in this section evidence for a possible eastwards transmission of sedentary farming lifestyles across Iran, including animal husbandry will be discussed. The eastward expansion of the Neolithic from the Zagros across the Iranian Plateau likely followed two routes dictated by the landscape, north and south of the great Dash-e Lut desert of central Iran (Figure 2.1) (Matthews and Fazeli Nashli 2022, 86). However, traditionally the Zagros region has been the subject of more archaeological investigations than the Iranian Central Plateau beyond the Zagros (Weeks 2013, 56). Therefore, the Neolithic transition of Iran beyond the Zagros is less understood. The main focus of this regional overview is on the Caspian Littoral, since this region is crucial for our understanding of the eastward spread and development of the Neolithic.

So far, it has been argued that initial dispersal of the Neolithic outward from the Zagros region across Iran was a major movement of people with new herding and farming practices, bringing their animals and crops with them (Matthews and Fazeli Nashli 2022, 79) and that the whole of Iran outside the Zagros region was possibly very sparsely inhabited and continued the hunter gathering lifestyle during the period of 10000-6000 cal BC (Weeks 2013; Matthews and Fazeli Nashli 2022, Chapter 4). However, Iran is a very big, climatically diverse area (Weeks 2013; section 2.1). In other regions such as Anatolia and the WFC early animal management strategies varied locally (Arbuckle and Atici 2013; Arbuckle *et al.* 2014). Furthermore, the same species were not adopted everywhere; the westward expansion of the Neolithic did not involve a set ‘package’ (Arbuckle *et al.* 2014). So, it could be possible that husbandry and farming strategies developed in varied ways in different regions of Iran. Both environmental and cultural factors might have led to the adoption and adaptation of different herding practices per region. In addition, Iran is the homeland of most of the introduced domesticated species, so multiple local domestication events or intermixing of wild and domestic animals cannot be ruled out.

However, there are a number of problems with zooarchaeological data from Iranian sites, especially with those of older sites. Firstly, the older excavations are often poorly documented and stratigraphic records are poor (Harris and Coolidge 2010, 57; Leroy *et al.* 2019, 350). Also, the identifications of animal bones made at the time might be erroneous, since faunal assemblages were not commonly studied (Mashkour and Bon 2019, 47). Sieving was not common practice during older excavations, leading to a recovery bias of bigger bones and animals. Although this also continues to be an issue in more recent excavations where sieving is not employed as a standard procedure (Mashkour 2006; Gręzak *et al.* 2010). A further issue in comparing sites is the publication format of the data and nature of the zooarchaeological assemblages are also problematic. Complete species lists are not always provided in the publications, which makes it difficult to compare subsistence economies from different sites with one and another. Publications almost never include fusion data and mandible wear stages, essential to determine age of the specimens (Chapter 3). Also, measurements are rarely provided, and it is therefore not possible to compare the size of domestic and non-domestic mammals over mainland Iran and integrate these data with the Zagros region. This is often not caused by incomplete publication or research, but because most bone assemblages from the region are small and the bones are often very fragmentary (Berillon *et al.* 2009; Dobney and Jacques 2010; Gręzak *et al.* 2010; Pollock and Bernbeck 2011; Roustaei *et al.* 2015; Rezvani and Roustaei 2016).

2.5.1 The Epipalaeolithic and Neolithic on the Caspian Littoral and northeast Iran

The region along the Caspian coast shows more evidence for pre-Neolithic occupation than central Iran (Matthews 2019). In the Epipalaeolithic, intensive seal hunting was very common on the Caspian coast as shown at the sites Hotu, Ghar-i Kamarband and Ali Tappeh. Cave sites Hotu, Ghar-i Kamarband and Ali Tappeh were excavated in the 1950s and 1960s. Hotu and Ghar-i Kamarband (also named Belt cave) have been recently re-excavated and the re-excavations of Hotu cave will be a major part of this thesis (Chapter 6).

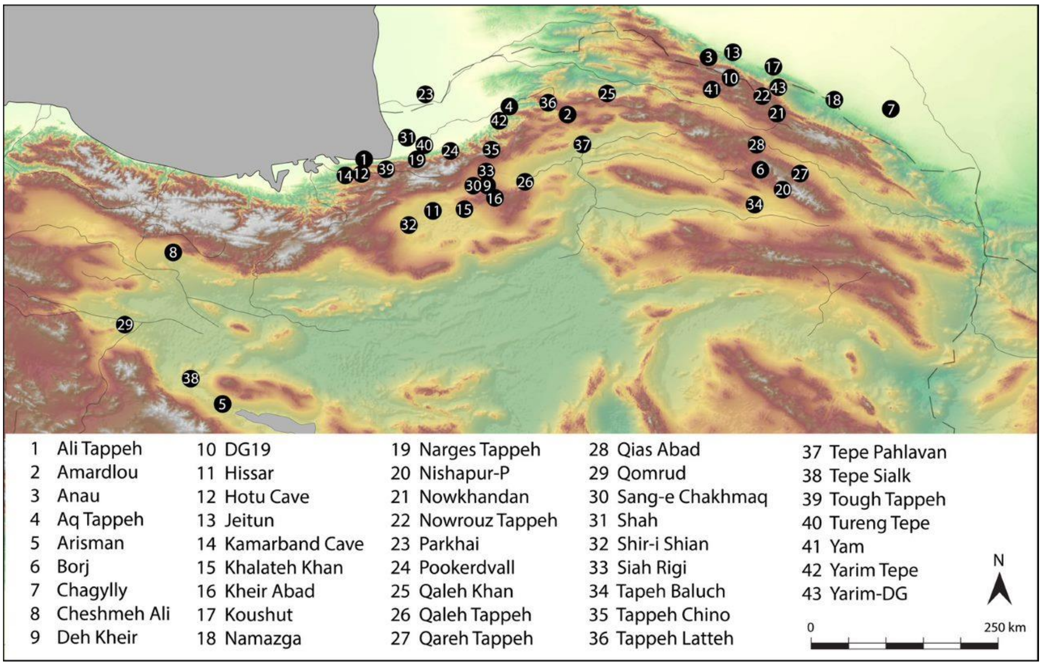

Figure 2.4: Epipalaeolithic and Neolithic sites in northeast Iran (Matthews and Fazeli Nashli 2022: Fig. 5.54. Map created by Amy Richardson).

The early phases of these three sites are all overlain by later phases of occupation and the stratigraphic information from original reports is ambiguous (Coolidge 2010, 55). The prehistoric layers from Ali Tappeh are all Epipalaeolithic; radiocarbon dates display ages from ca. 11200-9800 cal BC (Manca *et al.* 2018). Gazelle is the most abundant species in the zooarchaeological assemblage in all stratigraphic layers, although the relative abundance of gazelle decreases over time and the of seals sharply increases (McBurney 1969; Harris and Coolidge 2010). Other animals exploited were onager, wild sheep, aurochs, wild boar and fox as well as birds (Manca *et al.* 2018). Clearly the inhabitants of the site used varied resources and exploited the different types of environments available to them. The presence of gazelles indicates a steppe environment, while boar and aurochs normally live in more covered spaces and clearly the inhabitants were exploiting resources from the Caspian Sea too (Manca *et al.* 2018, 139). The in decrease in the exploitation of gazelle and increase in seal exploitation, as well the increase in gazelle and decrease in seal exploitation have been argued to reflect changes in vegetation and high and low Caspian Sea Levels respectively over time (McBurney 1969; Harris and Coolidge 2010, 55). Ghar-i Kamarband and Hotu both have Epipalaeolithic and Neolithic layers. The Epipalaeolithic layers from Ghar-i Kamarband date to 11350 cal BC and the Neolithic occupation begins at ca. 7500 cal BC. Hotu's Epipalaeolithic layers date between 12800 and 8900 cal BC (Harris and Coolidge 2010, 56), and later layers date between 7500-4000 cal BC (Leroy *et al.* 2019, 350), but these levels have been re-dated for this research (Chapter 6). The sites were both first excavated for two seasons over a course of nine weeks, but with a lack of rigour in the recording of the finds (Harris and Coolidge 2010, 57; Leroy *et al.* 2019, 350) and only part of the animal assemblage was published (Coon 1951). Nevertheless, clear changes in faunal assemblage at Hotu cave were said to have been observed over time. In the oldest Epipalaeolithic layers, gazelle are present, but they are absent from all Neolithic levels. Goat and aurochs also begin to appear towards the top of the upper Epipalaeolithic horizon; whereas the lower Epipalaeolithic layers are dominated by red deer, Caspian seal and water birds (Leroy *et al.* 2019, 350). The inhabitants made use of resources from different environments. Coon (1951) documented a large ratio of young goat in the late Epipalaeolithic horizons, which he interpreted as evidence for the start of goat husbandry in the late Epipalaeolithic (Coon 1951, 50). He also suggested that domesticated sheep, pig, dog, and cattle were present in the Neolithic layers of the site (Coon 1951, 1957). However, no analysis has been published to verify these statements (Harris and Coolidge 2010, 57). The site of Hotu was re-excavated in 2021 by a team directed by Hassan Fazeli Nashli from the University of Tehran (Figure 2.5). The re-excavation of the site uncovered 124 stratigraphical layers, with archaeological layers spanning from the Epipalaeolithic to the Parthian period. Further analysis of the material found during this excavation is still ongoing. The zooarchaeological assemblage from the re-excavation of Hotu cave in 2021 forms a key component of this PhD thesis (Chapter 6), since it provides an unique insight in changes of animal abundancy and animal management from the Epipalaeolithic into the late Neolithic.

Komishani cave and Komishani Tepe are both sites on the Caspian Sea shores (Figure 2.4) which have been recently excavated. Komishani cave had highly disturbed and potentially looted stratigraphic levels containing mixtures of Iron Age, Bronze Age and Chalcolithic pottery and Neolithic flint tools, but an undisturbed Epipalaeolithic layer. Radiocarbon dates from these layers provides ranges from 12096 -11777 cal BC and 10811-10711 cal BC (Vahdati Nasab *et al.* 2011). Only the animal bones from the Epipalaeolithic layers have been studied, since the analysis of unstratified looted layers would not generate valuable information. Gazelle is the most abundant taxon and no caprines have been found at the site. Wild boar, fox and birds have been identified as well (Maskhour *et al.* 2010). Only three fish bones and two molluscs were present in the assemblage and no seal bones. The different types of bird found at the site provide an indication of the different types of environments which were exploited (Mashkour *et al.* 2010). Komishani Tepe, situated in the valley in front of Komishani cave was excavated in 2017. The horizons of the site span from the late Epipalaeolithic into Early Neolithic dating from between ca. 14300-14200 and 9200-8200 cal BC (Leroy *et al.* 2019). Few animal bones have been found at the site, but sheep and goat are the most abundant species in both the Epipalaeolithic as in the Neolithic layers. Wild boar, aurochs, fox and deer are also present as well as a large variety of water birds, but there is no evidence for the exploitation of marine resources. The zooarchaeological assemblage of the Late Epipalaeolithic and Neolithic does not differ in terms of species found. Stable carbon and nitrogen isotope analysis of sheep and goat bones does not show any differences in diet between wild and Neolithic sheep and goat (Leroy *et al.* 2019, SI).

Tappeh Sang-e Chakhmaq is a later Neolithic site further away from the coast in the Alborz Mountain foothills (Figure 2.4). The site consists of a West Mound and an East Mound, situated 100 metres apart from each other, which date around 7000-6700 cal BC and 6200 to 5300 cal BC respectively (Roustei *et al.* 2015, 591). Both the West and the East Mound were first excavated in the 1970s and have been re-excavated more recently in 2009. The West and the East Mound show no change in the general spectra of plants exploited and the lithic tradition remains unchanged. However, the architecture of the site varies and while no pottery has been found at the West Mound, at the East Mound pottery has been recovered resembling the Jeitun culture style, which is commonly found in Turkmenistan further east (Roustaei *et al.* 2015). The excavations in 2009-2010 uncovered about 400 identifiable animal bones. Sheep and goat were the most represented species, with goat outnumbering sheep at both the east and West Mound. Based on the size of the bones and size and shape of the horn cores it is argued that the goat were already fully domesticated in the earliest layers of occupation of the West Mount. According to the authors the goat are smaller than those at Ganj Dareh, but no measurements are provided (Roustaei *et al.* 2015, 582). The kill-off pattern based on tooth wear from the West Mound indicates most goat died between six months and two years, which suggests they were mainly kept as a source of meat (Roustaei *et al.* 2015, 590). The domestic status of the aurochs and sheep at the site is unknown. Gazelle remains very abundant, and is the most common in the zooarchaeological assemblages after caprines (Roustaei *et al.* 2015).

During a survey project another Neolithic site, just 2.5 km away from Sang-e Chakhmaq has been discovered (Roustaei 2012) (Figure 2.4). Two radiocarbon dates from this site, Deh Kheir, date between 6050-5600 cal BC, which indicates that the site was possibly contemporary with the East Mound of Sang-E Chakmaq (Rezvani and Roustaei 2016, 20). The faunal assemblage of Deh Kheir is very similar to that of Sang-e Chakhmaq.

At Deh Kheir the inhabitants exploited both wild and domestic taxa, goat is the most common domestic animal and gazelle the most abundant wild animal (Mashkour *et al.* 2016). No domestic sheep were identified (Rezvani and Roustei 2016, 22). It is unclear whether domestic sheep were not kept at all, or if it is due to the small zooarchaeological assemblage that they are absent from the site (Rezvani and Roustaei 2016, 22). Domestic cattle were present, but in small quantities. Neither domestic pig nor wild boar have been identified at the site, which seems to have been absent at all sites in the region (Mashkour *et al.* 2016; Rezvani and Roustaei 2016, 22). During the same survey project, Qaleh Khan (Figure 2.4) was discovered and subsequently excavated. Radiocarbon dates of the site range from 5600-5300 cal BC (Roustaei 2016, 61). This site is situated between two seasonal or semi-permanent drainages on an alluvial fan. The inhabitants were agro-pastoralists who kept domestic goat, sheep and cattle. Gazelle, wild boar and wild equid are found too, indicating wild resources were used alongside domestic animals (Roustaei 2016, 64).

The exploitation of different types of food sources such as shellfish and seal cannot be directly linked to developments such as the broad spectrum revolution since shell already seems to have been exploited in the Upper Palaeolithic at the Caspian Littoral. Goat and sheep are clearly the most exploited domestic animals during the Neolithic in the region. There is no evidence for the presence of domestic cattle, except for the Late Neolithic site Khalateh Khan. No domestic pigs are present at any of the sites and also wild boar is rare. Sheep and goat were already present and exploited in the Late Epipalaeolithic and there seemed to have been no significant difference in diet of sheep/goat between the Late Epipalaeolithic and Neolithic (Leroy *et al.* 2019). This might indicate local domestication rather than the introduction of species from a different area. Ancient DNA evidence argues against single common origin of domestic goat and sheep but has not indicated a local domestication event in Iran outside of the Zagros region (Perdrosa *et al.* 2005; Naderi *et al.* 2006; Daly *et al.* 2018). Since there is no large body of data available to compare size and kill off patterns of sheep goat from the Epipalaeolithic to the Neolithic, little can be said about their domestic status and if management practices were developing. Further research must be done in this area to get a better understanding of the development of the Neolithic and animal husbandry. In Chapter 7 new evidence from Hotu Cave will be discussed.

Figure 2.5: Picture of the excavation at Hotu cave during the 2020 field season (picture by Hassan Fazeli Nashli)

2.5.2 The Neolithic of Turkmenistan

Current day Turkmenistan is a very important region to understand the spread and development of the Neolithic outward of Iran into Central Asia (Matthews and Fazeli Nashli 2022). So far, there is no evidence for local domestication and an independent development of agriculture in Turkmenistan, but little is known about the area (Harris 2010, 91-2). The so called Jeitun phase, with distinctive pottery starts in Turkmenistan around 6000 cal BC. The Neolithic site the culture has been named after, Jeitun, is a small mound in the foothills of the Kopet dag. The site was initially excavated between 1950-1960 and later multiple field seasons were held between 1990-2010 (Harris and Gosden 2010). Radiocarbon dates of the site fall between 6300-5600 cal BC, although the time the site was occupied might have been shorter (Harris *et al.* 2010, 121-2). Sheep and goat were the only domestic animals found at the site, goat outnumbering sheep, but they make up the vast majority of the zooarchaeological assemblage. Due to the quite small (n=538) and fragmentary nature of the zooarchaeological assemblage little can be said about the husbandry strategies. Wild animals were found too, including gazelle, tortoise, fox, hare, small rodent and some reptiles (Dobney and Jacques 2010). During the recent excavations, all sediment was sieved, in contrast to most excavations in Iran, so this might explain the higher number of smaller animals found at this excavation.

Monjukli Depe is a Neolithic site also situated just over the border of current day Turkmenistan, in the foothills of the Kopet dag (Figure 2.4). The site has both Neolithic and Chalcolithic layers, the Neolithic occupation dates between 6375-5900 (Pollock and Bernbeck 2011, 183-184). Only 195 bones from the Neolithic period could be identified of which 188 were sheep/goat. The very high abundance of sheep and goat in the archaeological assemblage suggests a reliance on domesticated species. Since the bones are very fragmentary, it is not possible to ascertain if sheep or goat were more common in the herds (Pollock and Bernbeck 2011, 209-213). Two cattle bones were recovered from Neolithic layers, but the domestic status of those is uncertain, and no wild boar/pigs were found. Gazelle (n=1) and onager (n=2) were also attested. The Jeitun style sites do not seem to differ much from the nearby sites in Iran. Domestic caprines were the most common animals and domestic cattle was possibly present but not in large quantities.

2.5.3 The Neolithic of Central Iran

The Iranian Plateau was possible sparsely inhabited during the Palaeolithic. Few Iranian Upper Palaeolithic sites in Central Iran have been found, but it remains unclear whether this is the result of the distribution of archaeological investigations or because of the nature of human activity and distribution in the Upper Palaeolithic. The Zagros region would have been a favourable location for early modern humans. Caves are very abundant, which provide shelter and there is access to drinking water and raw materials (Darabi 2015, 22; Matthews and Fazeli Nashli 2022, 39-41). Human presence in the Palaeolithic and Epipalaeolithic outside the Zagros region is best documented in northeast Iran (Matthews 2019, 14). The Neolithic also seems to have arrived late on the Central Iranian Plateau. The whole of the Central Iranian Plateau was possibly very sparsely inhabited and continued the hunter gathering lifestyle during the period of 10000-6000 cal BC (Weeks 2013; Matthews and Fazeli Nashli 2022; Chapter 5) (Figure 2.6; 2.7). No Early Neolithic sites have been found in this region (Fazeli Nashli *et al.* 2019). All Neolithic sites in Central Iran seem to have fully adopted the Neolithic lifestyle; pottery, cultivation of cereals and pulses and animal husbandry are all present (Matthews and Fazeli Nashli 2022, 102-4).

Tepe Sialk is possibly the most well known site in this region, first excavated by a French team in the 1930’s but recently re-excavated by the Iranian Centre for Archaeological Research (Curtis 2019) (Figure 2.6). The site consists of a North and a South mound, which were inhabited during different times. The occupation at the North Mound starts around 6000 and 5700 cal BC and lasts until 4900 cal BC. After a hiatus in occupation of 800 years, the site is inhabited again at the South Mound around 4100 cal BC (Curtis 2019, 2). The animal remains from the old excavations have been re-studied and new excavations yielded some new animal remains (Mashkour 2004; Mashkour and Bon 2019). At the original excavations, both wild and domestic sheep and goat have been identified, as well as gazelle, horse, wild boar/pig and cattle (Mashkour and Bon 2019). The new excavations and the restudy of the old zooarchaeological assemblage confirmed the presence of domestic sheep and goat from the earliest layers (Mashkour 2004; Mashkour and Bon 2019). In addition, micromorphological analysis indicates trampled burned herbivore excrement and straw on floors which has been interpreted as burned stable floors or seasonal burning of livestock waste (Kourampas *et al.* 2013, 195). This indicates sheep and goat were both fully morphologically domesticated and managed locally from the start of the occupation. Only a very small number of wild caprines have been found and the most abundant wild animal is gazelle. The domestic status of the wild boar/pig and the aurochs/cattle is uncertain. The restudy of the zooarchaeological assemblage indicated that wild onager was present, so hunted resources were still exploited (Mashkour 2004; Mashkour and Bon 2019, 48).

Two other ceramic Neolithic sites on the Tehran plain, Tepe Pardis and Cheshmeh Ali (Figure 2.4), have also been excavated. Very few animal remains (N<50) could be identified to species level at those sites, so the zooarchaeological assemblages cannot be compared to others in the region (Young and Fazelhi Nashli 2013). Tepe Ebrahimabad was identified during a survey in 2001 and partly excavated in 2006 (Fazeli Nashli *et al.* 2009). The site was continuously occupied in the Late Neolithic, from 5600-5200 cal BC. The ceramic shows similarities with pottery from Chahar Boneh. The archaeological assemblage is dominated by domestic caprines. In contrast to the slightly older sites in the central plateau, very few wild animals are found, indicating subsistence was based on pastoralism (Fazeli Nashli *et al.* 2009; Young and Fazeli Nashli 2013). Tepe Khaleseh lays higher in the Qazvin plain (Figure 2.4). The site was identified during a survey in 2001, but was already heavily damaged by current land use and illegal excavation. Therefore, a rescue excavation was carried out in 2009 (Grężak *et al.* 2010). The site has similar pottery styles to early Chahar Boneh and therefore is thought to date between 6000-5500 cal BC (Valipour *et al.* 2012, 2). Animal remains found at the site were fragmented but 71% (n=9700) of them could be identified. Caprines make up 90% of the identified material, although it is not possible to ascertain how many of these belong to domesticated specimens due to the fragmentary nature of the assemblage. Aurochs/cattle and wild boar/pig bones are present, but it is also impossible to determine whether they came from wild or domestic individuals (Gręzak *et al.* 2010). In all central Iranian sites collated within this review, domestic caprines seem to make up the vast majority of the zooarchaeological assemblage. The archaeological evidence from Sialk indicated that caprines were kept at the site, which indicates that they were closely managed. This might have been the case at all pottery Neolithic sites at the Central Iranian Plateau.

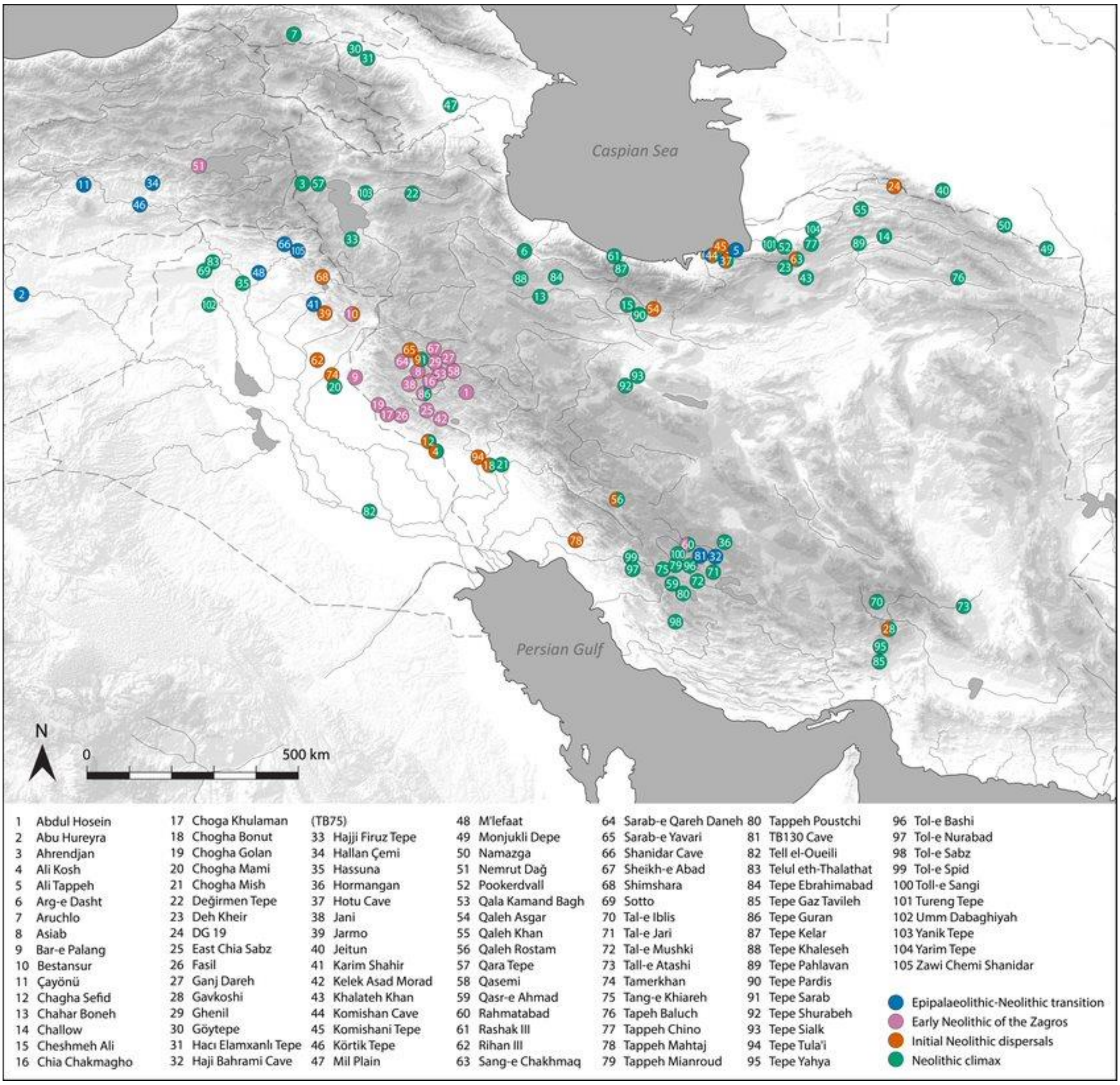

Figure 2.6: Epipalaeolithic and Neolithic sites in Iran (Matthews and Fazeli Nashli 2022: Fig. 5.1. Map created by Amy Richardson).

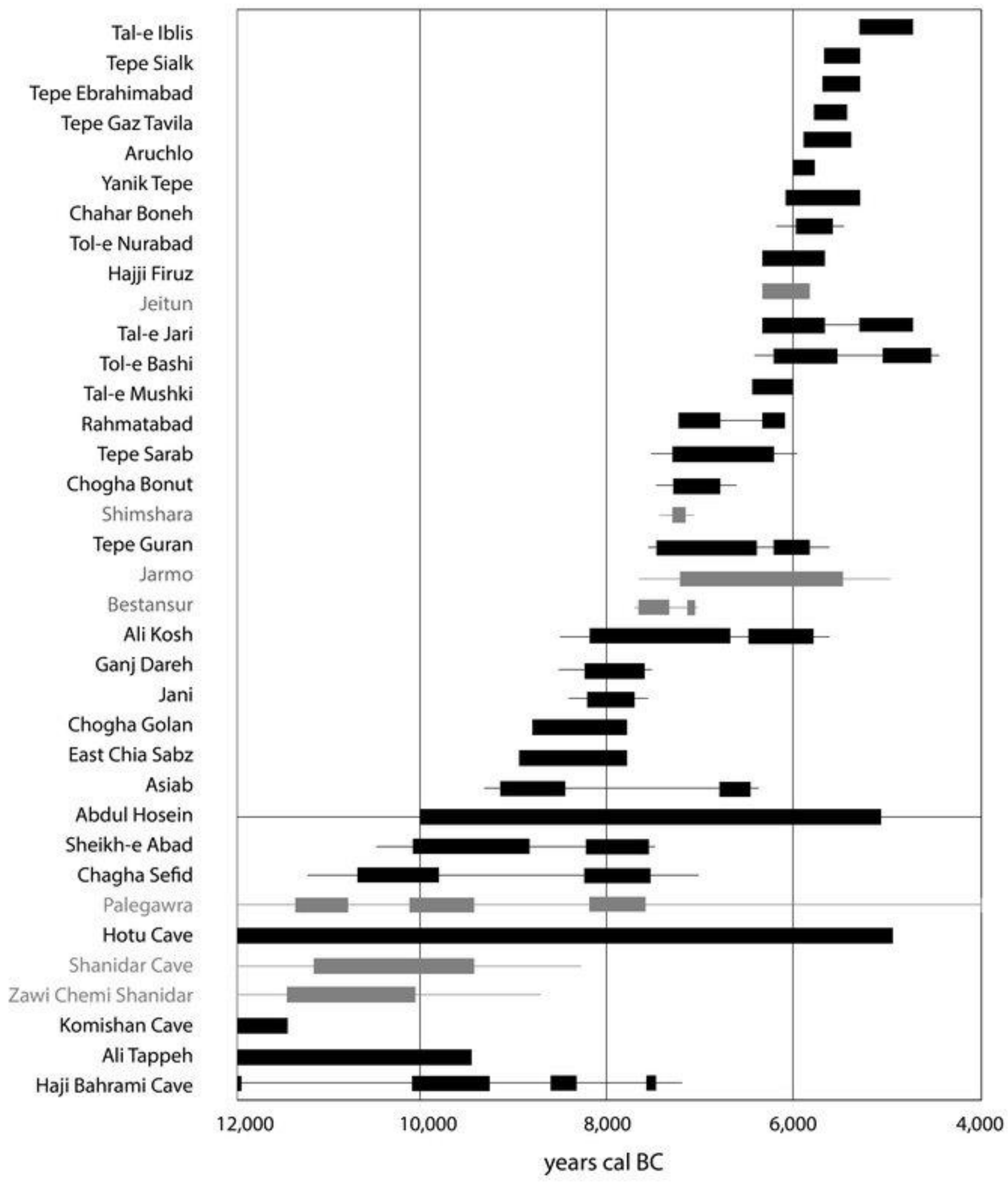

Figure 2.7: Chronology of Epipalaeolithic and Neolithic sites in the Eastern Fertile Crescent and Iran, sites in Iraq are in grey and sites in Iran in black (Matthews and Fazeli Nashli 2022: Fig. 5.2).

2.6 Stable Isotopes in Southwest Asia

Stable isotope research has been widely applied in archaeology over the past decades on both bone collagen and teeth enamel to get a better understanding of human animal relationships. In research on the Neolithic and animal domestication stable isotopic analysis on bone collagen and tooth enamel has been used to gain insight into foddering practices and transhumance (Balasse *et al.* 2002; Pearson *et al.* 2007; Henton 2012; Makarewicz and Tuross 2012) important for the first steps of domestication.

Makarewicz and Tuross (2012) analysed the stable isotopic composition of carbon and nitrogen in bone collagen of gazelle and goat in the Middle and Late PNNB sites Abu Gosh and Basta in the Southern Levant. Their results showed likely human involvement in the diet of goat. The diet of gazelles at both Abu Gosh and Basta represents a restricted wild isotopic dietome, while the isotope ratios of goat at both sites is very varied.

Pearson *et al.* (2007) applied stable carbon and nitrogen isotopic analysis on bone collagen of sheep and goat from Neolithic and Çatalhöyük and Aşıklı Höyük. Their results showed a change in management practices over time at Çatalhöyük. In early phases the diet of the caprine populations was isotopically uniform, but during the later phases of the Neolithic the diet becomes more varied per individual. It has been suggested that flocks were separated and pastured in different areas. The results of stable isotopic analysis from Aşıklı Höyük indicated that the diet of caprines did not include any C_4 plants, while they were present in the area (Pearson *et al.* 2007), since the stable isotopic analysis of wild cattle indicated that C_4 resources were present within their diet. Thus, it has been argued that people possibly kept the animals close to the site and exercised a high level of control over the movement or diet of the flock, excluding C_4 plants from their diet (Pearson *et al.* 2007). Stable isotopic analysis on bone collagen has not widely been applied in the Zagros region, although bone collagen at some sites can be well enough preserved to give reliable results (Bocherens *et al.* 2000; Müldner 2013).

In addition, sequential sampling of caprine teeth has been applied in multiple regions in the Southwest Asia (Henton 2012; Makarewicz 2017; Maskhour 2003). Mashkour (2003) carried out oxygen and carbon isotopic analysis on modern day sheep and goat teeth from the Iranian Zagros with known life-history. The results confirmed that transhumance in the Zagros was visible. Also, a fair distinction between sheep and goat was visible. Henton (2012) used sequential sampling of oxygen isotopic analysis combined with dental microwear analysis on molars of the PPN and PN site Çatalhöyük East (7400- 6000 cal BC) in central Anatolia. The research showed that the herders did not manipulate birth season or carry out long distance transhumance. The inhabitants of Çatalhöyük East did not seem to exercise close control over the flocks but let them graze in grasslands nearby. Makarewicz (2017) sampled molars for stable oxygen and carbon analysis from sheep, goat, aurochs/cattle and gazelle from two Neolithic Jordanian sites, ’Ain Jammam, and el-Hemmeh. The results showed opposing carbon and oxygen cycles in sheep and goat. Sheep and goat eat both exclusively C_3 plants during the summer months and more ^{13}C enriched plants during the winter months. This might indicate that the animals were moved to higher elevations during summer months, since C_4 plants do generally not grow in these higher regions. It could be also possible that people gave the flocks ^{13}C enriched fodder during winter months (Makarewicz 2017).

In this study stable isotopic analysis will be used on bone collagen of sheep, goat, pigs and various wild animals. This will be done to get a closer insight in possible differences between sheep, goat and other wild herbivores and therefore possible human foddering strategies. Isotopic differences between caprines could indicate human influence over diet, by restricting them access from certain food sources as argued to have happened at Aşıklı Höyük (Pearson *et al.* 2007) or by providing them extra fodder. Isotopic analysis on bone collagen of pigs could indicate possible contact with humans. If pigs come in contact with humans or are managed by humans their diet could change. Wild boar are omnivorous, but most of their diet consists of plant material. However, since pigs are omnivorous and non-critical eaters, their diet can be adjusted by humans in many ways. When pigs are kept in the settlement and are fed on domestic waste, which might include animal products, this would make the pigs more carnivorous. It is also possible that pigs are mostly or only fed on agricultural waste, or that pigs are led through forests, where they can forage for themselves. In that case, the diet would not differ largely from their wild counterparts (Albarella *et al.* 2006, 221-2).

2.7 aDNA of the Eastern Fertile Crescent and Iran

Recently aDNA has also provided more information on the domestication of plants and animals. Both mtDNA and genomic DNA have revealed useful information about the spread and early domestic traits of animals. Also, DNA of modern domesticated animals can reveal the genetic basis of domestic traits (Zeder *et al.* 2006; Daly *et al.* 2018; Frantz *et al.* 2020). mtDNA has mainly been used to document the locations of domestication centres and the dispersal of domestic animals. In animals, mtDNA has a rate of evolution which is five-to-ten times greater than the nuclear DNA. This fast evolution rate makes it ideal for tracking divergence between wild and domestic populations and the introduction of new populations of animals (Zeder *et al.* 2006). Also, mtDNA generally preserves better than genomic DNA (Rizzi *et al.* 2012). No mutations or genetic variants in genomic DNA which could be assigned to early stages in the domestication process have been found for so far. This is probably due to the fact that is harder to detect the genes which influence behavior, than genes which influence morphology. The domestication process may have consisted of small shifts in multiple different loci of genes, and therefore these changes are not that easy to trace (Zeder *et al.* 2006). Genomic DNA from modern domesticated animals has helped to understand domestication. An issue with using modern animals for studies about domestication in the past is that it is often unclear whether the genetic variances and genomic traits are the result of initial domestication or more recent changes (Frantz *et al.* 2020).

Studies by Naderi *et al.* (2008) and Daly *et al.* (2018) give major new insights into domestication of goats. They sampled both mtDNA, and genomic DNA of modern and ancient goats in the Fertile crescent. mtDNA analysis indicates there were multiple centers for goat domestication, in the central Iranian Plateau, the southern Zagros as well as in eastern Anatolia and possibly the Northern and Central Zagros (Naderi *et al.* 2008). Evidence of genomic aDNA supports that there were multiple centers of goat domestication (Daly *et al.* 2018). Analysis of sheep mtDNA have identified three distinct mtDNA lineages, suggesting that sheep were domesticated at least three different times in three different centers of origin, although the exact locations of these origins are unknown (Pedrosa *et al.* 2005; Bruford and Townsend 2006). Little research has been done on the genomics of pigs in the Fertile Crescent. However, research on genomics of pigs in Anatolia and Europe has revealed that the domestication of pig seemed to have multiple origins too (Ottoni *et al.* 2012).

2.8 Summary

This chapter has provided an overview of the concept of domestication and the domestication processes of the key domesticates in the Zagros region and Iran, as well as the current state of research of the Neolithic transition in the Zagros region and Iran beyond the Zagros. Animal domestication had multiple origins and is a process which happened over several millennia, however what the first steps towards domestication exactly entail is uncertain. Archaeological evidence from the Zagros area indicates goat was domesticated in the high Zagros Mountains and pig could have been locally domesticated in the lower Zagros, but so far the only evidence for this is from Jarmo. Domestic sheep is absent in the Early Neolithic in the Zagros region, but present in the Zagros region in the Ceramic Neolithic. It is unknown if humans in the Early Neolithic at the Caspian coast practiced any form of animal husbandry, and if so, if animal were locally domesticated or introduced or a combination of the two. In the next chapters the zooarchaeological methods and the isotopic methods used in this research to further our understanding of the first steps of animal domestication in the Zagros Mountains and Iran and the transition to animal husbandry will be discussed.

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Chapter 3: Methods

Human niche construction is used as the explanatory framework for domestication and the transition from gathering and hunting to farming and herding. For human niche construction to lead to domestication, it requires both humans and the domesticates to undergo long term changes (Chapter 2.2). To further our understanding of how niche construction led to animal management and domestication in the Neolithic in the Zagros area and possibly at the Caspian littoral, I will apply both traditional zooarchaeological analysis as well as stable isotopic analysis. For this research the Neolithic Zagros sites of Ganj Dareh, Bestansur, Jarmo and Shimshara will be studied (Figure 3.1). The sites cover a time span from the Early Neolithic into the ceramic Neolithic (see table 2.1) and therefore make it possible to study long term changes during the domestication process as well as possible local variation (Figure 3.2). The zooarchaeological assemblage of Ganj Dareh was restudied by Zeder (2008) and this restudy indicated that Ganj Dareh is a key site to understand the initial goat domestication in the Zagros mountains. To obtain further insight in the animal management practices at this site stable isotopic analysis will be applied on the caprine remains. The zooarchaeological assemblage of Jarmo has been restudied by Zeder (2008) and Price and Arbuckle (2015) and has indicated to be an important site to understand goat management in the foothills of the Zagros Mountains, the introduction of sheep management in the Zagros region, as well as pig domestication in the Zagros. Stable isotopic analysis will be applied on animal remains of Jarmo to secure a further insight into animal management practices. Bestansur is a site which is still being excavated. Primary analysis of the zooarchaeological assemblage of this site (Bendrey *et al.* 2020) indicated it could be a key site for our understanding of goat management in the lower Zagros, as well as management of pigs. Shimshara, too, has been recently re-excavated and the archaeological assemblage indicated it might be a centre for the development of pig management and therefore will be investigated further in this research (Bendrey *et al.* 2020). The spread of the Neolithic from the Zagros region eastwards or the possible local development of animal husbandry in the Caspian Littoral is poorly understood. The site Hotu cave is a key site to obtain a clearer insight into these developments, since the site has Epipalaeolithic, Early Neolithic and ceramic Neolithic phases and in all these stratigraphic layers a rich faunal assemblage has been recovered (Figure 3.1; 3.2).

For the sites Bestansur and Hotu cave, species abundancy, size and age death of animals are studied in order to investigate possible human management of populations.

Species abundancy needs to be studied to understand which animals were important for the food economy, to obtain insights into the environment and to investigate local variations in animal exploitation practices. Size of sheep, goat and pigs is studied to obtain further insights into human management practices. Sexual dimorphism is the main factor affecting body size of caprines and pigs (Chapter2, section 2.3), so the size of the animals can give insight into sex distribution of the slaughtered animals. Overall body size decrease is not a marker for initial domestication, but some elements decrease in size relatively early under the process of domestication. In pigs, teeth in the jaw are affected by the domestication process. Teeth further back in the jaw seem to be most affected by this size reduction in the first stages of domestication, so the size of the teeth can give is insights about their domestic status and human management (Chapter 2, section 2.3). Kill-off patterns will be studied since they are crucial to understand the first steps towards domestication. The switch from targeting prime adults to herd maintenance, by culling young males and keeping females is attested at various sites in the Zagros region (Chapter 2, section 2.4). Stable isotopic analysis on bone collagen is used to get insight in the diet of the animals. Human foddering could be one of the early steps of animal management in the Neolithic, which has been attested at several sites in Southwest Asia (Chapter 2). Sequential isotopic analysis on tooth enamel will give further insight diet of animals and changes in their diet, and their location throughout the year. Therefore, sequential oxygen and carbon analysis can give insights into foddering practices of and human influence on animal movement such as possible transhumance (Chapter 2, section 2.6). This Chapter will first give an overview of the zooarchaeological methods used in this thesis. This will be followed by a closer overview of stable isotopic analysis (section 3.1). The Chapter will end with the methods used in the laboratory for isotopic analysis (section 3.2.5). Methods used are also discussed in each individual article (see Chapter 4, 5 and 6), but in this Chapter I give an overview of the methods used across this thesis.

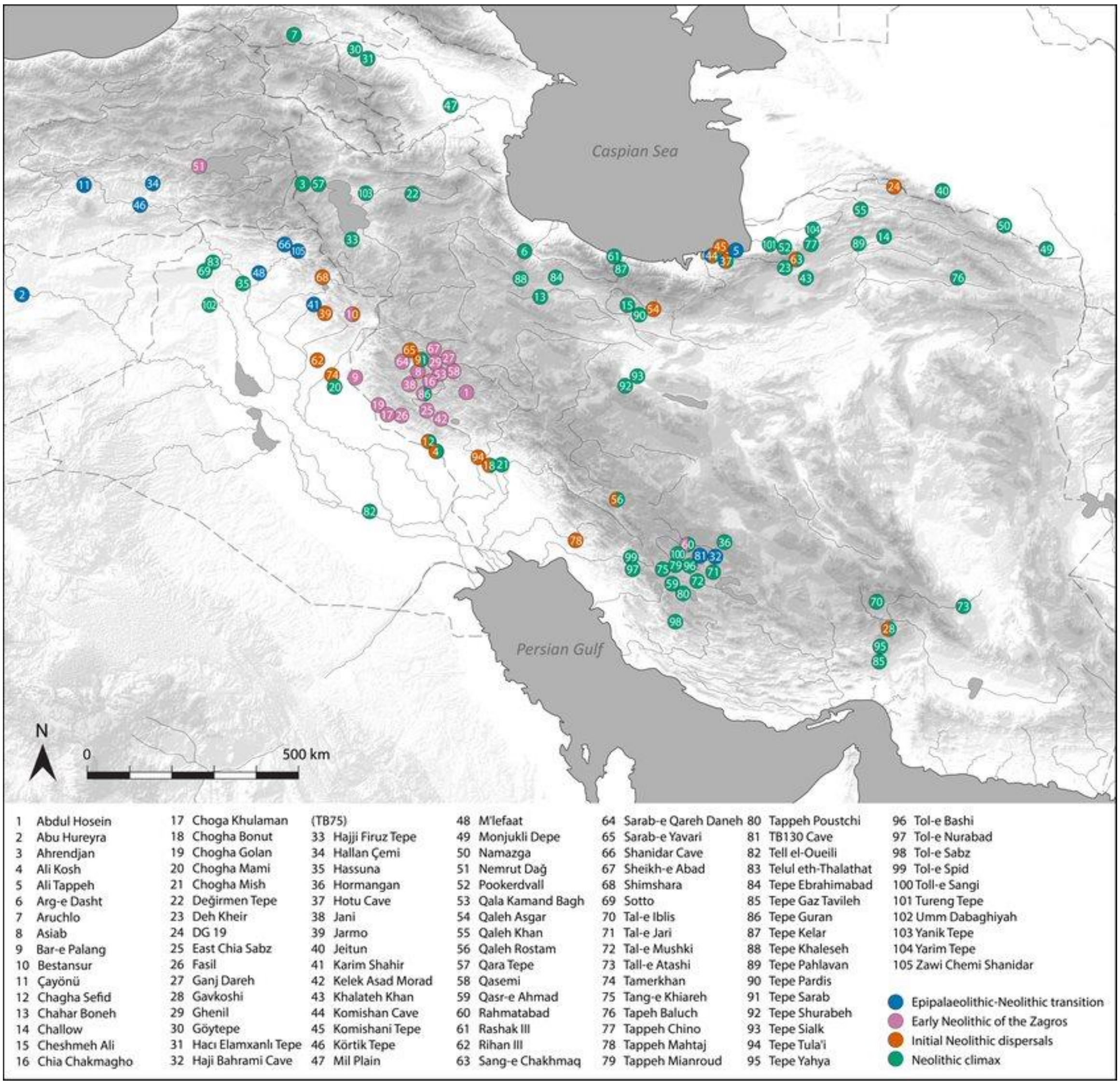


Figure 3.1: Epipalaeolithic and Neolithic sites in the Eastern Fertile Crescent and Iran (Matthews and Fazeli Nashli 2022: Fig. 5.1. Map created by Amy Richardson).

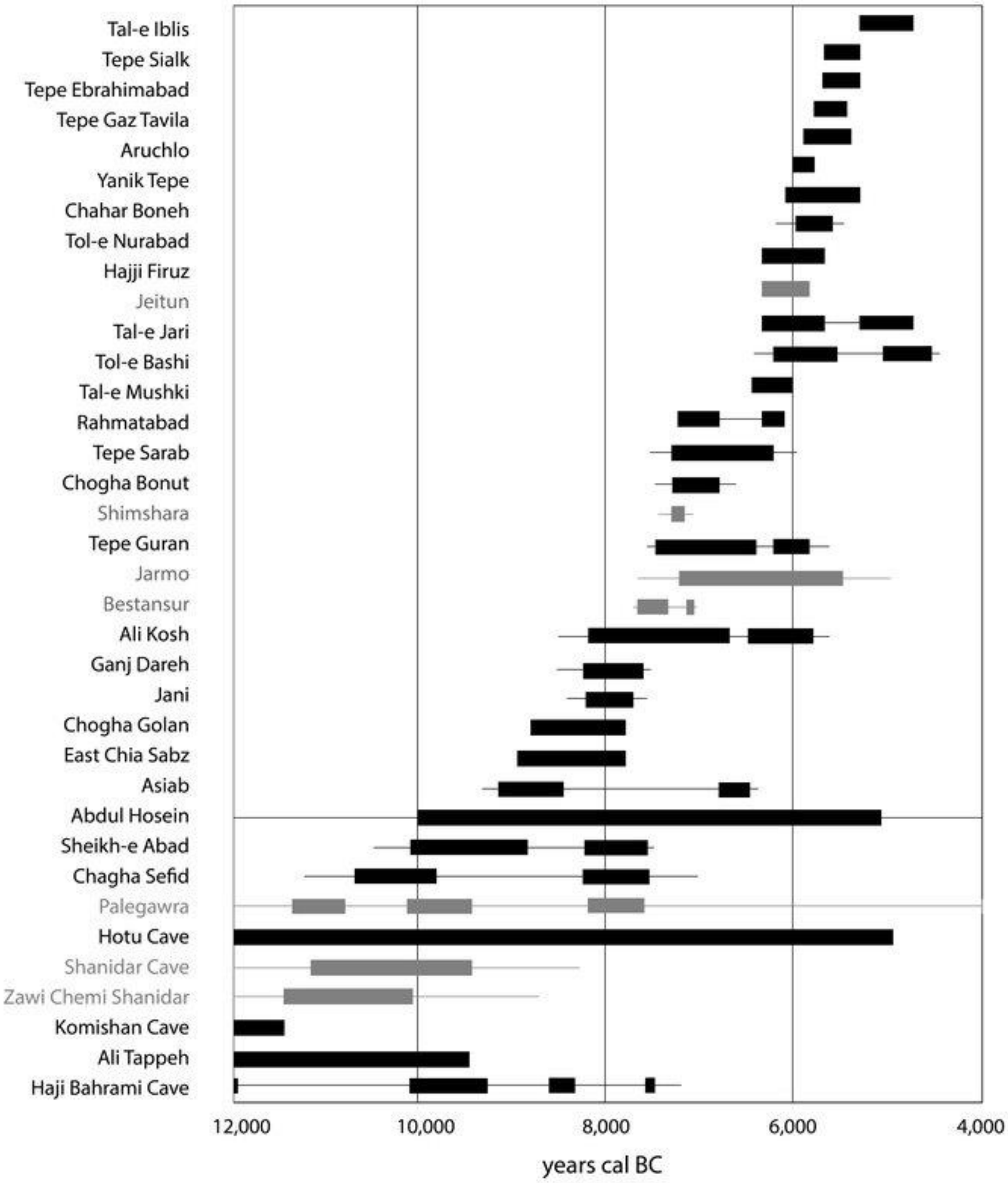


Figure 3.2: Chronology of Epipalaeolithic and Neolithic sites in the Eastern Fertile Crescent and Iran (Matthews and Fazeli Nashli 2022: Fig. 5.2).

3.1 Zooarchaeological methods

The majority of the analysis of the zooarchaeological assemblage of Bestansur was carried out in the field, while a smaller amount of the zooarchaeological assemblage was exported to the United Kingdom for further study. Identification of the elements was carried out by the author, but the new data were added to the database used by the previous member of the project, Robin Bendrey. The data collected during previous field seasons are also used in this study (Bendrey *et al.* 2020) (NISP analysed by Bendrey 25216, NISP analysed de Groene 3615, the analysis by Bendrey includes Neolithic and post Neolithic specimens, the analysis by de Groene includes only Neolithic specimens).

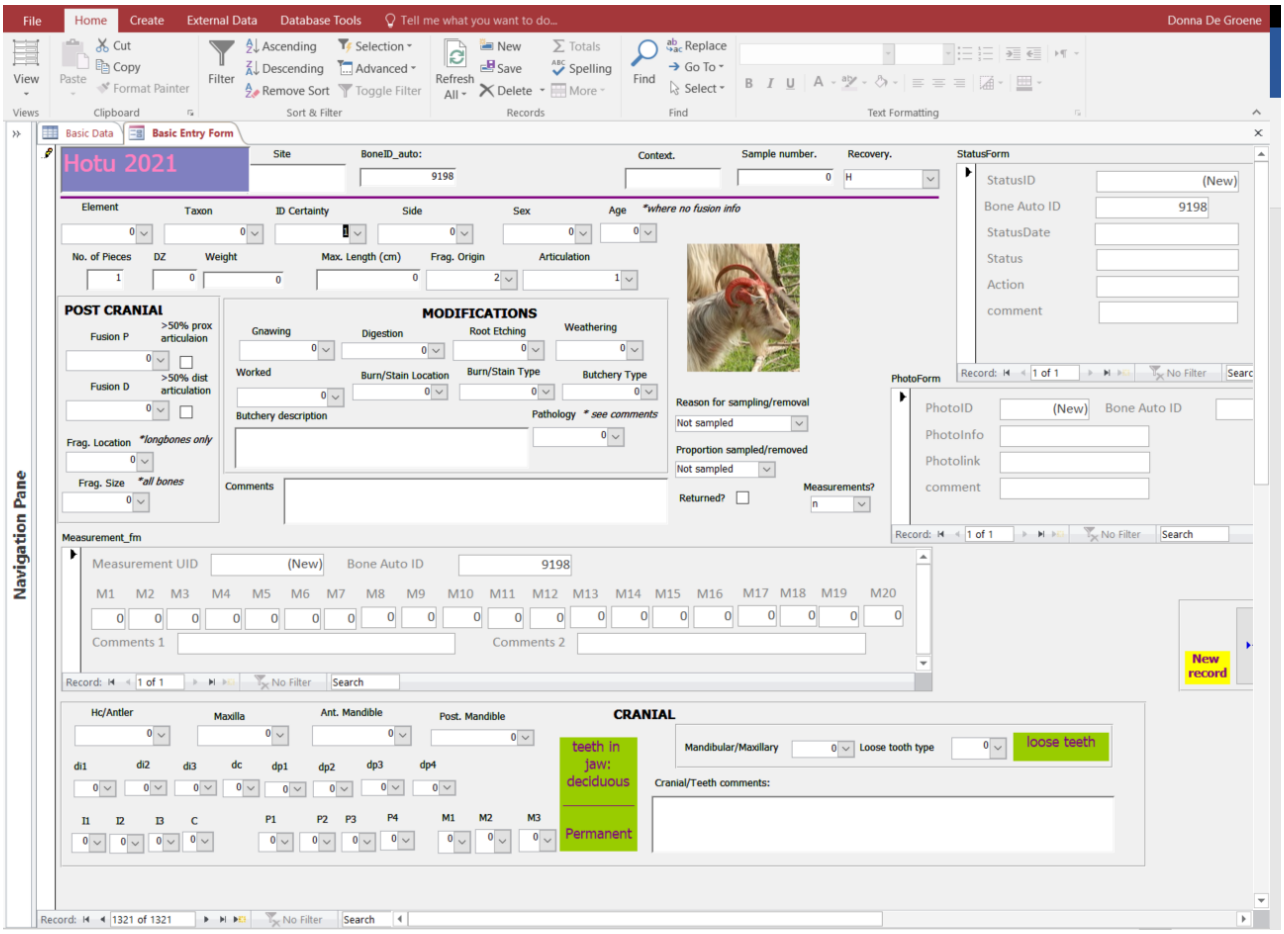
Due to the hot circumstances in the field, hand collected bones were, as far as possible, wrapped directly into tin foil, to reduce temperature change during excavation, and put into a cool box on site. At the end of each day all finds were transferred to an air-conditioned lab. All the soil from Neolithic contexts was dry sieved on a 4 mm mesh and selected amounts of soil were wet sieved over a 4mm, 2-4 mm and 2-1 mm mesh. Animal remains of Hotu cave (excavation in 2021) were collected using three different methods; hand-picking during excavation, dry sieving and flotation of excavated deposits, the entire heavy residue was collected and sieved to different sieve sizes and sorted with the naked eye for plant materials. Each heavy residue fraction was dry-sieved in Endecott brass sieves into fractions of 1 mm and 400 µ. All zooarchaeological material of Hotu cave was analysed by the author at the University of Reading zooarchaeological lab, using the University of Reading osteological lab reference collection.

To make the datasets as homogenous and complementary with other zooarchaeological datasets from Southwest Asia as possible, the methods used by Bendrey *et al.* 2020 were followed. For each element a standardized set of information was recorded in an Access database (Table 3.1; Figure 3.3). The quantification method used for the specimens was based on number of identified specimens (NISP). Diagnostic zone was recorded during analysis as employed by Bendrey *et al.* (2020), but not used further in this thesis since it is not commonly used in the study region. While the NISP is influenced by the amount of bones an animal has (e.g. pigs have five metapodials where sheep/goat have one), recovery methods and the fragmentation of the animal bones this is the standard method used for zooarchaeological assemblages in Southwest Asia, which enables comparison of relative abundancy with other zooarchaeological assemblages from Southwest Asia.

Table 3.1: Information recorded per specimen.

Recording category	**Recorded information**
Taxon	e.g. *Ovis aries, Sus scrofa*
Element	e.g. tibia, humerus, claudal vertebrae etc.
Part of the element	e.g. distal shaft, proximal epiphyses
Symmetry	left, right, axial
Fusion stage	unfused, fusing, fused
Weight	weight in grams

Measurements	following Von Den Driesch (1976) and Albarella and Payne (2005)
Recovery method	handcollected, dry sieve, flotation
Burning stage	different stages (e.g. calcinated, black burnt)
Pathologies	observations
Cutmarks/Butchery marks	according to Binford (1981)



Site
BoneID_auto: 9198
Context.
Sample number. 0
Recovery. H
Element 0
Taxon 0
ID Certainty
Side 0
Sex 0
Age 0 *where no fusion info
No. of Pieces 1
DZ 0
Weight 0
Max. Length (cm) 0
Frag. Origin 2
Articulation 1
Fusion P 0 >50% prox articulaion ☐
Fusion D 0 >50% dist articulation ☐
Frag. Location 0 *longbones only
Frag. Size 0 *all bones
Gnawing 0
Digestion 0
Root Etching 0
Weathering 0
Worked 0
Burn/Stain Location 0
Burn/Stain Type 0
Butchery Type 0
Butchery description
Pathology * see comments 0
Comments
Reason for sampling/removal: Not sampled
Proportion sampled/removed: Not sampled
Returned? ☐
Measurements? n

StatusForm
StatusID (New)
Bone Auto ID 9198
StatusDate
Status
Action
comment
Record: 1 of 1 No Filter Search

PhotoForm
PhotoID (New)
Bone Auto ID
PhotoInfo
Photolink
comment
Record: 1 of 1 No Filter Search

Measurement_fm
Measurement UID (New)
Bone Auto ID 9198

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Comments 1
Comments 2
Record: 1 of 1 No Filter Search

Hc/Antler 0
Maxilla 0
Ant. Mandible 0
Post. Mandible 0

di1	di2	di3	dc	dp1	dp2	dp3	dp4
0	0	0	0	0	0	0	0

I1	I2	I3	C	P1	P2	P3	P4	M1	M2	M3
0	0	0	0	0	0	0	0	0	0	0

Mandibular/Maxillary 0
Loose tooth type 0
Cranial/Teeth comments:

Record: 1321 of 1321 No Filter Search

Figure 3.3: Screenshot of the access database used to record the information of each specimen.

The specimens were identified based on their osteological morphology. The identification of elements was conducted using bone atlases (eg. Hillson 2005; Schmidt 1972), pictures from reference collections and a small reference collection made in the field. During the study of the Hotu zooarchaeological assemblage the reference osteological reference collection at the University of Reading was used. Since sheep and goat are osteologically very similar the criteria Boessneck *et al.* (1964) were used to identify cranial elements and Zeder and Lapham's (2010) criteria were used to distinguish post-cranial bones. Sheep/goat mandibular teeth were not separated since this have proven to be unreliable (Zeder and Pilaar 2010). Where separation was not possible, the bones were categorised under the category sheep/goat. *Dama mesopotamica* and *Cervus elaphus* were separated morphologically following the criteria of Lister (1999), when separation was not possible they were recorded under the category 'large cervid'. *Dama dama* is unlikely to have been present in the studied zooarchaeological assemblages as it falls outside of its past habitat (Uerpmann 1987, 57-63). *Dama mesopotamica* is larger than *Dama dama,* and has different antlers (Uerpmann 1987, 57-8). *Dama mesopotamica* is treated as a subspecies of *Dama* by some taxonomists, while others treat it as a separate species and in this thesis is treated as a separate species. For the identification of bones of foetal and neonatal specimens the atlases by Prummel (1987a, 1987b, 1989) were used.

If a certain bone could not be identified to species level, they were recorded in the category micro mammal, small mammal, sheep size, pig size, cattle size etc. No distinction between domestic and non-domestic mammals was made based on primary osteological characteristics. All possible anthropogenic modification to the bone were recorded, as well as pathologies. Butchery marks were recorded following Binford (1981) and when necessary extra information about the location or the type of butchery mark was added. Measurements of the bones were taken following Von Den Driesch (1979), additionally, to measure dental elements of suidae, Albarella and Payne (2005) were followed.

The Log Size Index (LSI) method is used to get a better understanding of the size of the animals. This is a logarithm to base 10 of the ratio between the measurement and its standard (Meadow 1999). The method makes it possible to compare different elements, largely increasing the dataset used for comparison. The standards used are those commonly used for zooarchaeological assemblages of the Fertile Crescent (Arbuckle *et al.* 2014), a modern Anatolian wild female boar (Hongo and Meadow 2000), the averages measurements of goat from the Taurus mountains (Uerpmann and Uerpmann 1994) and a modern wild sheep from Kermanshah, Iran (Zeder 2008, 263). Postcranial and dental measurements were analysed separately since they can react differently on changing circumstances such variations in environments and domestication (Payne and Bull 1988). Skewness and kurtosis have been used to describe the shape of LSI diagrams. Skewness describes the asymmetry of the distribution of a variable, a skewness value of '0' represents a normal distribution. Positive skewing shows a curve with a tail on the right of the mean, and negative skewing the opposite, a curve with a tail on the left. Kurtosis refers to the height of a distribution with positive values representing a tall peaked curve while negative values indicate a low peak in the distribution, and a value around zero would be a normal distribution (Arbuckle and Atici 2013, 223). The kill-off of young males is expected to be identified in results in the LSI data. A characteristic distribution for young male kill-off exhibits strong positive skewing and positive kurtosis (Arbuckle and Atici 2013, 223) (Figure 3.4).

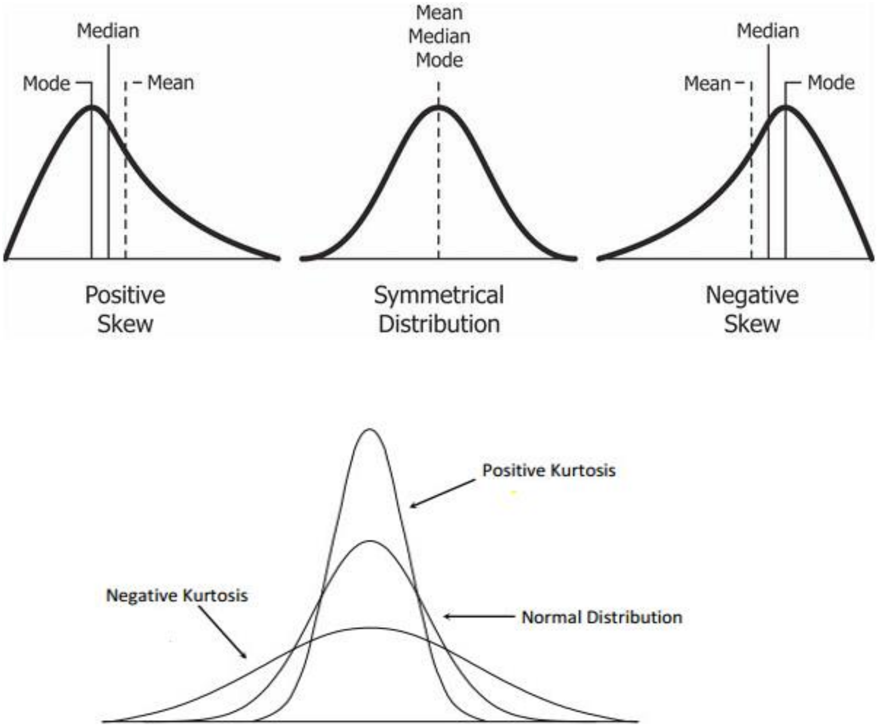


Figure 3.4:The shapes graphs take with negative and positive skewness and kurtosis (Figure by Author).

Age of death has been reconstructed based on dentition and bone fusion. Using both dental and bone fusion data allows to check whether the mortality profile is consistent. While bone fusion does not provide an exact age but only tells whether an animal died before or after the element was fused, dental wear and eruption provides an estimated age. It has been argued that the time of fusion of the bones differs between domesticated animals and maybe even between the different sexes, while dental eruption data are uniform. It has been found that the same elements fuse consistently in different populations, but this is restricted to ‘improved’ animals from the last century show different bone development (Zeder *et al.* 2015, 148). Both dental dentition-based and fusion-based age profiles are not free from taphonomic biases and observer error. Unfused bones of young animals have proven to be more porous and degrade faster. Also, jaws of young species also are more likely to be fragmented than those of older animals, since deciduous teeth and tooth germs are less robust (Çakırlar 2012, 7; Zeder *et al.* 2015, 149). Different systems to link an age to fusion stage and dental wear have been developed. Concerning the age of fusion Zeder (2006) was followed for sheep and goat, Zeder *et al.* (2015) for suids. Dental eruption and wear were recorded following Lemoine *et al.* (2014) and was used for suids, although their suggestion to look at maxillary teeth as well was not used, since this has not been systematically done from the beginning of the research. Their suggestion to add the score, mineralization of the crown, was not incorporated either. Sheep and goat teeth were aged following Payne (1973). These methods are commonly used by zooarchaeologists in the research area, making comparison with other sites easier.

3.2 Isotopic analysis

Isotopes are variants of elements that have the same number of protons and electrons but differ in the number of neutrons and consequently differ in atomic mass. So, isotopes of the same element have the same atomic number, but due to their difference in weight they behave differently in several chemical reactions. Isotopes can be stable, radioactive or radiogenic. Stable isotopes do not decay nor are they the product of decay, while radioactive isotopes decay over time and radiogenic isotopes do not decay but are the product of decay of another element (Sharp 2017). The differences between isotopes make them behave slightly differently in some chemical processes. Processes in which the ratio of the isotopes differs due to their weight are called fractionation processes (Sharp 2017). The ratios of the stable isotopes are often calculated towards a standard in per mil (Sharp 2017). For carbon the standard is PeeDee BelemniteCarbonate (PDB), a marine carbonate and for nitrogen the standard is AIR (ambient inhalable reservoir), comparing a measurement to the ratio of the air (Schoeninger and Moore 1992). The relative composition of oxygen isotopes is normalised using VSMOW (Vienna Standard Mean Ocean Water) (Pederzani and Britton 2019, 78). The δ is used in order to show the range of the stable isotopes towards the standard. The basic formula is:

$$\delta = \left(\frac{R_x - R_{std}}{R_{std}} \right) \times 1000$$

In archaeology the different types of isotopes are used for dating, provenance, seasonality, and diet reconstruction. Carbon and nitrogen isotopic ratios have been the most important elements for diet reconstruction in archaeology (Lee-Thorp 2008). To investigate seasonality and provenance both stable and radiogenic isotopes are used. Oxygen isotopes have been used to reconstruct both seasonality and provenance. The most used commonly used element for provenance studies is strontium (Slovak and Paytan 2012). In this study only stable isotopes will be used. The use of isotopes and the fractionation processes important for this research will be explained in this Chapter. The results of these studies will be more elaborately discussed and compared to the new data in Chapter 4 and 5.

3.2.1 Carbon

In nature Carbon (C) occurs in two stable isotopes, ^{12}C and ^{13}C. These isotopes do not decay, and neither are the product of decay of another element. Therefore, the ratio of these isotopes on earth is stable. ^{12}C forms 98.89% of all the carbon on earth, while ^{13}C only forms 1.11% of the stable isotopes. Carbon also has one natural radioactive isotope, ^{14}C, but this is negligible in the isotopic ratio when it comes to diet reconstruction, since makes up only around 0,000 000 000 1 % of all carbon on earth (Sharp 2017, 8). Plants use CO_2 for the photosynthesis, which they absorb out of the air. The main difference in carbon isotopic composition in plants is based on their photosynthetic pathway. The process of carbon fixation varies in three different type of plants, C_3 plants, C_4 plants and CAM plants. C_3 plants fractionate more during carbon fixation than C_4 plants, so C_3 plants are more depleted in the heavier isotope ^{13}C compared to C_4 plants. CAM plants can fix carbon in both ways (O'Leary 1981).

The exact composition of ^{12}C and ^{13}C in plants is dependent on light intensity, temperature, humidity, moisture and recycling of CO2. Variation between the isotopic ratios occurs within the plants. C_3 plants display δ^{13}C ranges from 37− 20‰ (average: − 27‰) and C_4 plants display δ^{13}C ranges from 21-9‰ (average: − 12‰) (Lee-Thorp 2008, 927). In semi-arid areas the differences in δ^{13}C in C_3 biomes vary according to environmental conditions (Heaton 1999). On a seasonal basis in semi-arid environments the δ^{13}C in C_3 plants shifts to changes in moisture availability, humidity levels, and night-time temperatures. The carbon composition of C_3 grasses is heavily dependent on water availability. In periods of droughts grasses tend to conserve water by closing their stomata, the microscopic pores on leaf epidermis regulating transpiration and CO_2 uptake (Agurla *et al.* 2018). Consequently, less CO_2 from the air will be taken up during dry periods and leaves will get enriched in $\delta^{13}C$ (Makarewicz and Pederzani 2017, 2-3). Environments characterized by high temperatures and limited water availability typically feature both C_3 and C_4 plants (Makarewicz and Pederzani 2017, 2-3). Southwest Asia has been roughly divided into three regions concerning the proportion and ecological role of C_4 plants. In the Euro-Siberian and Mediterranean regions C_4 plants are negligible, in the Iranian-Turonian region C_4 plants can be important in saline environments, but are not widespread, while in the Saharo-Arabian region C_4 plants are very widespread as grasses (Bocherens *et al.* 2000). The abundance C_3 and C_4 plants is dependent on season and altitude as well (Makarewicz 2017, 18). C_4 plants blossom later than C_3 plants when temperatures have increased and die earlier in autumn when lower temperatures interfere with their growth (Makarewicz and Pederzani 2017, 2-3). On higher altitudes the relative abundance of C_4 plants decreases. The exact elevation when C_4 plants decline is dependent on the local mean temperature for the summer months (Makarewicz 2017, 18).

Freshwater organisms use a combination of terrestrial detritus and the CO_2 that is dissolved in water. Consequently, the ratios of the carbon isotopes are dependent on the contribution of the carbon sources (Schoeninger and Moore 1992). In general, freshwater animals tend to have lower $\delta^{13}C$ values than terrestrial mammals (Schoeninger and DeNiro 1983). Specimens from a riparian forest tend to display $\delta^{13}C$ in between a riverine and an open environment (Balasse *et al.* 2016, 33-4). The $\delta^{13}C$ values of plants are reflected within their consumers, but the enrichment in bone collagen in the ^{13}C is about +5‰ and +11 to +13.5‰ in tooth enamel. A small enrichment in $\delta\ ^{13}C$ per trophic level of about +1 to 2‰ is observed as well (Lee-Thorp 2008, 927-928).

3.2.2 Nitrogen

Nitrogen (N) also occurs in two stable isotopes ^{14}N and ^{15}N. ^{14}N makes up 99.63% of the natural nitrogen, the remaining natural nitrogen (0.37%) is ^{15}N (Sharp 2017). The ratio of nitrogen isotopes in organisms varies due to fractionation processes. On earth, 99 percent of the nitrogen is in the form of the molecule dinitrogen (N_2), either in the air as gas, or dissolved in water. This N_2 is brought into the biosphere by algae and by bacterial nodules on plant roots, which can fix it and convert the N_2 (Schoeninger and Moore 1992). Nitrogen atoms can stay into the biological sphere after the death of an organism. The molecules in which nitrogen is fixed, are turned into nitrates by bacteria, which are fit for direct use by plants. Plants that use these nitrates are slightly more enriched in the heavier nitrogen isotopes than plants which fix N_2 from the atmosphere, since organisms are more enriched in the heavier isotope (Schoeninger and Moore 1992). Another factor which influences the nitrogen isotopic composition in plants is in which part of the plant nitrogen is assimilated (Szpak 2014, 2).

The main difference in nitrogen isotope ratios between organisms is related to their trophic level. The heavier isotope ^{15}N is easier absorbed in the tissue than the lighter ^{14}N. During metabolism the bonds between ^{15}N and carbon do not break as easily as the bonds between ^{14}N and carbon. Therefore, relatively more ^{14}N can be found in urine (Schoeninger and Moore 1992). Generally, there is an enrichment of 2-6 (average 3) ‰ due to biological fractionation per step in the food chain (Lee-Thorp 2008, 928). Because in both marine and freshwater ecosystems often more trophic levels exist than on land, the animal at the top of these food chains will be more enriched in ^{15}N than specimens at top of the food chain in terrestrial ecosystems. If land animals mostly rely on marine or freshwater resources, the $\delta^{15}N$ level in their tissue will increase (Lee-Thorp 2008, 927-9).

Apart from the trophic-level effect nitrogen isotopes vary according to environmental conditions, most notably aridity (Hartman 2011; Spzak 2014). In arid regions both plants and animals are more enriched in ^{15}N. The reason for this enrichment is not completely understood but seems to be mainly the effect of more nitrogen loss in plants in hot and arid ecosystems, while the nitrogen is recycled in colder and wetter ecosystems (Hartman 2011). Manuring of crops will enrich them in ^{15}N as well, but this seems only to have major effect when manuring is carried out over structurally over a longer time period (Fraser *et al.* 2011).

3.2.3 Oxygen

Oxygen occurs in three stable isotopes, ^{16}O, ^{17}O and ^{18}O. ^{16}O is the most abundant isotope making up 99.76 % of all oxygen on earth, ^{17}O is the least abundant making up 0.04 % and ^{18}O making up the remaining 0.2 % (Sharp 2017). The $\delta^{18}O$ composition in water around the world varies according to fractionation processes involved in evaporation and condensation events during moisture transport and precipitation (Pederzani and Britton 2019). Due to the difference in weight $H_2{}^{16}O$ is evaporated easier than the heavier $H_2{}^{18}O$. During the condensation phase of evaporation $H_2{}^{18}O$ tends to accumulate and rain out easier, leaving clouds depleted in ^{18}O after rainout. Precipitation at increasing distances from the coast and higher altitudes is typically depleted in $\delta^{18}O$ (Dansgaard 1964). As a standard there is an

0.3‰ decrease in $\delta^{18}O$ values of precipitation for every 100 m increase in altitude. Although, variation based on local environmental conditions exists (Makarewicz 2017).

The oxygen isotopic composition of local meteoric water is indirectly reflected in plant tissues and leaf waters. Fractionation during water uptake by plants is minimal but leaf water is enriched in ^{18}O relative to non-transpiring parts of the plants (Makarewicz 2017, 17). It differs per plant how much the leaf water is enriched in ^{18}O (Pederzani and Britton 2019, 81). Another factor which influences the oxygen isotopic composition of plants, especially in (semi) arid areas is the source of water uptake of the plant. Plants with shallow roots predominantly take up water from the upper soil layer of which has already undergone evaporative enrichment. Plants with deeper roots access lower subsurface waters, which have isotopic composition more similar to local precipitation isotopic compositions (Pederzani and Britton 2019, 81). Waterbodies can also display different $\delta^{18}O$ value than the local precipitation. Open waterbodies can mainly consist of water from different sources, for example water from higher altitudes. Closed waterbodies can be subject of evaporative enrichment in $\delta^{18}O$, resulting on high $\delta^{18}O$ during periods of drought (Pederzani and Britton 2019, 80).

Variation in oxygen isotopic composition in skeletal remains is driven by the isotopic composition of body water which is determined by oxygen composition of ingested water and oxygen structurally bound in food (Pederzani and Britton 2019). The oxygen isotopic composition in teeth enamel largely reflects isotopic values of the ingested water (Makarewicz and Pederzani 2017, 78). In non-obligate drinkers, such as sheep and goat, the $\delta^{18}O$ values in bone and teeth can be similar to the leaf water values of their food (Faith 2018; Pederzani and Britton 2019, 78-81). Grazers are typically more dependent on surface water than browsers, since grasses lose more water during periods of drought (Faith 2018).

3.2.4 Bone collagen and teeth enamel

Isotopic differences occur within different tissues of a single organism. This is the result of multiple factors influencing isotopic composition. Teeth mineralise in the early life phase and their isotopic composition will not change once they are fully mineralised. So, the isotopic composition of tooth crown will reflect the diet of a species from the time before the tooth was mineralized. Bone, by contrast, is a living tissue and will be constantly renewed during the life span of a vertebrate. Each bone has a different turnover time, so it is dependent on the bone which period of the life of the animal it reflects isotopically. In humans, ribs have the shortest turnover time, about seven years, and the skull the longest turnover time, about 25 years (Lee-Thorp 2008, 926-7). No studies of the turnover times for animal bones have been conducted so far. Secondly, it has been debated which part of the diet is reflected in bone tissue and which part of bone is best to be sampled. Both bone and teeth consist of an organic part and inorganic part. The organic part of the bone mainly consists of collagen proteins, while the inorganic part mostly consists of apatite minerals. Apatite minerals survive longer, but apatite in bone is highly reactive material (Lee-Thorp 2008, 930).

Without any influence of diagenesis, apatite and collagen can reflect different isotopic signals. Carbon of the protein component of the diet is preferentially routed towards bone collagen. Consequently, high protein food is mainly reflected in the isotopic composition of the collagen. This can result in an underrepresentation of plant foods in the collagen. This means it might not always be immediately visible what type of plant food or if plant food was consumed by a species with an omnivorous diet (Lee-Thorp 2008). This must be taken into consideration during the interpretation of the isotopic analysis. Bone apatite, in contrast, reflects an isotopic composition of the total diet (Lee-Thorp 2008, 930-5).

Collagen degrades faster than apatite, but it is a very robust biomolecule and can survive up to a hundred thousand years. Studies have shown that, even when most of the collagen has disappeared the isotopic composition of the remaining collagen remains intact. Nevertheless, it is still important to discount post-mortem diagenesis before interpretations are made. Three criteria are used to assess collagen quality (Ambrose 1990). The first criterion is the percentage yield of collagen relative to the original sample weight. Whenever the total yield is smaller than 1% of the sampled bone weight, the data are not very reliable (Brock *et al.* 2010, Vaughan *et al.* 2013, 308). The second criterion is the carbon and the nitrogen ratio in the collagen sample; this must range between 2.9-3.6. These methods will exclude samples; however, samples do exist which fall within these ratios, but still are altered by diagenesis. The third criterion is the carbon and nitrogen concentration in the collagen. Both drop when the collagen is badly preserved. However, the precise indicators for well versus poorly preserved collagen varies between geographic regions (Ambrose 1990). No standard has been adopted for the researched region.

Bone collagen is extracted from bone by demineralising getting the bone in Hydrochloric Acid (HCL) solution. The HCL removes soil fulvic acids or organic matter (Ambrose 1993). During the demineralization phase it is important that the collagen does not gelatinize (Ambrose 1993; Collins and Galley 1998). Research has shown that the collagen preserves best when demineralization is done at low temperatures (1-5 degrees Celsius) (Brown *et al.* 1988; Collins and Galley 1998). Grinding of the bones has a negative effect on the collagen extraction, so full bone pieces are preferred for analysis (Collins and Galley 1998). The bones can be treated with the base sodium hydroxide (NaOH) to remove lipid and humid acid contamination (Ambrose 1993). However, this step causes some collagen loss and loss of some amino acids of the collagen. It has been shown this step is not essential to remove humic acids, since the HCL and filtration can remove all those (Chisholm *et al.* 1983). After this the collagen is gelatinized by putting samples in pH 3 solution and heating them. The solution should then be filtered to remove insoluble bits (Chisholm *et al.* 1983). Hereafter the solution is freeze-dried to get solid collagen (Ambrose 1993).

Tooth enamel is almost entirely composed of hydroxyapatite and is less reactive than apatite minerals in bone (Lee-Thorp 2008, 931). The carbon and oxygen isotopic component of the apatite reflects the overall diet (Balasse 2002). In most herbivores enamel of bioapatite in herbivores forms layer by layers and mineralises directly after formation. Therefore, the apatite represents a chronological record of the changes in isotopic values during formation. So, intra-tooth sampling can show seasonal changes isotopic values of in the food and water intake of an herbivore. The time resolution of the intra-tooth resolution is dependent on the precision of the sampling procedure and the pattern of enamel mineralization (Balasse 2002). In sheep and goat, the formation of the second mandibular molar takes place approximately between 2 to 10 months in age, while the third mandibular molar begin around 10 months in age in completed at the second year (Hillson 2005).

The pre-treatment procedures of bioapatite are less straightforward than those of bone collagen. During the pre-treatment acids are used to remove organic material and secondary carbonates. The protocols adapted for bone collagen do not influence the isotopic compositions (Ambrose 1991; Lee-Thorp 2008). However, the different pre-treatment methods for teeth enamel influence the data significantly (Snoeck and Pellegrini 2015; Pellegrini and Snoeck 2016). Some of the commonly used pre-treatments are unable to remove secondary carbonates (Snoeck and Pellegrini 2015). Secondly, the use of organic pre-treatments causes side-effects which were previously unknown. The use of the base sodium hypochlorite (NaCLO) causes the absorption of new exogenous carbonates into the bioapatite (Snoeck and Pellegrini 2015). The other commonly used pre-treatment, the acid hydrogen peroxide (H_2O_2) is unable to remove all secondary carbonates and heavily attacks the primary carbonate (Snoeck and Pellegrini 2015). Acetic acid (CH_3COOH) removes exogenous carbonate, but also attacks the carbonate and causes a big mass loss (Balasse *et al.* 2002; Snoeck and Pellegirini 2015). On top of this several pre-treatments did cause changes in the isotopic composition of the samples (Pellegrini and Snoeck 2016). Samples treated with hydrogen peroxide were up to 2‰ depleted in ^{13}C compared to untreated samples, while samples pre-treated with sodium hypochlorite were up to 2.5‰ enriched in ^{13}C in the study of Pellegrini and Snoeck (2016). Enamel appetite samples were less influenced than bones (Pellegrini and Snoeck 2016). The effects of the pre-treatment on $\delta^{18}O$ were more variable. Enamel samples are enriched or unaltered after pre-treatment, while bone apatite was often depleted in ^{18}O. The effects on $\delta^{18}O$ in teeth enamel were smaller in the study, the enrichment lower than 1‰ in all samples (Pellegrini and Snoeck 2016). Acetic acid did not seem to change the isotopic compositions of the apatite. Weak acetic acid causes less mass loss than strong acetic acid (Pellegrini and Snoeck 2016) so is a preferred form of pre-treatment. So far, no standard protocol for sampling of enamel has been adopted. Those differences in isotopic compositions based on pre-treatment hampers immediate comparison between datasets. Another issue is that unlike for bone collagen no standard has been adopted to assess the quality of the archaeological teeth enamel.

3.2.5 Laboratory methods used for isotopic analysis

Stable isotopic analysis of tooth enamel of domestic and non-domestic animals has already improved our understanding of animal management in the Levant and Anatolia (Chapter 2.6). Sequential isotopic analysis can provide a better understanding of possible transhumance and possible seasonal foddering practices, which both might have been managed practices applied by humans during the early stages of domestication Sampling of bones and teeth was partly done at the University of Reading and partly in the labs of the Field Museum, Chicago and the Smithsonian Research Centre, Washington DC. All further isotopic analysis was done at the labs of the School of Geography, Archaeology, and Environmental Science at The University of Reading.

Bone was sampled following the methods described in Müldner and Richards (2005). Robust parts of the bones were cut of using a Dremel saw. After that adhering soil and trabecular bone was removed using a scalpel. Inner and outer external surfaces of the bone were removed using a drill. Between 300-800 mg bone was sampled. After this bone samples were broken into shards. To demineralize the samples, 0.5 M HCL was poured over the bones. The 0.5 M HCL added to sample was also kept in the fridge at a temperature of around 3 degrees Celsius. The samples in the acid were then put in the fridge, to slow down the speed of the reaction. The samples were left in the fridge until most of the bone was demineralized. It differed per sample how long this process took, but it was in the beginning checked throughout the day, and after the initial day the samples were checked daily. After demineralization the samples were rinsed to neutral pH with de-ionised water. Then the samples were placed in tubes and gelatinised in a pH 3 HCl solution at 70 °C for 48 h. After removing reflux-insoluble residues with a 5–8 µm Ezee®, the samples were placed in the freezer. When thoroughly frozen, the samples were placed in the freeze-drier for 48 hours. In total 40 bones of Bestansur and 20 of Jarmo were sampled for stable isotopic analysis.

The protocol for sampling teeth is adapted from Balasse (2002). Teeth were cleaned with dental tools and brush before sampling. When cementum was covering the enamel, it was removed with a drill. Sequential sampling was performed from the tip to the basis of the crown, perpendicularly to the tooth growth axis. Samples were taken using a diamond-coated drill, as evenly spaced as possible over the crown height and through the whole enamel thickness. Sampling was performed over a piece of aluminium foil. In between sampling the drilling was cleaned. The samples are treated with acetic acid 0.1 M, since this does not change the isotopic composition (see Chapter 3.2.4). The samples were left to react at room temperature for 4 hours, tubes open to prevent precipitation of the CO2 produced by the reaction. Subsequently the samples were five times rinsed to neutral pH with de-ionised water. The samples were then frozen and when completely frozen put in the freeze-drier for an hour. In total 47 molars from archaeological contexts were sampled, 25 M2’s and 12 M3’s, as well as one modern M3 from a sheep in the modern village Bestansur. The number of samples taken per teeth varies, since some teeth were damaged, but it was attempted to take at least 10 samples per molar. Both right and left and molars were sampled, but only when they came from different contexts. The molars chosen were those with limited toothwear.

Zooarchaeological data are recorded in access database, and species abundancy based on NISP, mortality patterns, sex patterns and size changes will be assessed in detail. Stable isotopic carbon and nitrogen analysis will be applied on bone collagen and stable oxygen and carbon will be applied on teeth enamel of caprines. In the next three chapters I will apply these methodologies on the chosen assemblages and interpret and discuss the results.

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Chapter 4: Pigs in the Neolithic of the Eastern Fertile Crescent: New evidence from Pre-pottery Neolithic Bestansur and Shimshara, Iraqi Kurdistan (7800 – 7100 BC)

Running head: Pig exploitation at Neolithic Bestansur and Shimshara (7800-7100 BC)

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Abstract

Pigs are one of the earliest domesticated livestock species, first domesticated at least 10,000 years ago. The domestication of wild boar, including associated morphological changes, is a long process over several millennia. Across Southwest Asia, management, domestication and the adaption of the different livestock species was a highly localized process, influenced by both cultural and environmental factors.

This paper explores the size, age and diet of the suids of the Pre-Pottery Neolithic sites of Bestansur and Shimshara in order to further our understanding of the origins of suid management in the Neolithic Eastern Fertile Crescent. Our data suggest that the relationship between wild boar and humans was more complex than a strict hunter-prey relationship. This study demonstrates that the Neolithic in the Zagros was not uniform in the adaption and exploitation of different animals.

1 Introduction

The domestication of animals is a process in which relations between humans and animals gradually change (Zeder 2012). Pigs are one of the earliest domesticated livestock species, first domesticated at least 10,000 years ago (Albarella *et al.* 2006; Zeder 2008). According to recent aDNA analyses, they were independently domesticated during multiple events in both Western and Eastern Eurasia (Frantz *et al.* 2019; Zeder and Lemoine 2020a). Southwest Asia was one of the places where pigs were domesticated, and this has been the topic of research for several decades (Flannery 1982; Ervynck *et al.* 2001). However, the processes which led to their domestication are still not completely understood (Zeder 2012). One main difference between the domestication of pigs and the other key livestock species (goat, sheep, cattle) is that pigs are omnivores. Therefore, they potentially have a wider range of relationships with humans than purely herbivorous livestock (Albarella *et al.* 2006). Wild boar could have been attracted to food waste at early human settlements, so the first steps of domestication might be both through a hunter-prey relationship and/or a commensal one (Price and Hongo 2020, 9-10; Zeder 2012). Furthermore, humans can apply a wider range of management strategies for omnivores, since they can be kept and fed in different ways and consequently, the domestication process of wild boar may be more complex (Albarella *et al.* 2006).

The domestication of wild boar, including associated morphological changes, is a long process over several millennia (Price and Evin 2019; Zeder 2015). The earliest human management precedes morphological changes related to domestication, which makes it more complex to identify in the archaeological record. The postcranial size change of pigs under domestication is a continuous development, which may take millennia, and therefore pigs are not expected to be significantly smaller than their wild counterparts during the initial stages of domestication (Price and Evin 2017). Overall size reduction coincides with morphological changes (Albarella *et al.* 2006). Pigs undergo the largest brain size reduction of all domesticated animals (Zeder 2012), changing the skull shape completely so that, even in early stages of domestication, teeth in the jaw can be affected by this skull change. Teeth further back in the jaw (i.e. M2 and M3 to an even greater extent) seem to be most affected by this size reduction in the first stages of domestication (Albarella *et al.* 2006, 261). Demographic data of animal populations can be a more reliable early indicator than a change in their body size for the start of changes in human-suid relationships (Zeder 2012). Since managed pigs are often slaughtered when or just before they reach their full body size, to obtain maximum meat gain (Hadjikoumis 2012), a higher percentage of suids less than 2 years old would be expected in a managed herd than in a hunted population. Early management strategies, however, would likely not have as much of an emphasis on killing young animals as in current day domestic herds. Herd sizes were possibly smaller, so therefore a higher proportion of animals would have to be kept alive to reproduce. Also, since suid populations grow rapidly and pigs have larger litters than bovidae, intensified hunting can lead to a higher percentage of juveniles (Rowley-Conwy *et al.* 2012). However, at multiple prehistoric sites in Southwest Asia, a change in the mortality profile has been attested and interpreted as the start of pig management (Ervynck *et al.* 2001; Peters *et al.* 1999). Another indication for human management could be changes in the diet of wild boar. Wild boar are omnivorous, but their diet consists mostly of plant material such as roots, acorns and fruits. Since they are omnivorous, their diet can be easily adjusted by humans. When pigs are kept in a settlement and are fed on domestic waste, which might include animal products, they may become more carnivorous. On the contrary, pigs could also be managed extensively, being allowed to forage themselves in areas around the settlement. In that case, the diet need not necessarily differ largely from their wild counterparts. The composition of plant-based food for managed animals could still be different, with an increased uptake of agricultural waste instead of a more wild plant-based diet, which would include more root products (Albarella *et al.* 2006; Hadjikoumis 2012; Rowley-Conwy *et al.* 2012).

In the Northern Fertile Crescent, an initial form of suid management has been suggested at Hallan Çemi (10th-9th millennium BC) based on a change in kill-off patterns (Price and Hongo 2020, 34; Rosenberg *et al.* 1998, 33). Later analysis indicated that around 68% of the pigs were slaughtered before or around the age of two and foetal/neonatal bones make up 44 % of the pig remains (Lemoine *et al*, 2014). It has been argued this would be the result of specified hunting strategies rather than management (Lemoine 2012). More conclusive evidence for pig management has been identified at Çayönü (9000-7500 BC) (Ervynck *et al.* 2001). Little evidence for pig management has been found in the Early Neolithic of the Eastern Fertile Crescent (Flannery 1983; Mashkour 2006; Price and Arbuckle 2015). However, the recent re-excavations at Asiab (10th millennium BC) in the high Zagros of western Iran, have recovered a ‘special deposit’ comprising 19 wild boar skulls in the centre of a large structure, implying a special status of the wild boar (Bangsgaard *et al.* 2019). In addition, a recent restudy of the Jarmo zooarchaeological assemblage gives evidence for possible wild boar management in the Pre-Pottery Neolithic (PPN) and management of domestic herds in the Pottery Neolithic (PN) (see SI for dates of phases) (Price and Arbuckle 2015, 446). Little is known about the diet of wild and managed suids in the Neolithic in the Fertile Crescent, since the collagen in bones often does not survive for dietary isotopic analysis.

Across Southwest Asia, management, domestication and the adaption of the different livestock species was a highly localized process, influenced by both cultural and environmental factors (Arbuckle and Atici 2013; Arbuckle *et al.* 2014). In this paper we explore the size, age and diet of the suids of Bestansur and Shimshara in order to further our understanding of early suid management in the Neolithic Eastern Fertile Crescent. This aim will be achieved by analysing the zooarchaeological assemblage from the Early Neolithic sites of Bestansur and Shimshara in Iraqi Kurdistan (Matthews *et al.* 2020).

Initial studies of the animal bones from both sites indicate that the percentage of suids at these sites was notably higher than at contemporary sites in the region (Bendrey *et al.*

2020) and a coprolite from a suid was found on site at Bestansur (Elliot 2020) indicating close interaction between humans and suids. In this study, our research aim is to investigate and more fully articulate the nature of human-suid interrelationships in this foothill region of the Zagros range through integrated analysis of the zooarchaeological evidence from two sites of 8th millennium cal BC date. The analysis of these assemblages will not only provide us with further understanding of human animal relationships in the Zagros area but with further insights in the domestication processes.

2 The sites: Bestansur and Shimshara

Bestansur is a Neolithic site located in the foothills of the Zagros Mountains, in Iraqi Kurdistan. The site has been excavated since 2012 over the course of eight field seasons by a team from the University of Reading in collaboration with the Sulaimaniyah and Erbil Directorates of Antiquities and Heritage. The site is about 4 ha and the top of the mound is 8 metres high, although on the edges of the site the Neolithic deposits are only 30-50 centimetres below modern plough depth (Richardson *et al.* 2020, 116). Neolithic occupation spans from ca. 7700-7000 BC, with Neolithic layers of at least 4 metres (Matthews *et al.* 2020a, 629), in places covered by a significant occupation dating to the Iron Age (first millennium BC) and later. The site is ca. 550 metres above sea level. It is situated close to a variety of ecosystems comprising springs, flat steppe, river and marshlands, the foothills of the Zagros and the high Zagros mountains (Matthews *et al.* 2020, 633; Figure 1). Present day vegetation is strongly influenced by environmental variables such as precipitation and temperature, with both the cold winter period and hot dry summer inhibiting plant growth (Zohary 1973,35)

Shimshara is a Neolithic site ca. 110 km northeast of Bestansur (Figure 1). Today the region is characterized by mountain forest vegetation and mountain riverine forest. In the Neolithic the inhabitants of Shimshara had access to these different ecozones (Matthews *et al.* 2020b, 177). In phytogeographic terms Bestansur and Shimshara falls into the Kurdo-Zagrossian sub-division of the Irano-Turanian region, which is dominated by climax vegetation mostly in the form of steppe- or park-forests (Elliot *et al.* 2020, 92). Shimshara was previously excavated in the 1957 by a Danish team (Mortensen 1970). Both Neolithic and Bronze Age layers were excavated. Since then, the site has been eroded by waters of a dam and a rescue excavation was carried out by the Central Zagros Archaeological Project in 2013. The material excavated has been radiocarbon dated to between 7450 and 7180 BC (Matthews *et al.* 2020b, 178-9).

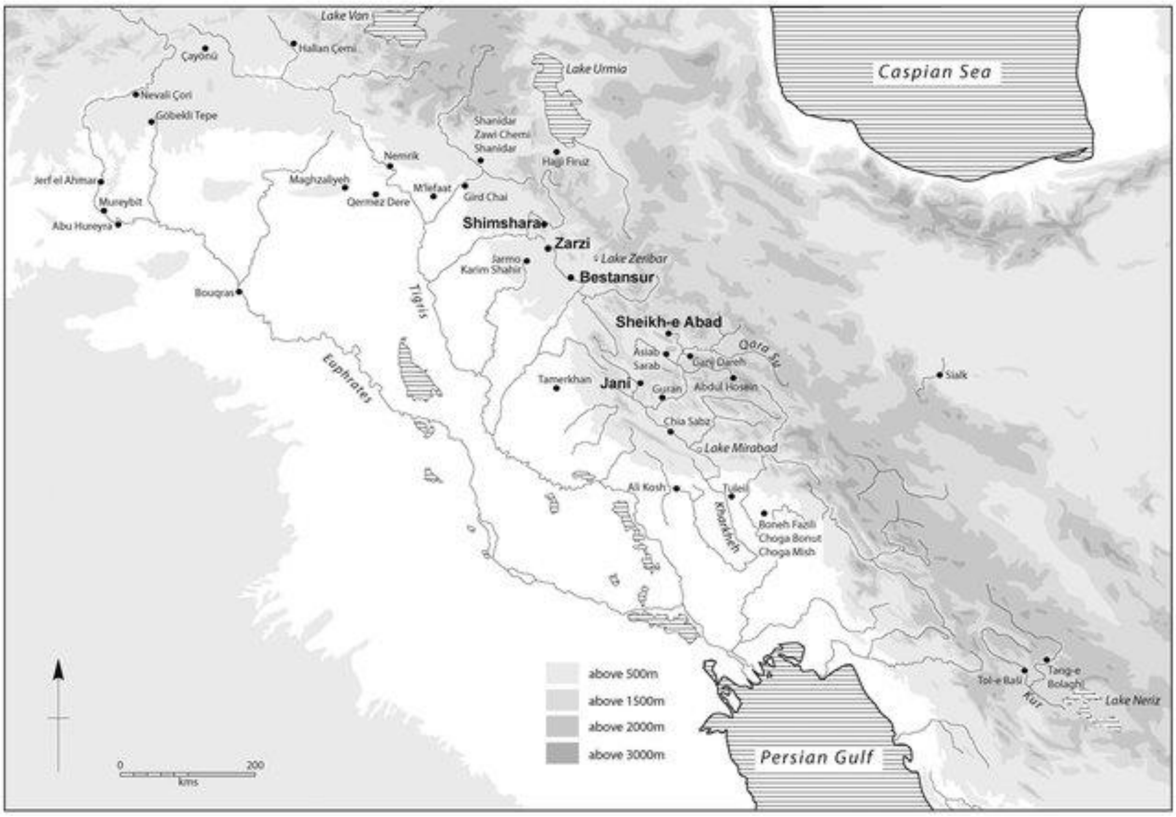

Figure 1: Map showing Epipalaeolithic and Neolithic sites in the Eastern Fertile Crescent.

3 Methods and material

This study includes all animal remains from the Neolithic layers of Bestansur from all field seasons up to spring 2019 and material excavated during the 2013 field season in Shimshara. Animal bones were collected using three different methods; hand-picking during excavation, dry sieving of the excavated deposits through a 4 mm mesh, and selected amounts of soil were wet sieved through a 4mm, 2-4 mm and 2-1 mm mesh. So far, 6117 fragments of animal bones have been recorded, a sample of which have been published at Bestansur and 4033 bone fragments have been recorded at Shimshara (Bendrey *et al.* 2020). Most of the zooarchaeological assemblages are currently stored at Sulaimaniyah Directorate of Antiquities and Heritage, but some specimens have been sampled and exported to the University of Reading for further analysis. The preservation of the bones is moderate, full bones have been found, but tend to fall apart after excavation.

The relative abundance of the different species has been calculated based on NISP (number of identified specimens) (see SI). For this study both cranial and post cranial elements were measured, according to von den Driesch (1976) and Payne and Bull (1988). Breadth measurements were taken on all the molars and the dP4, and lengths of the third molar and dP4.

In order to assess the size of the animals at Bestansur and Shimshara and compare them to other sites, the Log Size Index (LSI) method is used (Meadow 1999), comparing different measurements to a standard animal. The standards are the ones commonly used in Southwest Asia (Price and Arbuckle 2015); a modern Anatolian wild female boar (Hongo and Meadow 2000) for post cranial measurements and the mean values of a population sample of modern wild boar from Kizilcahamam, Turkey, for dental metrics (Payne and Bull 1988).

The mortality profile of the pigs from Bestansur was reconstructed based on dental eruption and wear and bone fusion, following Zeder *et al.* (2015) and Lemoine *et al.* (2014). The diet of the suids of Bestansur is investigated using stable carbon and nitrogen stable isotopic analysis. The samples were taken and processed at the University of Reading, School of Archaeology, Geography and Environmental Science (details in SI).

4 Results

4.1 Relative abundance

Suids make up a very large part of the zooarchaeological assemblage of Bestansur as well as at Shimshara (see). At Bestansur caprines make up the majority of the assemblage, sheep outnumbering goat, but both based on NISP, suids are the second most abundant group (see Figure 2 and Figure 3). This high abundance of suids is unusual at Epipalaeolithic and Early Neolithic sites in the Eastern Fertile Crescent, only Shimshara showing a higher relative abundance of suids (see Figure 3).

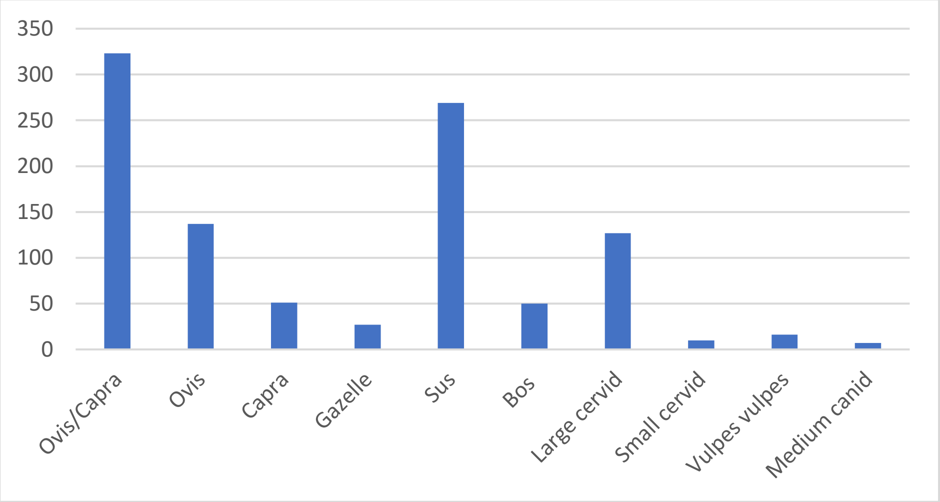

Figure 2: The count of the identified animal remains (NISP) of Bestansur (mammals only, small mammals and micromammals not included).

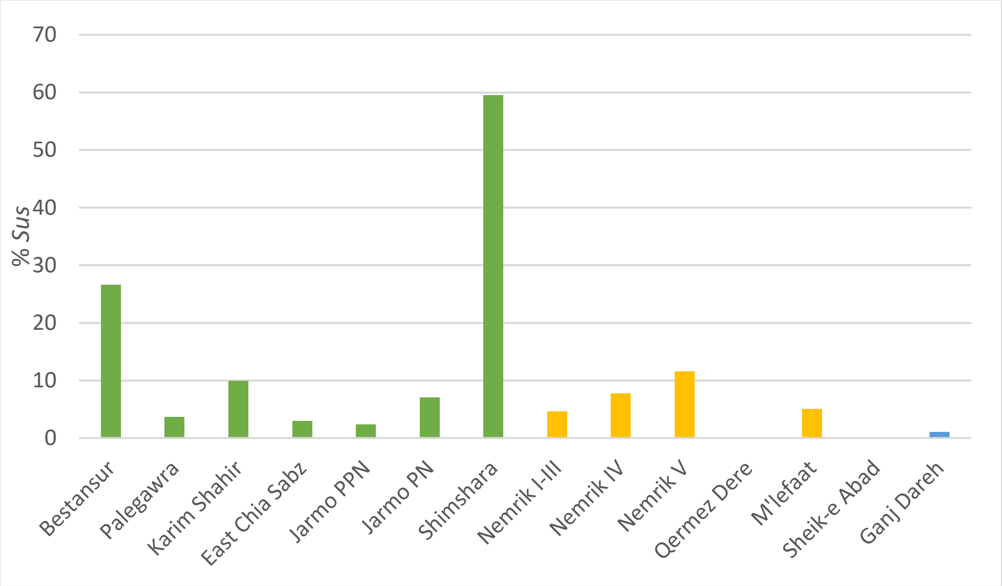

Figure 3: Percentage (NISP of total of the mammals identified to genus and sheep/goat) of suids at Epipalaeolithic and Early Neolithic sites in the Eastern Fertile Crescent. The colours represent the ecological setting of the site: green=piedmont, yellow=steppe and blue= highland (see supplementary information for NISP and references).

4.2 Biometry

The LSI data of both the cranial and the post cranial measurements of Bestansur display two ‘groups’ (see Table 3 and 4; Figure 4 and 5). For the post cranial measurements these two peaks could be the results of sexual dimorphism or domestic status, since adult male wild boar are about 1.3-1.4 times larger than females (Zeder and Lemoine 2020a, 7). However, the teeth measurements are less influenced by sex differences (Rowley Conwy *et al.* 2012, 14) and also show two peaks. Only one postcranial measurement of Shimshara was available.

The large post-cranial remains of the suids from Bestansur are overall larger than those of all other Epipalaeolithic and Neolithic sites in the Zagros (see Figure 5). The smaller ‘group’ of the post cranial elements of Bestansur are still bigger than the smaller domestic animals of Pottery Neolithic Jarmo or late Neolithic Hajji Firuz (see Figure 5). The molars of the suids at Bestansur are not bigger than those of all other sites, although fewer data are available. The smaller values of the molars from Bestansur are smaller than those of the domestic pigs at Pottery Neolithic Jarmo (see Figure 4). The molars of the suids at Shimshara all fall within the ‘larger range’ (see Figure 4).

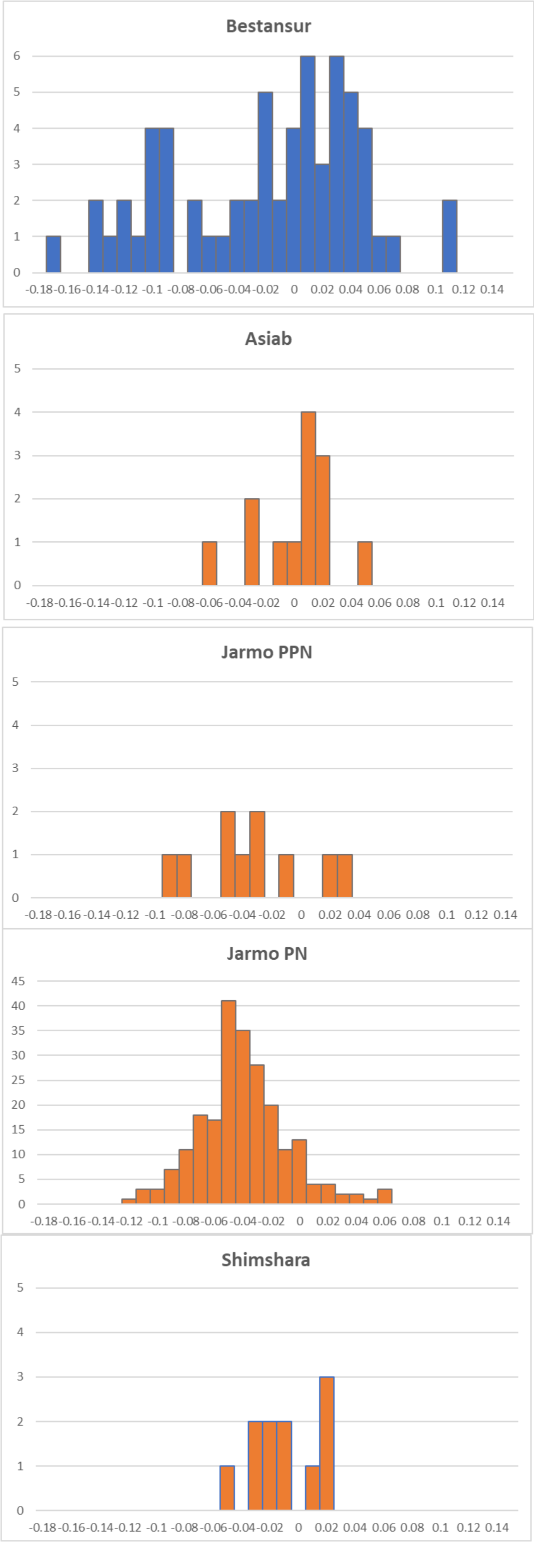

Figure 4: The LSI of the teeth measurements of Bestansur, Asiab (Bansgaard et al. 2019), Jarmo, Jarmo divided in PPN and PN (Price and Arbuckle 2014) and Shimshara (Bendrey et al. 2020 and this study), see supplementary information for dates of the sites and measurements.

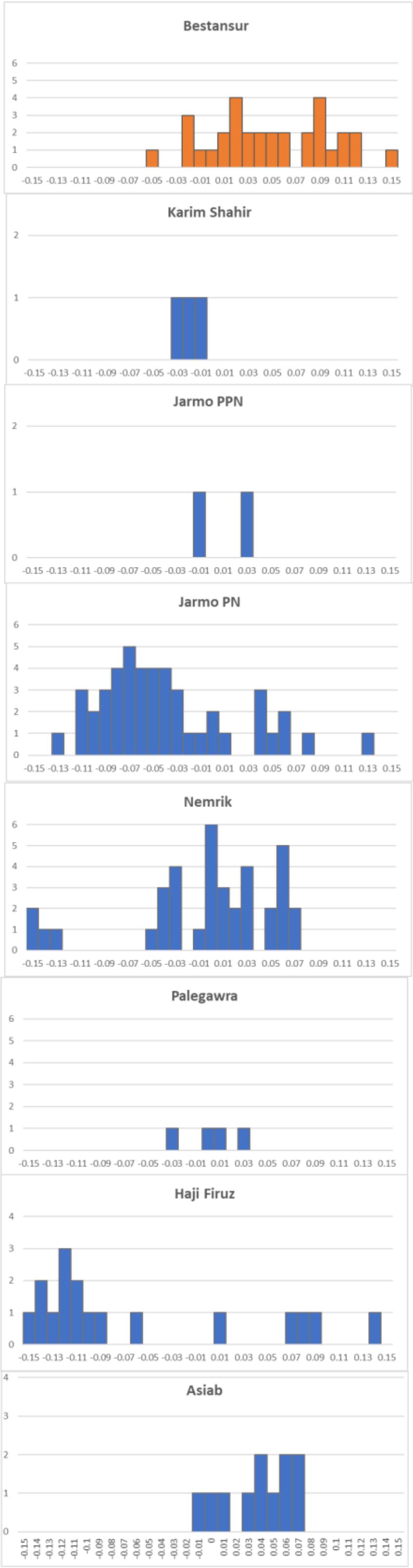

Figure 5: The LSI of the postcranial measurements of suids from Epipalaeolithic and Neolithic sites in the Eastern Fertile Crescent, see supplementary information for references and dates of the sites. Only one postcranial element of Shimshara provided usable metrics and has an LSI of 0.05 (see Table 4).

4.3 Kill-off patterns

The age reconstruction of Bestansur suids based both on bone fusion (table 1) and the dentition (table 2), show that the suids died at a relatively old age. The majority of the suids died after they reached an age of two years. However, the age reconstruction based on dental eruption and wear shows that some young animals were present at the site too, including three animals under one year and one under two years (see table 2). The jaws were all fragmented so none of the animals could be aged with the 'specific' age class, neither could the sex of the animals be established (see supplementary information).

Cranial remains of suids under two years were identified, but bones of young individuals were absent. Unfused bones of juveniles are in general more porous and therefore degrade faster (Zeder *et al.* 2015, 149), so it is possible those are underrepresented at the site. Not enough data are available to make an age reconstruction for suids at Shimshara.

Table 1: The age of the suids of Bestansur based on bone fusion (age categories following Zeder et al. 2014).

Fusing Elements	Age class	Age (months)	Fused	Unfused	Fusing	% fused
Scapula	D	7-8	3			
P. Radius	D	7-8	4			
Total D	**D**	**7-8**	**7**			**100**
D. Humerus	E	8-18	6			
Phalanx II	E	8-18	4	2		
Total E	**E**	**8-18**	**10**	**2**		**83.3**
D. Tibia	F	18-24	5			
Phalanx I	F	18-24	4			
Total F	**F**	**18-24**	**9**			**100**
D. Metapodials	**G**	**24-36**	**2**			**100**
Calcaneum	**H**	**36-48**	**2**			**100**
D. radius	I	48-60	2	1		
D. Femur	I	48-60	2	1	1	
P. Tibia	I	48-60	1	1		
D. & P. Ulna	I	48-60		4		
Total I			**5**	**7**	**1**	**46.2**
Radius and ulna	**K**	**>96**	**1**	**2**		**33.3**

Table 2: The age of suids from Bestansur based on dentition (age categories from simplified A (Lemoine et al. 2015*), for full data see SI).*

Age (months)	NISP
<12	3
12-24	1
24-36	
36-52	1
>54	8

Table 3: Teeth measurements of the suids of Bestansur and Shimshara (following Payne and Bull 1988). All LSI values are included in the diagram, even though some come from the same specimen given the size of our dataset and the fact that the values often differ. Mant=mandible with teeth and maxt= maxilla with teeth.

Bestansur									
Bone ID	Context	Element	Tooth	Anterior (mm)	Posterior (mm)	Length (mm)	LSI Anterior	LSI Posterior	LSI Length
2518	1333	MANT	M1	11.2	12.4	19.3	-0.03	-0.02	
2622	1312	MANT	M1	9.4	10.5	17.6	-0.10	-0.09	
2666	1333	MANT	M2		17.5	25.2		0.03	
3025	1331	MANT	M1			12.5			
3146	1350	MANT	M3	20.8		48.3	0.06		0.07
3366	1340	MANT	M3	20			0.04		
7420	2122	MANT	M1	11.9	13.8	17.1	0.00	0.03	
7420	2122	MANT	M2	14.7			0.05		
7394	2117	MANT	M3	18.2		39.4	0.00		-0.02
7339	2117	MANT	dP4			22.4			0.11
7739	2217	MANT	M1	12.5	13.3	21.2	0.02	0.01	
7241	1976	MANT	M1	11.9	13.9		0.00	0.03	
7241	1976	MANT	M2	15.5	17	24	-0.01	0.01	
7187	1976	MANT	M2		17			0.01	
7187	1976	MANT	M3	20.2		43.6	0.04		0.02
7527	2129	MANT	dP4			21.8			-0.02
7527	2129	MANT	M1	12	12.7	20.4	0.00	-0.01	
7546	2129	MANT	M2	15	17.6	22.2	-0.02	0.03	
7546	2129	MANT	M3	16.9		37.9	-0.03		-0.04
7743	2161	MANT	M1		9.5			-0.10	
7743	2161	MANT	M2	10.7	12.1	20.3	-0.17	-0.13	
7748	2161	MANT	M1	12.1	13.9	18	0.01	0.03	
2623	1312	LM1	M1		10.6			-0.05	
3357	1412	LM3	M3	20.4		44.5	0.05		0.03
4550	1357	LDP4	dP4		10.1	21.5			-0.02
3370	1336	MAXT	M3	22.1			0.01		
3371	1336	MAXT	M1	20.5			0.11		
4125	1331	MAXT	dP4		9.5			-0.14	
4663	1347	MAXT	dP4		10	14.8		-0.12	-0.07
7559	2129	MAXT	dP4		9.6	15.8		-0.14	-0.04
7559	2129	MAXT	M1	12.7	13	14.5	-0.10	-0.09	
7559	2129	MAXT	M2	15.7	15.9	20.6	-0.11	-0.09	
7290	2117	MAXT	M1		17			0.02	
7290	2117	MAXT	M2			17.4			
3085	1331	UM2	M2	16.3	17	20.5	-0.09	-0.06	
3086	1331	UM1	M1	13.6		15.9	-0.07		
3087	1331	UM2	M2		15.5			-0.10	
7271	2103	UM3	M3	24.3		42.7	0.05		0.04

7190	1976	UM3	M3	23.8		40	0.04		0.01
Shimshara									
183	1276	MAXT	M1	14.8	15.1	17.5	-0.03	-0.03	
184	1276	MAXT (possibly same specimen as 183)	M2		19			-0.01	
2	SF113	MANT	M2		15.7			-0.02	
2	SF113	MANT	M3	19.3		42.1	0.02		0.01
182	1276	MANT	M1	10.7		18.4	-0.05		
182	1276	MANT	M2	15.2	15.9	24.6	-0.01	-0.02	
639	1660	MANT	M2	16.5	17.1	24.9	0.02	0.02	

Table 4: Postcranial measurements of the suids of Bestansur and Shimshara (following von den Driesch 1976) All LSI values are included in the diagram, even though some come from the same specimen given the size of our dataset and the fact that the values often differ.

Bestansur									
Scapula	Bone ID	Context	GLP (mm)	SLC (mm)	LG (mm(	BG (mm(	fusion	LSI (GLP)	LSI (LG)
	3290	1412	38	27.2	33.9	28.3		- 0.02	0.02
	7322	2117	47.9	38.4	39.7	37.1		0.08	0.09
	7143	1974	49	34.3	40.2	31.6		0.09	0.09
Humerus	Bone ID	Context	Bd	BT	HTC			LSI (Bd)	LSI (BT)
	6327	1721	53	40.4	24.4			0.06	0.03
	7425	2122	47.4	41.5				0.01	0.04
	7128	1950	47.6	40				0.02	0.03
	7737	2161		55.5	47.3				0.17
	7778	2161	56.1	46.6				0.09	0.09
Radius	Bone ID	Context	BpP	Bd				LSI (BFP)	LSI (BD)
	3226	1414	36.6					0.03	
	3704	1387		43.4			UF		0.04
	4931	1555		37.6			UF		-0.02
	7324	2117	41.7					0.09	
	7426	2122	38.1					0.05	
Ulna	Bone ID	Context	BPC					LSI (BPC)	
	5012	1538	25					- 0.01	
	6323	1721	22.8					- 0.05	
	7395	2103	35.6					0.15	
	7325	2117	33.7				UF	0.12	
	7616	2127	24.3					- 0.02	
MCIII	Bone ID	Context	BP	BD				LSI (BP)	LSI (BD)
	7331	2117	29.2	22.9				0.15	0.08
	7446	2122		21.4					0.05

MCIV	Bone ID	Context	BP	BD				LSI (BP)	LSI (BD)
	2767	1330	22.3	21.8				0.07	0.09
	7447	2122		23.2					0.12
Tibia	Bone ID	Context	BP	BD				LSI (BD)	LSI (BP)
	1996	1220		36.8					0.04
	2660	1333		40.1					0.08
	3153	1402	71.4				UF	0.10	
	7201	1976		42.8					0.11
Astragalus	Bone ID	Context	GLl	GLm				LSI (GLl)	LSI (GLm)
	7188	1976	51.3	47.2				0.03	0.03
	7497	2135	54.4	48.3				0.06	0.04
	7782	2161	49.4	44.3				0.02	0.01
	7356	2117	49.9	38.4				0.02	-0.06
Calcaneus	Bone ID	Context	GB	GL				LSI (GB)	LSI (GL)
	4088	1331	96	36.1				0.00	0.1
Metatarsal III	Bone ID	Context	Bp	Bd				LSI(Bp)	LSI (Bd)
	3056	1331	18.8					0.02	
	7749	2161	23.1					0.11	
Metatarsal IV	Bone ID	Context	Bp					LSI (Bp)	
	4077	1331	18.1					0.01	
Shimshara									
Radius	Bone ID	Context	BpP	Bd				LSI (BFP)	LSI (BD)
	-	1276		38.3					0.05

4.4 Isotopes and Diet

Forty bones of Bestansur were sampled for stable isotopic analysis of nitrogen and carbon. In general, the collagen quality was relatively low. The majority of the samples were unreliable because they did not match standards for bone collagen (Ambrose 1993, see SI for further information).

5 Discussion

The high representation of suids in the zooarchaeological assemblage at Bestansur indicates that they were of major dietary value. This high abundance can possibly be explained by the location and environment of the settlement. Bestansur is a piedmont site likely located close to forest during the Neolithic, which would have provided a favourable habitat for wild boar. The proximity to water sources associated with reeds and rushes would have been a place where wild boar could shelter (Bendrey *et al.* 2020). Other Epipalaeolithic and Early Neolithic piedmont sites do not show such a high percentage of suids, with the exception of Shimshara. It is possible that the environment in Shimshara, along the banks of the Lesser

Zab, was even more favourable for wild boar than Bestansur. Since the overall zooarchaeological assemblage of Shimshara is small, and limited data of the size and age of the suids at Shimshara is available, it is hard to say more on the nature of the human-suid relationships at Shimshara.

The bones of the suids of Bestansur are very large compared to other sites (Figure 3). Present day wild boar of the Zagros region are larger than those in the Western Fertile Crescent (Zeder and Lemoine 2020a). However, the 'larger group suids of Bestansur' have larger bones than the wild boar from the Epipalaeolithic and Neolithic from the Zagros region. The smaller group of suids of Bestansur is still larger than the group of early domestic pigs of Pottery Neolithic Jarmo and the domestic pigs of Haji Firuz. The possibly few smaller postcranial remains from Nemrik are from the later phase V, which dates >6400 cal BC (Sołtysiak *et al.* 2015) of were domestic pig could have been present.

In contrast, the molars of the suids of Bestansur are relatively small. The larger molars fall within the size range of the molars of Asiab and Pre-Pottery Neolithic Jarmo (Figure 4). It is striking that the smaller molars of Bestansur are smaller than those of the Pottery Neolithic suids of Jarmo, where pigs are argued to be domesticated (Price and Arbuckle 2015). Teeth are less influenced by sexual dimorphism and decrease in size as a result of the domestication process earlier than postcranial elements (Rowley-Conwy *et al.* 2012; Zeder 2012; Zeder and Lemoine 2020, 7-8). Therefore, the small molars of the Bestansur suids are likely to be an indication of early human management. The biological process behind the decrease in tooth size under domestication is unknown (Price and Hongo 2020, 22-3), so it is unsure how human suid interaction at Bestansur could have caused this tooth size decrease. None of the molars show heavy wear, so this should not have affected the size (SI), and most of the molars came from mandibles with multiple teeth present so misidentification is unlikely to have taken place.

The kill-off pattern of the suids from Bestansur is not representative of a managed population. Young individuals may be underrepresented in the assemblage, but the majority of the suids reached an age beyond 2 years (see Table 1 and 2). In a managed herd it would be expected that most animals would be slaughtered before an age of 2 years (Hadjikoumis 2012). In the Neolithic, a larger part of the herd may have been kept alive, since the herds were usually smaller, and a greater percentage would be needed for reproduction, although, an increase in juveniles in the archaeological record is still expected when a herd is managed. At Pottery Neolithic Jarmo, 97% of the suids were slaughtered before they reached an age of two years (Price and Arbuckle 2015, 444-445). The suids from Asiab, which are interpreted as wild and unmanaged (Bangsgaard *et al. 2020*), are of very mixed age categories. Both young suids and senile suids were present in this assemblage. However, it is significant that these suids come from a special deposit and therefore may have little in common with the animals that formed the mainstay of the hunted fauna (Bangsgaard *et al.* 2020, 453).

Isotopic analysis could not provide any further insights due to the preservation of the collagen. Little is known about the diets of suids at other sites, since, to date, no isotopic research has been conducted on Neolithic suid remains in Southwest Asia and collagen in bones in this area often does not survive.

It is very interesting that at Bestansur there are no young kill-off or no small body sized suids, but that the suids have small teeth. This association of attributes has not been attested at other Neolithic sites in the Zagros region. Faecal material of a suid has been found at Bestansur (Elliot 2020, 338), which indicates presence of a live suid at the settlement. So, even though the population at Bestansur does not show the young kill-off associated with early management strategies, suids were at least occasionally in close interaction with humans on site.

The high abundance of suids at Bestansur and Shimshara is likely to be a combination of the suitability of local environments to this taxon and cultural preference. Why wild boar and pig contributed only modestly to other sites and the late overall adoption of domestic pigs in the Zagros region requires further investigation. In general, wild boar have a large ecological tolerance but they do lack sweat glands, so in hot areas they need to thermoregulate by wallowing and resting in cool places (Leaper *et al.* 1999).

Wild boar inhabit steppe, shrubland and farmland as long as there is water and some tree cover (Spitz 1989). Nevertheless, in the high and Southern Zagros higher aridity and more limited riverine marshy environments could have meant fewer wild boar in the environment, thus discouraging early pig management and domestication. It is likely that Neolithic settlements in the southern Zagros were only able to incorporate pig husbandry when they adopted more intensive husbandry practices (Price and Arbuckle 2015). It has been argued that during the Neolithic of Southwest Asia, extensive husbandry was possibly the dominant management strategy of suids (Dobney *et al.* 2007; Ervynck *et al.*, 2001; Price and Arbuckle 2015; Price and Hongo 2020). Under such an extensive husbandry regime, herders maintain little control over pig reproduction, diet, and mobility, allowing pigs to forage for their own food and interbreed with wild boar (Price and Arbuckle 2015, 449). This approach could be mixed with more intensive strategies of keeping only the females at the settlement (Ervynck *et al.* 2001, Price and Arbuckle 2015). Strategies like this are employed by hunter-gathering groups in New Guinea (Price and Hongo 2020). However, at Jarmo, where pig management was practiced and where the location was favourable too, suids did not make up an important source of the food economy. The difference in relative abundance of suids between Shimshara, Bestansur and Jarmo and could be due to cultural preference or local environmental differences between two sites, with Bestansur and Shimshara more favourably located for rich proximate riverine environments. It is possible that this local favourable environment for wild boar encouraged the inhabitants of Bestansur and possibly Shimshara to experiment with such early management strategies. The animals at Bestansur clearly seem to be in a place in between wild and domestic. They have small teeth, but the inhabitants did not practice early kill-off and might have loosely managed the suids extensively.

6 Conclusion

The Bestansur and Shimshara zooarchaeological assemblages comprise an exceptionally high frequency of suids. The data of Bestansur suggest that the relationship between suids and human was possibly a different one than a strict hunter-prey relationship. The animals are very large but do have small molars relative to their body size. Most suids were slaughtered above an age of two years old, so there is no culling of young animals, which might be expected in a managed herd. It is possible that the suids were wild, but some experimentation with management strategies seems to have been underway. Young suids were present at the site and the evidence for pig faecal material indicates that they were probably brought to the site alive or kept there. Also, suids could have been attracted to the human settlement. Domestication may take several millennia and these site assemblages could represent examples where the animals are somewhere in this process.

This study has demonstrated that the Neolithic in the Zagros was not uniform in the adaption and exploitation of different animals. Environment does not seem to be the only factor influencing people’s choices regarding specific animals. Furthermore, the possible early management strategies of suids might have varied considerably throughout the Zagros region. So, it remains critical to study sites on their own terms in order to better understand the full Neolithisation process and the extent to which local environments and cultural traditions influenced early management and domestication practices and processes around the world.

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Data availability statement

The data that support the findings of this study are in the supplementary information.

Conflict of interest

No conflict of interest to declare.

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Supplementary information

Site	Environment	Period	*Ovis/Capra*	*Ovis*	*Capra*	*Sus*	*Bos*	Large cervid	Small cervid	Gazelle	*Equus hemonius*	*Vulpes* sp.	Other mammal	total	Literature
Bestansur	Piedmont	PPN	323	137	51	269	50	127	10	27		16		1010	This study
Palegawra	Piedmont	Epipaleolithic	29	10	9	15	3	74		74	164	31		409	Asouti *et al. 2020*
Karim Shahir	Piedmont	Epipaleolithic	93	28	3	19	9	19		11		9		191	Stampfli 1983
East Chia Sabz	Piedmont	PPN	246	174	77	16	7	0	0	11			11	542	Darabi *et al.* 2012
Jarmo PPN	Piedmont	PPN	884	72	82	33	126	35		83	72	12	14	1413	Price and Arbuckle 2015
Jarmo PN	Piedmont	PN	2401	117	294	241	103	89	2	136	13	8	24	3428	Price and Arbuckle 2016
Nemrik I-III	Steppe	PPN	1	10	2	7	3	1		68			60	152	Lasota-Moskalewska 1994
Nemrik IV	Steppe	PPN	11	15	12	24	94			111			44	311	Lasota-Moskalewska 1995
Nemrik V	Steppe	PPN	18	140	75	220	721	16		453			259	1902	Lasota-Moskalewska 1996
Shimshara	Piedmont	PPN	37	28	21	163	9	9	4			3		274	Bendrey *et al.* 2020
Qermez Dere	Steppe	PPN	38	42			12			1174	4	1677	49	2996	Dobney *et al.* 1999
M'lefaat	Steppe	PPN		50		7	2			73		6		138	Turnbull 1983
Sheik-e Abad	High Zagros	PPN	56	5	48		2	12				1	1	127	Bendrey *et al.* 2013
Ganj Dareh	High Zagros	PPN	21731	547	4689	308	174	63		5		579	13	28109	Hesse 1978
Hajji Firuz	High Zagros	PN		V	V	V	V	V					V		Meadow 1983

SI 1: *Table of the different Neolithic sites and the species abundance (based on NISP), the publication of Hajji Firuz only included if animals were present, indicated by V in table (references in main reference list of the article).*

WFC	Years BC	EFC	Years BC
Late Epipalaeolithic	12000 – 10000	Late Epipalaeolithic	15000 – 10000
PPNA	10000 - 8700	Early Neolithic/Pre-Pottery Neolithic	10000 - 7000
Early PPNB	8700 - 8200		
Middle PPNB	8200 - 7500		
Late PPNB	7500 - 7000		
Pottery Neolithic	7000 - 6000	Pottery Neolithic	7000 - 5200

SI 2: Timetable of the period in the WFC compared to EFC.

BoneID	Element	dp4	P3	P4	M1	M2	M3	Specific	Simplified a	Simplified B	Age determination (months)
2518	mant				9			X	X	II	12-52
2666	mant		12	12		12		X	F	III	52-96
3025	mant			13	14			8	F	III	52-72
3146	mant					13	9	8	F	III	52-72
3366	mant						9	X	X	II/III	0-52
7420	mant			12	18	15		9	F	III	72-96
7394	mant						9	X	X	II/III	12-96
7339	mant	14			10			4	C	I	8-12
7241	mant			14	17	15		9	F	III	72-96
7187	mant					16	10	9	F	III	72-96
7527	mant	10			10			3-4	B/C	I	6-12
7546	mant					12	9	8	F	III	52-72
7743	mant				11	9		X	D	II	12-16
7748	mant			11	15			8	F	III	52-72
4550	dP4	15						4	c	I	8-12
7559	maxt	11			10	8		3-4	b/c	I	6-12
7290	maxt				14	9	9	7	E	II	30-52

SI 3: Ageing of cranial elements of the suids of Bestansur, following Lemoine et al. 2014 Mant=mandible with teeth and maxt= maxilla with teeth.

SI 4: Description of isotopic sampling and results of Isotopic analysis

All isotopic analysis was done in the labs of the school of Geography, Archaeology, and Environmental Science at The University of Reading. Bone was sampled following the methods described in Müldner and Richards (2005). Robust parts of the bones were cut of using a Dremel saw. After that adhering soil and trabecular bone was removed using a scalpel. Inner and outer external surfaces of the bone were removed using a drill. Between 300-800 mg bone was sampled. After this bone samples were broken into shards, preferably over the long grain of the bone so the length of the collagen fibrils would be preserved. To demineralize the samples, 0.5 M HCL was poured over the bones. The 0.5 M HCL added to sample was also kept in the fridge at a temperature of around 3 degrees Celsius. The samples in the acid were then put in the fridge, to slow down the speed of the reaction. The samples were left in the fridge until most of the bone was demineralized. It differed per sample how long this process took. After demineralization the samples were rinsed to neutral pH with de-ionised water. Then the samples were placed in tubes and gelatinised in a pH 3 HCl solution at 70 °C for 48 h. After removing reflux-insoluble residues with a 5–8 µm Ezee®, the samples were placed in the freezer. When thoroughly frozen, the samples were placed in the freeze-drier for 48 hours.

The samples which yielded enough collagen were run in duplicates over different runs in the MassSpec. Since those two runs gave different results for the same samples, the samples were run a third time. This run gave different results again, so it was concluded this was because the samples were unreliable.

In addition, the majority of the samples were unreliable because they showed unreliable C:N ratios, they must range between 2.9-3.6 (Ambrose 1993). Also whenever, total yield of collagen is smaller than 1% of the sampled bone weight, the data are not very reliable (Brock *et al.* 2010, Vaughan *et al.* 2014, 308). The third criterion is the carbon and nitrogen concentration in the collagen. Both drop when the collagen is badly preserved. However, the precise indicators for well versus poorly preserved collagen vary between geographic regions (Ambrose 1990). No standard has been adopted for the researched region, but in N=>5·5 and C=>15% is used as general guidance (Ambrose 1990). Most of our samples do not meet those requirements.

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Table 1 of SI4 Isotopic results.

Bone ID	Context	Sp.	Element	Weight sample (mg)	Collagen extracted (mg)	Yield (%)	δ13C	δd15 N	Carbon (%)	Nitrogen (%)	C/N ratio
7778	2161	SUS	HU	466	2.6	0.6					
							-20.6	7.0	12.1	4.2	3.3
							-18.5	6.8	12.7	4.4	3.4
7550	2129	CH	RAD	559	8.8	1.6					
							-19.4	6.6	30.1	9.2	3.8
							-20.6	6.7	30.7	10.9	3.3
							-18.7	6.5	31.3	10.8	3.4
7396	2103	BOS	RAD+ UL	1120	2.2	0.2					
							-20.2	18.5	22.4	0.3	79.0
7693	2143	CER	RAD	638	0.4	0.1					
7429	2122	OA	RAD	447	12.2	2.7					
							-21.6	5.9	160.7	16.5	11.4
							-19.0	6.0	140.7	15.7	10.5
7147	1947	CER	FE	564	2.5	0.4					
							-19.0	7.3	1.5	7.5	0.2
7451	2122	OA	MT	379	0.2	0.1					
7425	2122	SUS	HU	630	0.1	0.0					

7330	2117	CH	MT	438	1.7	0.4					
							-20.3	5.7	20.2	16.8	1.4
7430	2122	OA	MC	400	3.9	1.0					
							-22.1	5.6	155.6	18.9	9.6
							-20.0	6.5	212.5	17.0	14.5
7712	2145	CER	RAD	535	8.0	1.5					
							-19.8	7.2	24.5	7.9	3.6
							-22.0	7.2	25.5	8.6	3.5
							-19.2	8.2	19.5	6.9	3.3
7324	2117	SUS	RAD	745	18.0	2.4					
							-20.2	6.2	22.0	7.0	3.7
							-21.3	5.7	24.6	8.8	3.2
							-19.3	6.7	24.9	8.8	3.3
7345	2117	CH	TIB	461	6.2	1.3					
							-19.9	6.7	20.5	6.7	3.6
							-20.9	6.5	23.5	8.4	3.3
							-19.0	7.3	22.8	8.0	3.3
7314	2117	SUS	UL	433	16.0	3.7					
							-20.5	6.0	10.5	3.5	3.6
							-20.8	6.3	11.4	4.1	3.3
							-19.3	7.5	11.2	4.0	3.3
7257	2103	CER	MC	592	6.0	1.0					
							-21.0	5.2	6.5	1.8	4.2
							-19.8	5.9	24.0	8.4	3.3
							-18.7	6.9	24.2	8.4	3.4
7854	2133	CH	RAD	367	8.0	2.2					
							-28.7	4.3	0.1	0.0	3.3
							-18.8	5.7	28.4	10.0	3.3
							-18.7	6.7	29.5	10.3	3.3
7727	2101	CER	HU	603	2.0	0.3					
							-19.3	7.1	25.2	8.6	3.4

7367	2103	BOS	RAD	403	5.0	1.2					
							-20.9	6.1	34.4	10.1	4.0
							-20.7	5.7	91.1	13.9	7.6
							-19.7	6.9	39.9	13.8	3.4
7843	2133	OA	MT	291	0.4	0.1					
7447	2122	SUS	MTIV	591	6.0	1.0					
							-20.9	5.0	21.8	6.6	3.8
							-20.5	5.1	20.5	7.2	3.3
							-20.2	6.2	21.7	7.5	3.4
7360	2129	OC	UL	496	8.1	1.6					
							-22.7	3.3	1.2	0.3	5.2
							-17.8	5.2	7.4	2.5	3.5
							-20.8	14.3	1.5	0.4	4.2
7313	2117	SUS	RA	455	12.5	2.7					
							-20.3	5.8	26.1	7.9	3.9
							-19.1	6.2	23.5	8.4	3.3
							-19.1	6.7	20.5	7.2	3.3
7476	2122	OC	MT	468	8.6	1.8					
							-19.9	5.9	131.5	15.0	10.2
							-19.5	6.1	106.3	15.2	8.2
7290	2117	SUS	MAX	515	4.0	0.8					
							-20.3	9.3	2.2	0.6	4.4
							-20.8	13.1	2.3	0.6	4.6
7549	2129	CH	HU	493	5.9	1.2					
							-21.0	4.7	3.6	0.9	4.5
							-20.2	2.9		49.0	0.0
							-19.3	10.0	4.6	1.4	3.7
7189	1976	SUS	FE	539	10.6	2.0					
							-20.6	5.5	4.7	1.4	4.1
							-19.6	6.7	12.1	4.2	3.3

							-18.9	8.5	4.9	1.6	3.5
7269	2103	OC	FE	507	7.5	1.5					
							-19.8	5.8	6.4	2.0	3.8
							-18.2	8.0	7.7	2.6	3.5
							-18.4	8.8	8.1	2.7	3.5
7427	2122	SUS	UL	533	17.0	3.2					
							-20.0	5.1	13.9	4.3	3.8
							-18.8	6.9	15.6	5.5	3.3
							-18.8	6.5	21.1	7.3	3.4
7548	2129	CH	HU	490	7.6	1.6					
							-23.9	7.2	1.3	0.2	9.1
							-20.6	11.0	1.4	0.5	3.7
							-20.8	8.9	5.3	1.5	4.2
7420	2122	SUS	MANT	499	12.7	2.5					
							-20.9	6.3	4.9	1.4	4.0
							-19.1	8.7	5.5	1.9	3.4
							-19.7	8.8	6.7	2.1	3.7
7713	2145	Cervid	long bone	585	4.4	0.8					
							-20.1	5.6	49.5	14.1	4.1
							-20.0	5.7	71.7	15.6	5.4
							-19.8	5.7	45.0	15.5	3.4
7498	2117	CE	RA	510	2.7	0.5					
							-25.6	17.1	3.1	0.3	11.1
7394	2117	SUS	MANT	542	22.9	4.2					
							-19.2	6.8	36.9	11.1	3.9
							-19.1	7.3	31.4	11.3	3.3
							-18.6	10.9	3.8	1.3	3.3
7559	2129	SUS	MAXT	348	1.3	0.4					
							-18.5	3.7	39.6	13.8	3.4
7544	2129	CAPR	MT	595	16.0	2.7					

							-20.2	6.9	2.7	0.7	4.3
							-18.3	6.2	33.3	11.9	3.3
							-18.3	9.1	4.7	1.6	3.3
7322	2117	SUS	SC	506	11.7	2.3					
							-18.2	6.6	13.2	4.1	3.8
							-17.4	7.2	10.9	3.9	3.3
							-17.7	8.3	14.1	4.9	3.4
7559	2129	SUS	MAXT	478	14.4	3.0					
							-19.6	3.6	7.0	2.0	4.0
							-23.2	6.0	1.9	0.5	4.2
							-19.1	6.1	9.0	2.9	3.6
7339	2117	SUS	MANT	559	16.7	3.0					
							-20.6	5.6	12.9	4.1	3.7
							-21.1	6.9	5.9	1.9	3.6
							-20.1	6.9	13.9	4.9	3.3
7187	1976	SUS	MANT	538	8.8	1.6					
							-20.5	6.1	16.8	5.3	3.7
							-22.8	-22.3		40.1	0.0
							-20.0	7.1	15.6	5.5	3.3
7327	2117	BOS	SC	547	23.8	4.4					
							-19.9	9.4	3.2	1.1	3.4

SI 5: further exploration of the pig dentition size

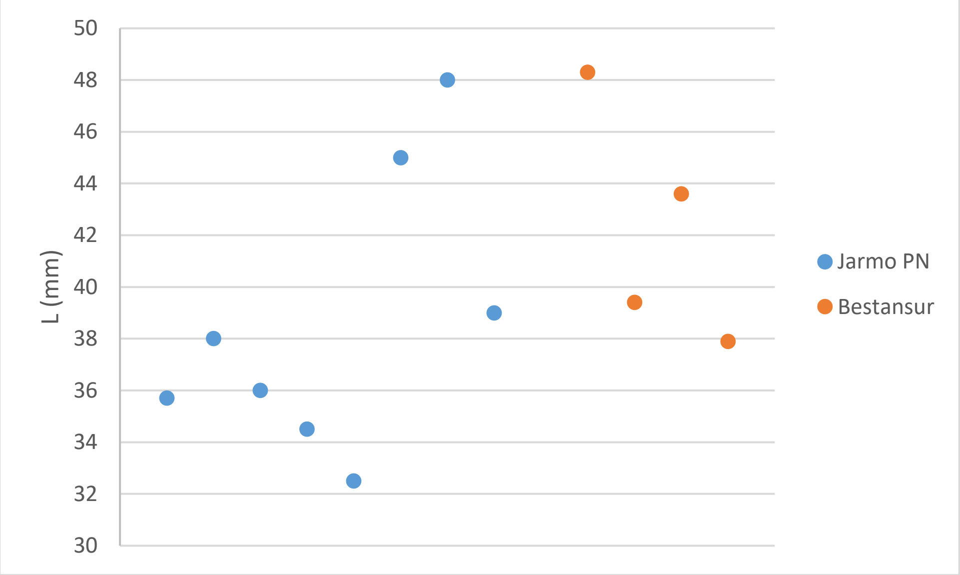
Table 1 SI: the measurements of teeth (as in presented article) but with further information of the molars. In this table the tooth wear stage of each molar is added (following Grant 1982, but with the additions of Lemoine *et al.* 2015). Also in the last column is added whether the tooth was in the mandible or maxilla, or whether it was a loose tooth. If it was a tooth in the mandible or maxilla it also noted which other teeth were present in the mandible/maxilla.

Bone ID	Context	Element	Tooth	Toothwear stage (Grant)	Anterior (mm)	Posterior (mm)	Length (mm)	LSI Anterior	LSI Posterior	LSI Length	In mandible (man) or maxilla (max)|, or loose tooth (lt)

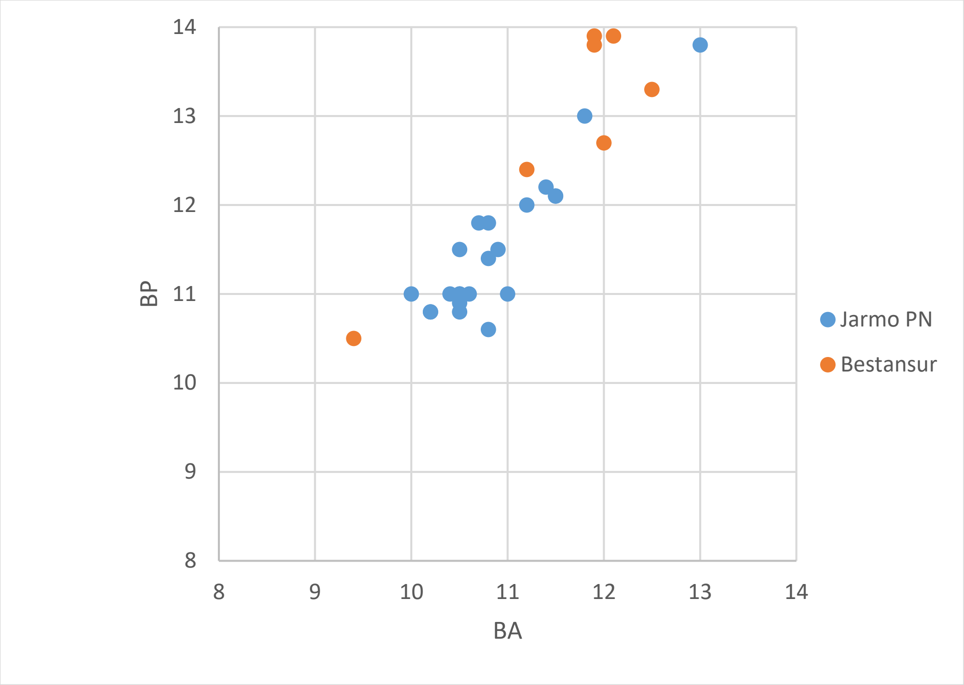
2518	1333	MANT	M1	c	11.2	12.4	19.3	-0.03	-0.02		Man, only M1 in mandible
2622	1312	MANT	M1	c	9.4	10.5	17.6	-0.10	-0.09		Man, P4 in mandible too
2666	1333	MANT	M2	f		17.5	25.2		0.03		Man, P3, P4, M1 (but damaged present too)
3025	1331	MANT	M1	h			12.5				P4, present, not used in LSI
3146	1350	MANT	M3	g	20.8		48.3	0.06		0.07	Man, M2 present
3366	1340	MANT	M3	c	20			0.04			Man, only m3 present
7420	2122	MANT	M1	m	11.9	13.8	17.1	0.00	0.03		I1,, I3, P3, P4, M1, M2 in man
7420	2122	MANT	M2	j	14.7			0.05			Same man as previous
7394	2117	MANT	M3	c	18.2		39.4	0.00		-0.02	Man only m3 present
7339	2117	MANT	dP4	h			22.4			0.11	man contains p2, p3, dp4, m1 (m2 might have been erupted but mandible broke of there)
7739	2217	MANT	M1	d	12.5	13.3	21.2	0.02	0.01		Same as previous
7241	1976	MANT	M1	l	11.9	13.9		0.00	0.03		P3, P4, M1, M2 there, part of the mandible with m3 not present
7241	1976	MANT	M2	j	15.5	17	24	-0.01	0.01		Same as previous

											mandible
7187	1976	MANT	M2	k		17			0.01		Man, M2, M3 present
7187	1976	MANT	M3	d	20.2		43.6	0.04		0.02	Same as previous man
7527	2129	MANT	dP4	d			21.8			-0.02	Man, dp3, dp4, m1 there then broken
7527	2129	MANT	M1	d	12	12.7	20.4	0.00	-0.01		Same as previous man
7546	2129	MANT	M2	f	15	17.6	22.2	-0.02	0.03		Man, M2, M3 present
7546	2129	MANT	M3	c	16.9		37.9	-0.03		-0.04	Same as previous
7743	2161	MANT	M1	e		9.5			-0.10		Man, M1, M2 present
7743	2161	MANT	M2	c	10.7	12.1	20.3	-0.17	-0.13		Same as previous man
7748	2161	MANT	M1	j	12.1	13.9	18	0.01	0.03		Man, P3, P3, M1, then broken
2623	1312	LM1	M1	c		10.6			-0.05		LT
3357	1412	LM3	M3	c	20.4		44.5	0.05		0.03	LT
4550	1357	LDP4	dP4	j		10.1	21.5			-0.02	LT
3370	1336	MAXT	M3		22.1			0.01			max
3371	1336	MAXT	M1		20.5			0.11			max
4125	1331	MAXT	dP4			9.5			-0.14		Max, dp4 lighlty in wear
4663	1347	MAXT	dP4			10	14.8		-0.12	-0.07	UdP2, UdP3, UdP4 in light wear
7559	2129	MAXT	dP4			9.6	15.8		-0.14	-0.04	Max, dp4, m1, m2 present
7559	2129	MAXT	M1	d	12.7	13	14.5	-0.10	-0.09		Same as previous
7559	2129	MAXT	M2	b	15.7	15.9	20.6	-0.11	-0.09		Same as previous
7290	2117	MAXT	M1	h		17			0.02		In max, M1,

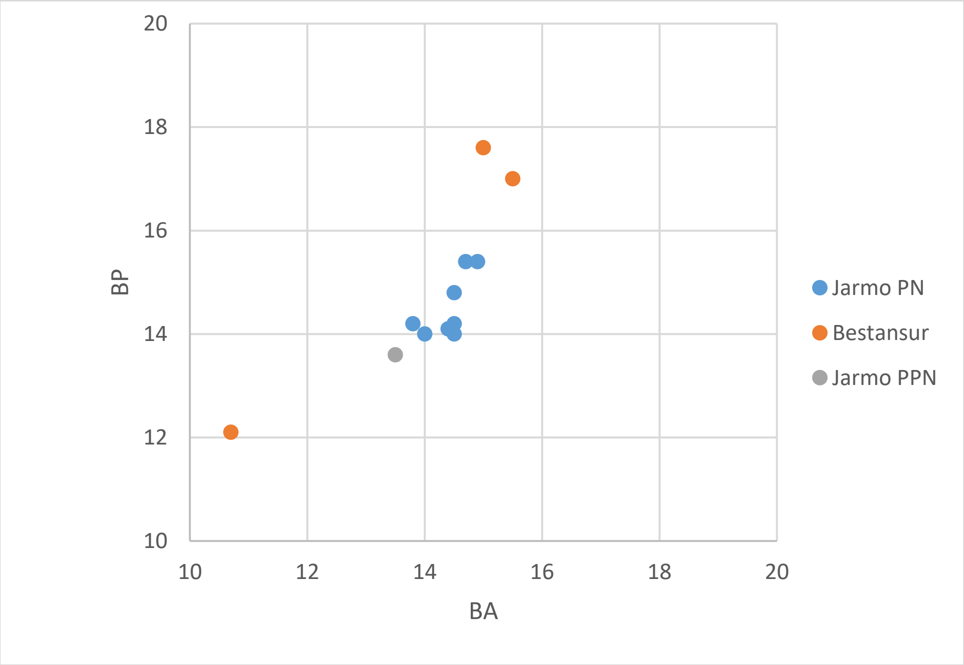
											M2, M3 present
7290	2117	MAXT	M2	c			17.4				Same as previous
3085	1331	UM2	M2		16.3	17	20.5	-0.09	-0.06		Lt
3086	1331	UM1	M1		13.6		15.9	-0.07			lt
3087	1331	UM2	M2			15.5			-0.10		lt
7271	2103	UM3	M3	c	24.3		42.7	0.05		0.04	Lt
7190	1976	UM3	M3	b	23.8		40	0.04		0.01	Lt



SI 5 figure 1: The lengths of the M3 of molars of Jarmo and Bestansur, for Bestansur only M3 in mandible were included: data from Jarmo from Price and Arbuckle 2015.



Appendix 5 Figure 2: posterior breadth and anterior breadth of the M1's from Jarmo and Bestansur. For Bestansur only M1's which were in the mandible are included. Data from Jarmo from Price and Arbuckle 2015.



Appendix 5 Figure 3: posterior breadth and anterior breadth of the M2's from Jarmo and Bestansur. For Bestansur only M2's which were in the mandible are included. Data from Jarmo from Price and Arbuckle 2015.

Chapter 5: Sheep and Goat Management in the Early Neolithic in the Zagros Region (8000-5500 BC): New Zooarchaeological and Isotopic Evidence from Ganj Dareh, Bestansur and Jarmo.

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Abstract

The transition from hunter gathering to farming is one of the most important episodes in the history of humankind. Considerable evidence indicates that this shift was a slow and complex and highly localized process, which took place in multiple places in Southwest Asia independently, from around 9500 BC. Caprines were arguably the first domesticated livestock, brought under human control during a process that began in the 9th millennium BC in a region extending from southeastern Turkey to northwestern Iran. In this research we integrate zooarchaeological analysis with stable isotopic data of faunal remains from three key Early Neolithic sites in the Eastern Fertile Crescent: Ganj Dareh (ca. 8000 BC), Bestansur (ca. 7800-7000 BC) and Jarmo (Early Neolithic and ceramic Neolithic). Some form of goat management seems to have been practiced at Bestansur based on spherulites, dung and shed deciduous teeth, while sheep were not managed, but hunted. At Ganj Dareh there is evidence for quite intensive human management of goat, based on young male cull, stable isotopic evidence and spherulites. At Jarmo there is evidence for young male culling of goat, but no evidence for sheep management has been found before the ceramic Neolithic phase at Jarmo. No clear evidence is found for systematic transhumance of caprines at all sites.

Key words

Neolithic, Eastern Fertile Crescent, Sheep/goat domestication, human-animal relationships, stable isotope analysis

1 Introduction

The transition from hunter gathering to farming is one of the most important episodes in the history of humankind. Considerable evidence indicates that this shift was a slow and complex process, which took place in multiple places in Southwest Asia independently, from around 9500 BC, rather than a sudden revolutionary change subsequently spreading from a single core zone (Fuller *et al.* 2011; Zeder 2011). Initial management strategies, especially of animals, were developed several millennia before the first detectable changes in skeletal morphology related to domestication (Zeder 2011; Zeder 2012). In addition, management, domestication and adaption of the different livestock and plant species was a highly localized process, influenced by both cultural and environmental factors (Fuller *et al.* 2011; Arbuckle and Atici 2013; Arbuckle 2014).

Caprines were arguably the first domesticated livestock, brought under human control during a process that began in the 9th millennium BC in a region extending from southeastern Turkey to northwestern Iran (Naderi *et al.* 2006; Zeder 2011; Daly *et al.* 2018). Both sheep and goat were a major food source for humans throughout the Palaeolithic and Epipalaeolithic in the Eastern Fertile Crescent (Zeder 1999; Matthews *et al.* 2013) and continued to be of major dietary importance in the Neolithic (Zeder 2008). The lack of morphological markers in the first stages of domestication makes it challenging to evaluate when people first started to manage caprines and what these first stages of animal management specifically involved (Makarewicz and Tuross 2012; Arbuckle and Atici 2013). During the early phases of management, humans may have started to control diet and movement, as well as changing their way to select animals for slaughter. The intensive culling of young males is practiced at some sites at the start of the Neolithic in the Zagros Mountains (Zeder 2008). However, clear evidence for young male kill-off appears considerably later than the origins of caprine management in the faunal record in Southwest Asia overall (Arbuckle and Atici 2012; Arbuckle 2013). Instead, early Neolithic caprine management practices were characterized by a high degree of local diversity. Foddering, control over mobility, penning and manipulation of weaning age need to be investigated to obtain a clearer picture of early animal management (Arbuckle and Atici 2012; Stiner *et al.* 2022).

In this research, we integrate zooarchaeological analysis with stable isotopic analysis from three key Early Neolithic sites in the Eastern Fertile Crescent: Ganj Dareh (ca. 8000 BC) (Zeder 2009; Yeomans *et al.* 2021), Bestansur (ca. 7800-7000 BC) and Jarmo (Early Neolithic and ceramic Neolithic) (Zeder 2008), to investigate local variation and the first stages of caprine management.

2 Research background of studied sites

2.1 Ganj Dareh

Ganj Dareh is a small mound site in the high Zagros Mountains at ca. 1400 m above sea level, in western Iran (Figure 1). The site was first excavated in the 1960s and 1970s and has been restudied and re-excavated over the last decade (Zeder 2008; Darabi *et al.* 2019). The site consists of multiple levels, which span 100-200 years of occupation. Goats are the most abundant animals in all levels, outnumbering sheep 15:1 (Zeder 1999). Apart from caprines, the zooarchaeological assemblage contains wild boar, hare, deer, aurochs and various birds. Evidence of crab, crayfish and land snail consumption is present (Hesse 1978). The presence of house mouse (*Mus musculus)* has been argued to indicate year-round occupation of humans (Hesse 1979). Carbonised plant remains are poorly preserved, making it impossible to determine their domestic status (Merrett *et al.* 2021).

2.2 Bestansur

Bestansur is a Neolithic site located in the foothills of the Zagros Mountains at 550 m above sea level, in Iraqi Kurdistan (Figure 1). The site has been excavated since 2012 over the course of nine field seasons by a team from the University of Reading in collaboration with the Sulaimaniyah and Erbil Directorates of Antiquities and Heritage. The site covers about 4 ha and the top of the mound is 8 metres high, although on the edges of the site the Neolithic is only 30-50 centimetres below modern plough depth (Richardson *et al.* 2020, 116). Neolithic occupation spans from ca. 7800-7000 BC, with Neolithic layers at least 4 metres thick (Matthews *et al.* 2020, 629), in places covered by significant occupation of Iron Age and later date (first millennium BC). The site is situated close to a variety of ecosystems comprising springs, flat steppe, river and marshlands, the foothills of the Zagros, all of which would have been accessible for the inhabitants of the Neolithic site (Matthews *et al.* 2020, 633). Apart from caprines, wild boar and large cervid are very abundant at the site (see SI).

2.3 Jarmo

Jarmo is a 1.3 ha Neolithic site located in the foothills of the Zagros Mountains, at ca. 800 above sea level, in Iraqi Kurdistan (Figure 1). The exact dating of Neolithic Jarmo is problematic (Price and Arbuckle 2013, 444) but the site contains both Early Neolithic and ceramic Neolithic layers, and so is likely to span ca. 7200-6500 BC. The site was excavated over the course of three field seasons between 1948 and 1955 (Braidwood and Howe 1960), and the zooarchaeological assemblage has since been reanalysed (Flannery 1983; Stampfli 1983; Zeder 2008; Price and Arbuckle 2015). In both Early Neolithic and ceramic periods, goat were the dominant taxon, followed by sheep. Aurochs, gazelle, deer, hemiones, fox, dog, lion, leopard, lynx, badger and hare remains were also recovered (Price and Arbuckle 2015).

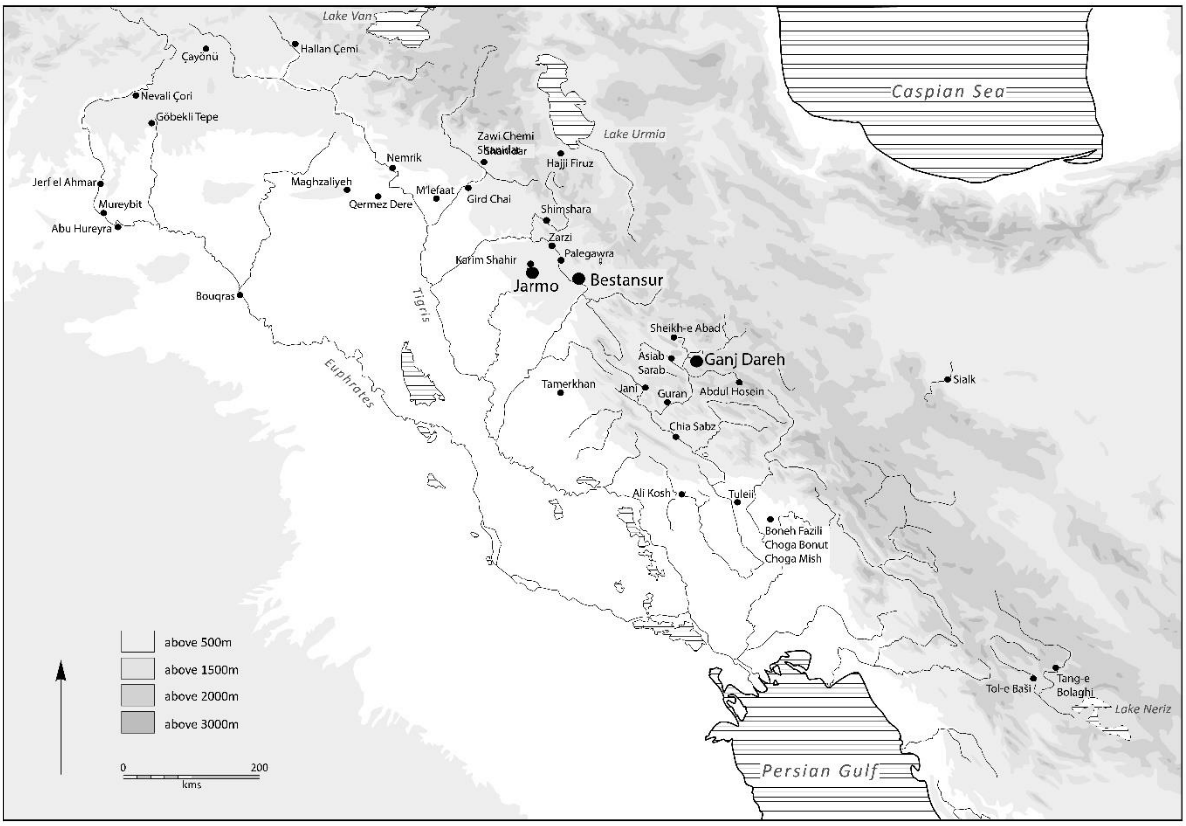

Figure 1: Map showing Neolithic sites in the Zagros region.

3 Methods and Material

3.1 Material

In this study we analyse the zooarchaeological material recovered from Bestansur during all field seasons up until 2021, integrating previously published and new data (Bendrey *et al.* 2020; de Groene *et al.* 2021). We use the demographic and biometric data of Ganj Dareh and Jarmo published by Zeder and Hesse (2000) and Zeder (2008). We sampled a total of 10 molars from Jarmo and 18 molars from Ganj Dareh for sequential carbon and oxygen isotopic analysis of tooth enamel. 8 molars from sheep/goat from Bestansur were previously sampled at the University of Reading and one molar from Bestansur was sampled for this study. Both M2 and M3 from the lower mandible were sampled, because of the limited availably of undamaged teeth, but only one molar per animal was sampled. All sampled molars from Jarmo derived from the ceramic Neolithic layers. All archaeological molars could be from either sheep or goat, since it is unreliable to distinguish molars of sheep/goat morphologically (Zeder and Pilaar 2010). One molar of modern sheep from the modern village Bestansur was also sampled. In the recent past sheep in this village were kept in the in the foothills of the mountains during spring, fallow fields in the summer, and at the village in the winter (Bendrey *et al.* 2016). However, with the construction of a road, access to the fallow fields in alluvial floodplains became restricted and caprines are now kept around the village all year (Elliott *et al.* 2015). It is unknown whether the modern sheep molar comes from the time before or after the construction of the road.

3.2 Zooarchaeological methods

Sheep and goat are osteologically very similar, so the criteria of Boesneck *et al.* (1964) were used to identify cranial bones, and Zeder and Lapham's (2010) criteria were used to distinguish post-cranial bones. When separation was not possible the bones were categorised under the category sheep/goat. No attempt was made to distinguish sheep and goat molars, since it has been shown to be unreliable (Zeder and Pilaar 2010). All possible anthropogenic modifications to the bones as well as pathologies were recorded. Butchery marks were recorded following Binford (1981) and when necessary extra information was added.

Measurements of the bones were taken following Von Den Driesch (1979). Age-at-death has been assessed based on bone fusion. Postcranial fusion ages from Zeder (2006) were followed for sheep and goat, since this system is based on caprines from the Zagros region. The assemblage consisted of few mandibles suitable for a dentition-based age profile, so this approach will not be included. To investigate possible young male kill-off, biometric data are used in addition to fusion-based age profiles. Goat exhibit a relatively high degree of sexual dimorphism and sheep are sexually dimorphic as well, although to a lesser extent. Therefore, male and female caprines can be distinguished based on the measurements of the long bones (Zeder and Hesse 2000). Considering the modest size of the dataset, the LSI (Logarithm Size Index) method is used to get a richer understanding of the size of the animals and the sex pattern. The LSI uses log10 of the ratio between the measurement and its standard (Meadow 1999), which makes it possible to compare different elements, largely increasing the dataset used for comparison. The standards which are published and commonly used in Southwest Asian archaeology are the average measurements of goat from the Taurus mountains (Uerpmann and Uerpmann 1994) and modern wild sheep from Kermanshah Iran (Zeder 2008, 263). Skewness and kurtosis have been used to describe the shape of LSI diagrams (Arbuckle and Atici 2013, 223). The kill-off of young males is expected to be identified in results in the LSI data. A characteristic distribution for young male kill-off exhibits strong positive skewing (with a tail on the right of the mean) and positive kurtosis (leptokurtic or 'peaked' distribution shape) (Arbuckle and Atici 2013, 223). In the LSI graphs unfused and fused elements are represented as well as the astralagus, which does not fuse. When young male-cull would have been practiced, larger unfused elements are likely to be represented in the LSI graph. Elements which fuse before 18 months are shown separately from elements which fuse after 18 months, since these elements could be representing animals which were slaughtered at young age, while elements which fuse after 18 months represent animals which survived into maturity.

3.3 Isotopic analysis

The diet and movement of the caprines was investigated using sequential stable isotopic carbon and oxygen analysis on tooth enamel. Stable isotopic analysis of tooth enamel of domestic and non-domestic animals has already improved our understanding of animal management (Balasse *et al.* 2002) in the Levant (Makarewicz 2017; Tornero *et al.* 2016) and Anatolia (Makarewicz *et al.* 2016).

Bezoar goat-preferred habitats are mountainous areas with a mix of rocky outcrops and vegetation. They can survive very well in relatively arid areas but can live in forests too (Weinberg *et al.* 2008). The bezoar goat is herbivorous, relying on both browsing and grazing, although they prefer browsing over grazing (Dwyer 2017). They are non-obligate drinkers, meaning they can survive longer periods without drinking water by relying solely on leaf waters (Dailey *et al.* 1984; Weinberg *et al.* 2008). The habitat ranges of bezoar goat and wild sheep overlap but in general wild sheep live in the lower mountains and foothills of mountains, while bezoar goat live higher up in the mountains (Zeder 2006). Similar to wild goat, wild sheep both browse and graze (Valdez and DeForge 1985). In contrast to goat however, they are more adapted to grazing and cannot cope with long periods without drinking water (Dwyer 2017).

The carbon isotopic composition of the bioapatite of herbivores is determined by the δ^{13}C values of ingested plant foods (Balasse 2002; Makarewicz and Pederzani 2012). In plants, apart from photosynthetic pathway (C_3 and C_4 plants), the ^{13}C/^{12}C ratio in plant tissues is dependent on light intensity, temperature, humidity, moisture availability and recycling of CO_2. Variation between the isotopic ratios occurs within intra-species and within plant tissue; C_3 plants display δ^{13}C ranges from 37− 20‰ (average: − 27‰) and C_4 plants are 21-9‰ (average: − 12‰) (Lee-Thorp 2008). Differences in δ^{13}C in C_3 biomes vary according to environmental conditions. On a seasonal basis in semi-arid environments the $\delta^{13}C$ in C_3 plants shifts according to changes in moisture availability, humidity levels, and night-time temperatures. The carbon isotope composition of C_3 grasses is heavily dependent on water availability. In periods of drought, grasses tend to conserve water by closing their stomata, the microscopic pores on leave epidermis regulating transpiration and CO_2 uptake (Argurla *et al.* 2018). Consequently, less CO_2 from the air will be taken up during dry periods and leaves will get enriched in $\delta^{13}C$ (Makarewicz and Pederzani 2017).

Nowadays, in the Zagros region, C_4 plants mainly occur locally in saline zones, which are common in semi-arid environments except for the southern Zagros, where C_4 grasses are generally abundant (Bocherens *et al.* 2000). The abundance of C_3 and C_4 plants is dependent on season and altitude as well (Makarewicz 2017). For sheep and goat, the precise carbon isotope fractionation between diet and tooth enamel bioapatite is unknown (Makarewicz and Pederzani 2017, 2-3). A fractionation value of around 14.5‰ which is measured in cattle (Passey *et al.* 2005) is normally applied (Makarewicz and Pederzani 2017, 2-3). Although the level of fractionation between diet and bioapatite for sheep varies based on diet (Cerling and Harris 1999; Zazzo *et al.* 2010).

Oxygen is assimilated in animal tissue from ingested water and oxygen in food. Oxygen isotopic composition of meteoric water is influenced by continental positioning, rainfall amount, temperature, seasonality, humidity levels and altitude (Makarewicz 2017; Pederzani and Britton 2019). On average, altitude leads to a 0.3 ‰ decrease in meteoric $\delta^{18}O$ values with every 100 metres increase in height and 0.6 ‰ increase in $\delta^{18}O$ values per increase in 1C in temperature (Poage and Chamberlain 2001). The local meteoric oxygen water composition is reflected in the plants; however, plants are in general enriched in ^{18}O relative to meteoric water (Makarewicz 2017). Combined with carbon isotopes, incremental samples of tooth enamel can therefore give information about seasonal variation in diet and possible seasonal movement (Pederzani and Britton 2019).

Sequential analysis of teeth was carried out to explore seasonal differences in diet and possible seasonal movement and birth seasonality of the caprines. In total 47 molars from archaeological contexts were sampled, 25 M2’s and 12 M3’s, as well as one modern M3 from a sheep in the modern village Bestansur. The number of samples taken per teeth varies, since some teeth were damaged, but we tried to take at least 10 samples per molar (SI).

The formation of caprine permanent molars spans 1-1.5 years, the second molar development starts between the second and third month, while the third molar development starts between 9-15 months. The start of the development of the third molar in particular has been shown to vary significantly between populations (Hadjikoumis *et al.* 2019; Upex and Dobney 2012). Enamel forms incrementally, so it shows different stages of the lifetime of the animal (Balasse *et al.* 2002). The protocol for sampling teeth is adapted from Balasse *et al.* (2002), see SI for full description of sampling method.

4 Results

4.1 Zooarchaeological results

Caprines are the most abundant animals at Bestansur. 70% of the elements which can be identified as either sheep or goat are sheep, indicating that the majority of bones identified as ‘sheep/goat’ are sheep (Figure 2). Sheep goat distribution in the Neolithic Zagros Mountains is likely related to the elevation of the sites, at Karim Shahir and East Chia Sabz sheep also dominate over goat (Figure 1, 2). Jarmo shows a different pattern from Bestansur, with goat slightly more abundant than sheep. At the Neolithic highland sites Sheikh-e Abad and Ganj Dareh goat significantly outnumber sheep (Figure 1, 2).

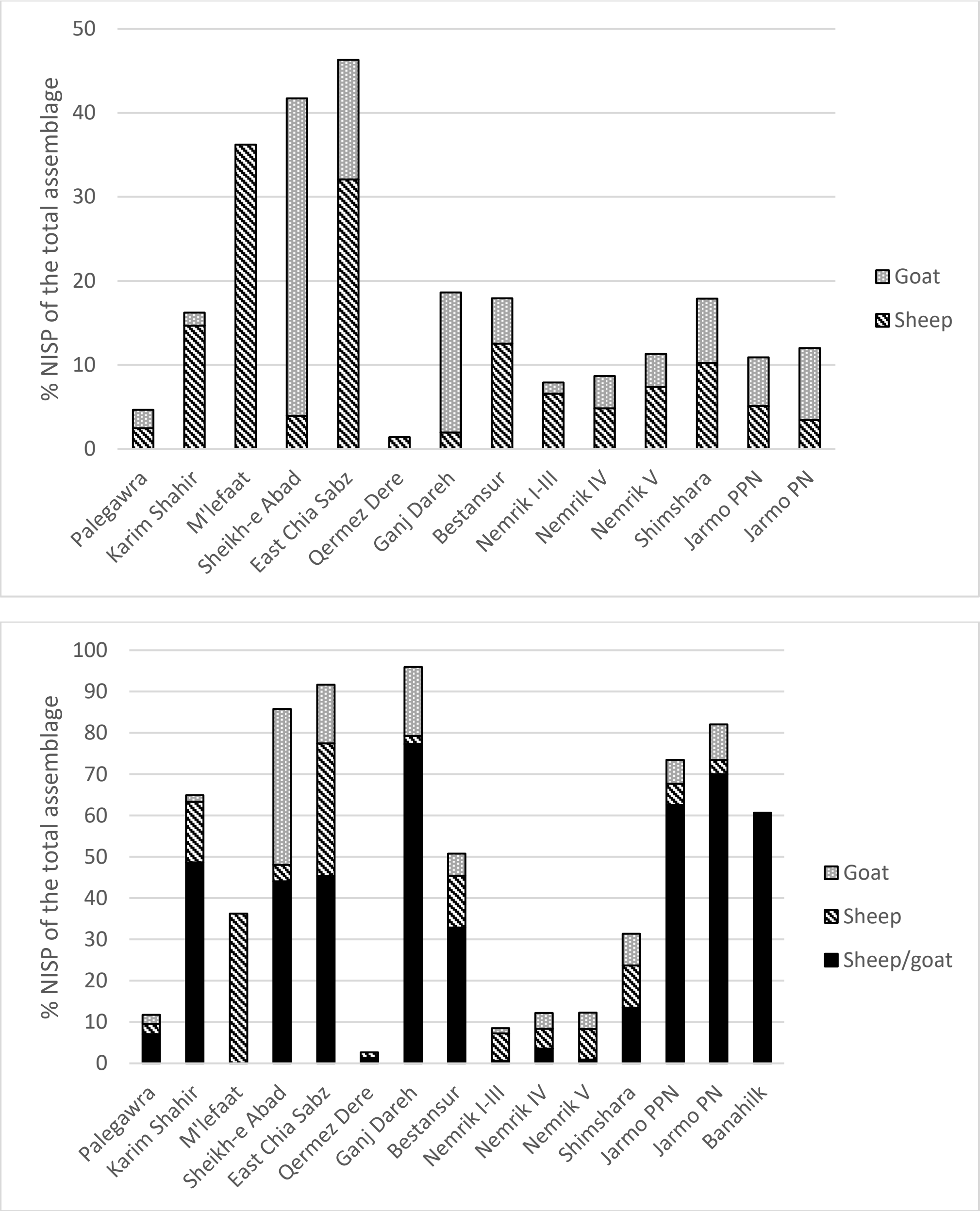

Figure 2: Figure 2a: The percentage of sheep and goat out of all identified mammals at Epipalaeolithic and Neolithic sites in the Zagros region, Figure 2b: The percentage of sheep and goat at Epipalaeolithic and Neolithic sites in the Zagros region, including sheep/goat (see supplementary information for NISP, dating and references).

4.1.2 Ageing and biometry

The sample size for age reconstruction based on bone fusion for Bestansur is modest (Table 1). The majority of sheep and goat at Bestansur reached an age into maturity (Table 1). Unfused bones are bones have proven to be more porous and degrade faster, so they might be underrepresented. Also, they are less often identifiable as either sheep or goat (Table 1), which makes it harder to reconstruct species specific kill-off patterns. Many of the unfused elements were not suitable for measurement, so only one unfused element of sheep and one of goat are represented in the LSI graphs (Figure 3, 4).

Sheep of the zooarchaeological assemblage of Bestansur all reached an age into maturity and mainly prime adults are represented (Table 1). The LSI data are negatively skewed and the kurtosis is positive (Skewness: -0.752, Kurtosis: 0.86) (Figure 3), which seems consistent with a focus on male prime-adults. The elements of sheep which certainly reached an age into maturity are represented over the whole LSI graph, indicating that there was no young male cull. The elements which do not fuse and elements which do fuse before 18 months could represented animals which reached an age over 18 months (Figure 3), which is likely given the few unfused elements of sheep found (Table 1). The assemblage clearly indicates this population was hunted and there was a focus on male prime adults.

However, all unfused bones of goat in the assemblage belong to animals which have been slaughtered between an age of 12-18 months. Most unfused bones of the ‘caprine’ group also are from animals between 12-18 months, but the sample size is too modest to draw definite conclusions from these data. A wide distribution in the size range of goats is visible (Figure 3). The LSI distribution of the goat is slightly negatively skewed and the kurtosis is negative too (Skewness: -0.126, Kurtosis: -0.261). The vast majority of the bones in the graph are elements which fuse before an age of 18 months. Therefore, it is not possible to determine whether the tail at the right end (the male individuals) are indicative of young male cull. Given the modest sample size and the few unfused bones suitable for measurement, as well as bones which fuse after an age of 18 months, it is not possible to determine whether goat management involving young male cull was practiced at Bestansur.

Table 1: Fusion data of sheep and goat of Bestansur (following fusion ages of Zeder 2006).

Age of fusion months fusion **(Sheep)**	Element	Zeder age category	fused	unfused	fusing
0-6	Radius proximal	A	6		
6-12	Humerus distal	B	4		
12-18	Phalanx 1	C	10		
12-18	Phalanx 2	C	5		
18-30	Tibia distal	D	3	1	
18-30	Metacarpus	D	9	1	
18-30	Metatarsal	D	7		
30-48	Calcaneus	E	2	1	
30-48	Radius distal	E	3	1	
Age of fusion in months **(Goat)**	Element		fused	unfused	fusing
0-6	Radius proximal	A	2		
6-12	Humerus distal	B	4		
12-18	Phalanx 1	C	10	3	
12-18	Phalanx 2	C	1		
18-30	Tibia distal	D	1		
18-30	Metacarpus	D	2		
30-48	Radius distal	E	1		
Age of fusion in months (**Sheep/goat)**			Fused	Unfused	Fusing
0-6	Radius proximal	A	4		
6-12	Humerus distal	B	6		
6-12	Scapula	B	7	3	
6-12	Pelvis	B	1		
12-18	Phalanx 1	C	2	4	
12-18	Phalanx 2	C	10	2	1
18-30	Tibia distal	D	8		
30-48	Radius distal	E		2	
30-48	Ulna distal	E		1	
30-48	Femur proximal	E	1		
30-48	Femur distal	E	3		
30-48	Tibia proximal	E	4		
30-48	Calcaneus	E		2	
48+	Humerus proximal	F	1		

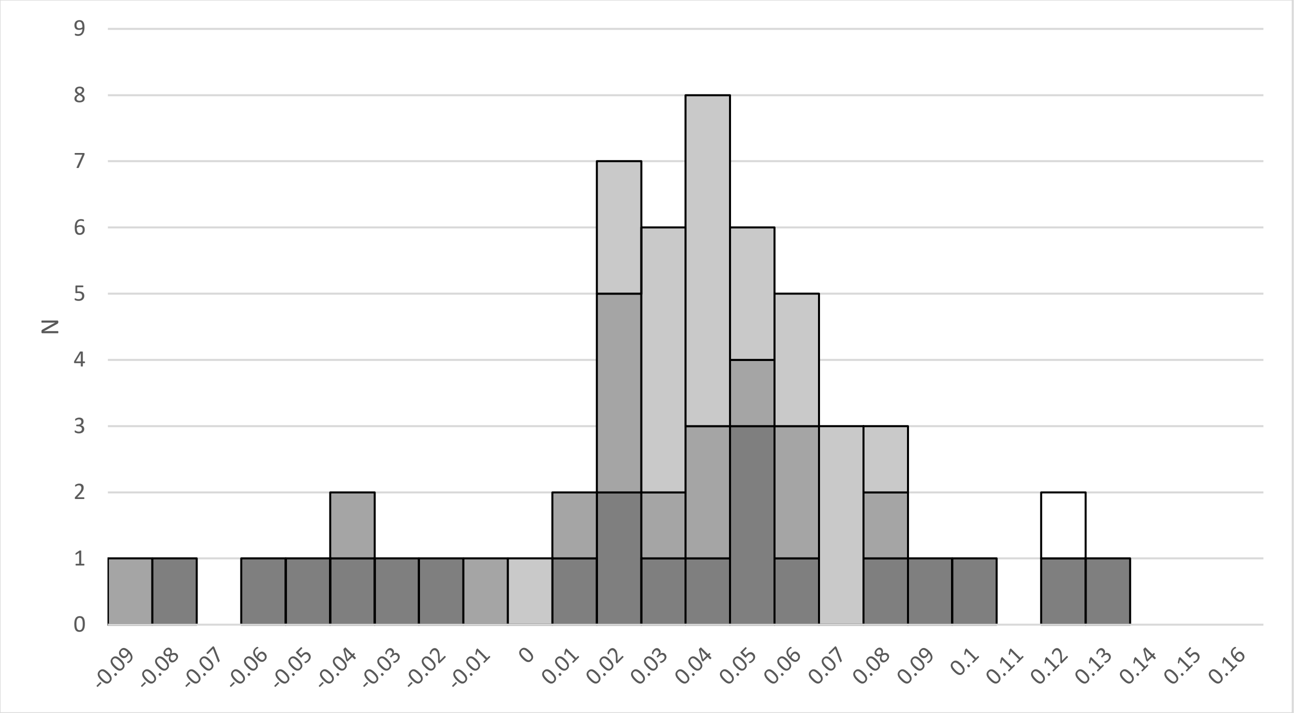

Figure 3: The LSI of measurements of sheep of Bestansur, dark grey= fused elements which fuse after an age of 18 months (n=20), lighter shade of grey=elements which do not fuse (only the astralagus) (n=14), lightest shade of grey=fused elements, which fuse before an age of 18 months (n=20), white= unfused elements (n=1).

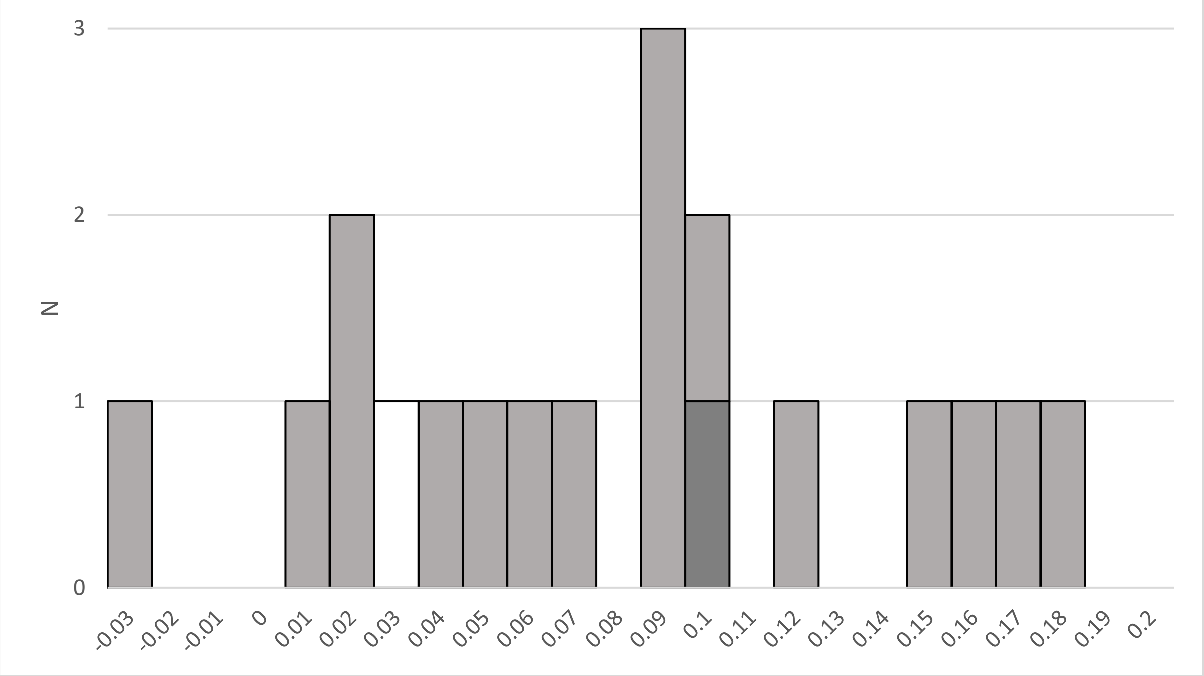

Figure 4: The LSI of the measurements of goat of Bestansur (only breadth measurement included). dark grey= fused elements which fuse after an age of 18 months(n=1), lighter shade of grey=fused elements, which fuse before an age of 18 months (n=17), white= unfused elements (n=1).

The zooarchaeological assemblage of Ganj Dareh is large in comparison to that of the other sites in the Zagros region (SI 1). The zooarchaeological assemblage of Ganj Dareh has been restudied by Zeder (2008). Goat are the most abundant animals in the zooarchaeological assemblage (SI 1). The large sample size made it possible to reconstruct sex specific harvest patterns. Biometry combined with bone fusion data indicated a focused kill-off of males between 1-2 years of age, while the females were kept alive for reproduction (Zeder 2008, 249-51). The metric data of the site indicate that the zooarchaeological assemblage is dominated by female goat, which is to be expected when young male culling is practiced, since unfused bones dissolve easier in the archaeological record and are less identifiable to species level (Zeder 2008). Sheep at Ganj Dareh, however, tend to reach an age well into maturity (Zeder 2008, 262). The biometric data show a heavy skew towards males, which is more indicative for a hunted population (Zeder 2008, 263).

At Jarmo caprines are the most abundant animals in both the Early Neolithic as well in the ceramic Neolithic (Figure 2). Since Jarmo was excavated in the 1950s and the bones were only hand collected, there is a likely recovery bias against the recovery of unfused bones. The majority of the zooarchaeological assemblage consists of bones from the ceramic Neolithic. At Jarmo (early Neolithic and ceramic Neolithic levels combined) the skewness for biometric data for both sheep and goat are positive (Zeder 2008; Arbuckle and Atici 2013). For goat there seems to have been a young male culling pattern since the Early Neolithic (Zeder 2008), although this is less evident than at Ganj Dareh, possible due to the recovery bias. Goat are clearly smaller in size at Jarmo than at Bestansur and Ganj Dareh (Figure 5). This decrease in size seems to have happened during the ceramic Neolithic, as at Sarab, another ceramic Neolithic site, goat are smaller as well. It is unclear why there is this overall decrease in size during the ceramic Neolithic.

The sheep population, however, does not seem to have been herded until the ceramic Neolithic period (Zeder 2008). Jarmo is still one of the earliest sites in the Zagros where both domestic goats and domestic sheep are present in the ceramic Neolithic. The skewness of the LSI is positive, suggesting a managed herd (Zeder 2008; Arbuckle and Atici 2013). As noted sheep are less sexually dimorphic than goat (Figure 6) and the size range of the first phalanges of sheep is smaller, as is the size difference between the modern male and female specimens. The same size decrease in the ceramic Neolithic sheep is visible as in goat (Figure 6). There is no evidence for local domestication of sheep in the Zagros region (Zeder 2008), so possibly smaller domesticated sheep from a lowland region were imported.

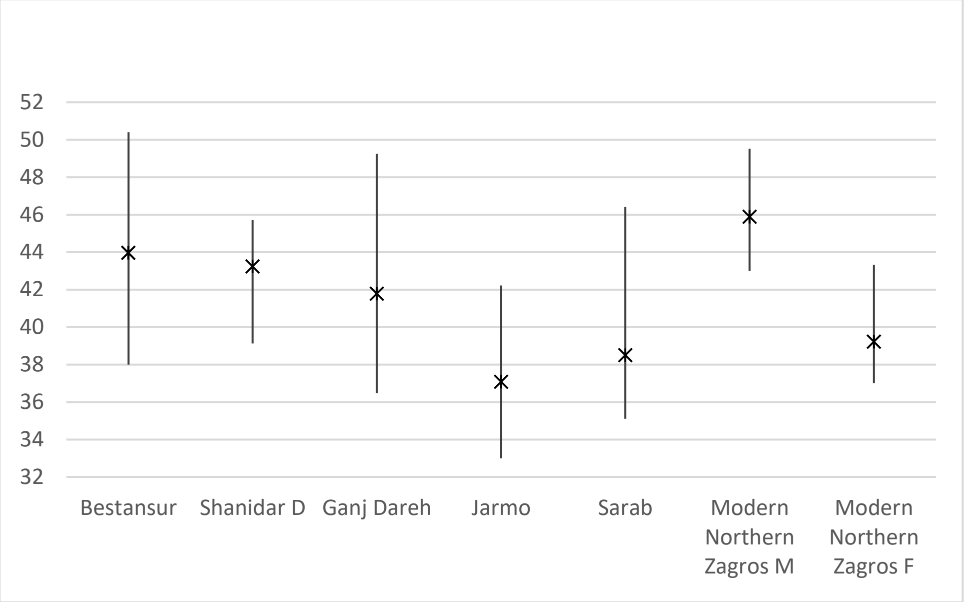

Figure 5: Comparison at different sites of the GL of the first phalanges of goat. A cross represents mean and lines end with minimum and maximum measurement of the sites (only fused bones included), modern wild goat of the Zagros M/ F M=male F=Female, N= from left to right 9, 3, 55, 38, 29, 23, 23, data of sites for comparison from Zeder 2008 appendix, see SI for dating).

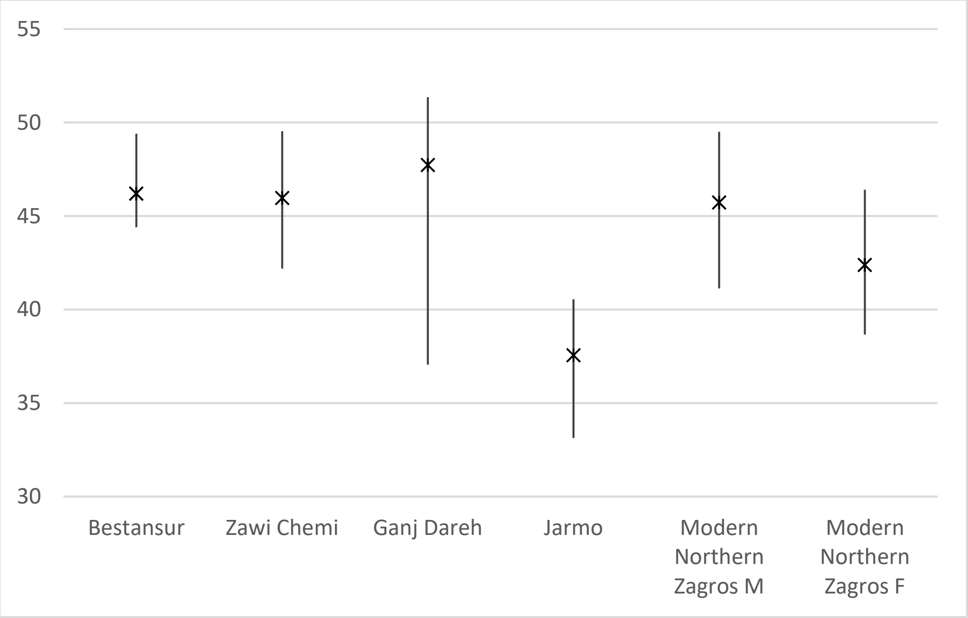

Figure 6: Comparison at different sites of the GL of the first phalange of sheep. A cross represents mean and lines end with minimum and maximum measurement of the sites (only fused bones included). modern wild sheep of the Zagros M/ F M=male F=Female, N= from left to right 9, 18, 18, 10, 154, 135 data of sites for comparison from Zeder 2008 appendix, see SI for dating).

4.2 Isotopes

4.2.1 Bestansur

Preservation of the teeth was modest. Of 130 sequential samples in total, 60 samples from Bestansur survived the pre-treatment: the remaining 67 dissolved completely during the acid step. All the molars of which enough samples survived show roughly sinusoidal seasonal curves in their $\delta^{18}O$ values, except for specify sample here (Figure 7). The mean value of the $\delta^{18}O$ values is -4.7 ‰., between a maximum of -1.3 ‰ and minimum of -7.9‰. (Figure 10) Since there is a difference in surviving samples between molars it is hard to draw comparisons between minimum and maximum values between the teeth. The max intra-tooth variation in $\delta^{18}O$ is 5.7 ‰ (Figure 10). The data of the modern M3 of Bestansur display a sinusoidal curve as well. Based on a model derived from a dataset of modern teeth, sinusoidal curves with ranges of more than 6‰ $\delta^{18}O$ intra-tooth have been suggested to imply strong seasonality, with cold and/or wet winters and hot summers with periods of drought (Henton 2012, 3269). This is not the case in Bestansur, where the ranges in $\delta^{18}O$ intra-tooth are on average smaller (no range >6‰), suggesting therefore that around the location of Bestansur was not strongly seasonal, or that during the summers people were moving animals to the cooler highlands. The small variations in $\delta^{18}O$ intra-tooth could be partly due to small sample size and the many incomplete sequences.

The mean of the $\delta^{13}C$ is -10.0 ‰., ‰ (1 s.d.), between maximum of -7.7‰ and minimum of -12.8 ‰ (Table 2). In the majority of the molars the $\delta^{13}C$ peaks close to the $\delta^{18}O$ peak, while in Bet5 the lowest $\delta^{13}C$ point coincides with the $\delta^{18}O$ peak. It would be expected that the $\delta^{18}O$ peak and the $\delta^{13}C$ peak coincide if the animals were grazing, since during summer grasses become enriched in ^{13}C. The fact that the $\delta^{13}C$ point coincides with the $\delta^{18}O$ peak coincide is likely related to the enrichment in $\delta^{13}C$ in plants during drier periods.

The modern sheep molar of Bestansur seems to give a clear signal of winter foddering, since the ^{13}C are higher during the winter (Figure 8). Foddering of straw and barley harvested during other seasons indeed occurs in the present-day village of Bestansur (Elliot *et al.* 2014).

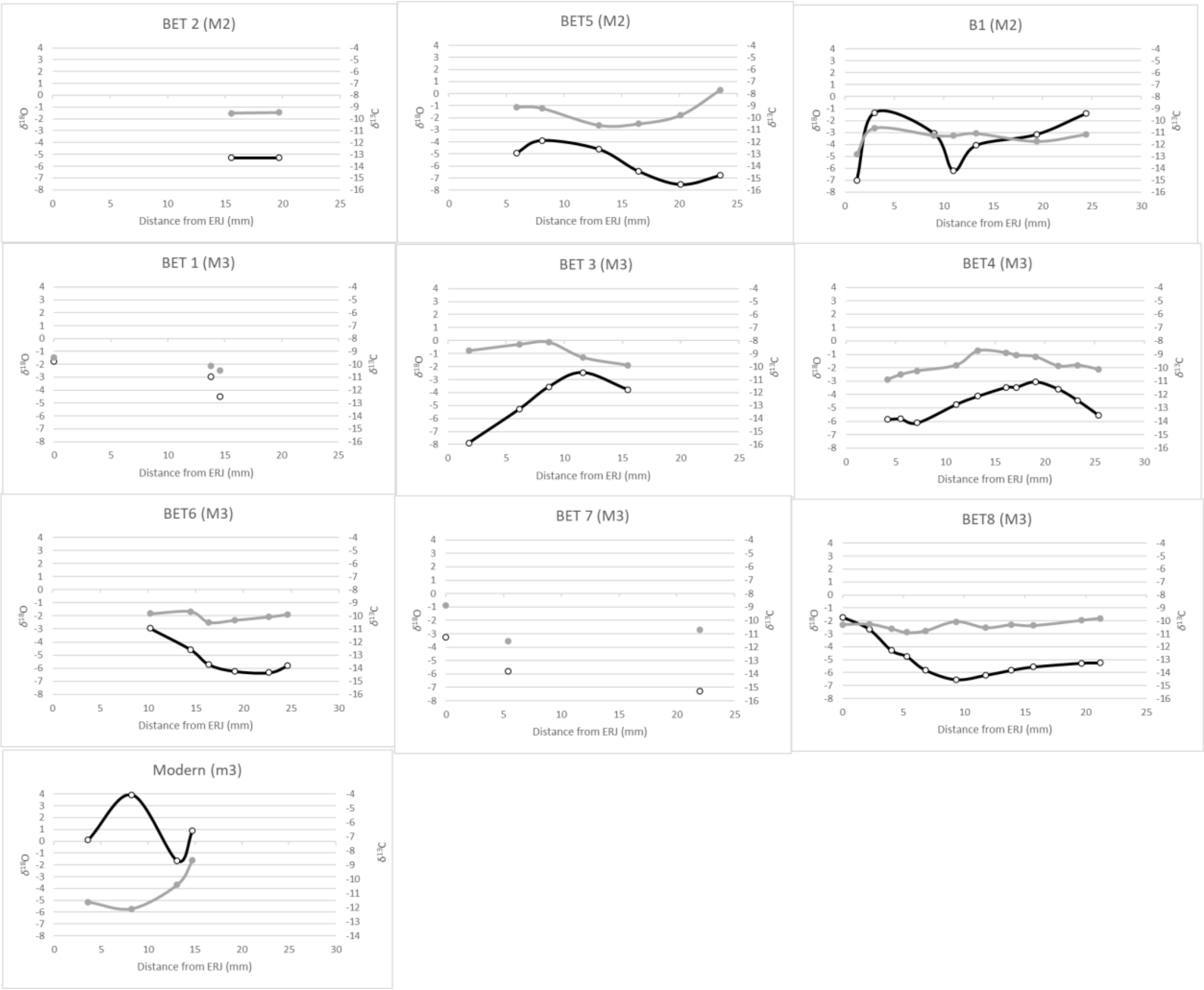

Figure 7:Sequential carbon (grey) and oxygen (black) isotope data from Bestansur.

4.2.2 Jarmo

The preservation of the teeth was moderate and the teeth had many scratches, therefore some of the samples might have been affected. Of 98 samples, 94 survived the pre-treatment. The average value of the $\delta^{18}O$ values is -2.3‰, with a maximum value of 4.4 ‰ of and minimum value of -6.9 ‰ (Table 2; Figure 8,10). Eight molars show sinusoidal seasonal curves (all except for T4 and T1), while one M_2 and one M_3 do not. The max intra-tooth difference in $\delta^{18}O$ values is 7.6 ‰ (Figure 8,10). 2 of the molars with sufficient samples to cover an annual cycle fall into category indicating strong seasonality (Figure 8, 10). The two molars of Jarmo which did not display sinusoidal curves of δ^{18}O could be the result of the caprines grazing on higher slopes during the summer (Henton 2012), where it would be cooler.

The mean of the δ^{13}C values is -9.9 ‰, between maximum of -7.6 ‰ and minimum of -12 ‰. In all M2's the δ^{13}C values were present around the peaks of the δ^{18}O peaks, which indicate the highest δ^{13}C was during the summer months, while in the M3s this pattern was not evident (Figures 8, 10). The relative increase in δ^{13}C in the summer months could be explained by the observed seasonal ^{13}C-enrichment in semi-arid environments and does not necessarily indicate the input of C4 plants.

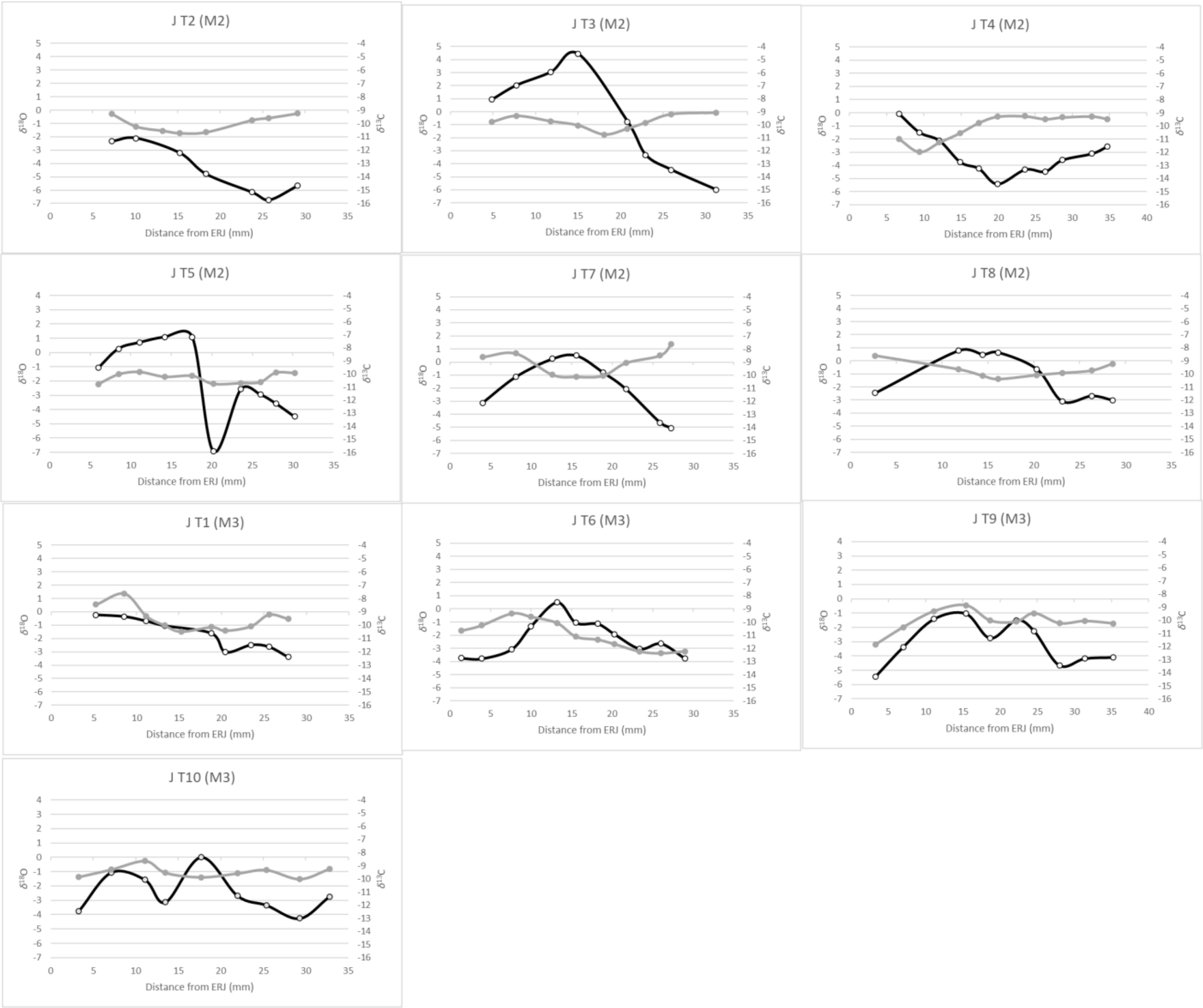

Figure 8: Sequential carbon (grey) and oxygen (black) isotope data from Jarmo

4.2.3 Ganj Dareh

18 molars of Ganj Dareh were sampled, and in total of 185 samples, 146 samples survived the pre-treatment. The average value of the δ^{18}O values is -1.5 ‰ with a maximum value of 3.1 ‰ and a minimum value of -8.8 ‰ (Table 2). The δ^{18}O values 15 of the molars show sinusoidal curves. The maximum intra-tooth difference in δ^{18}O values is 11.8 ‰ (Table 2; Figure 9,10). 12 of the Ganj Dareh teeth display ranges in δ^{18}O values which indicate strong seasonality. The 15 molars (all except for GD6, GD9, and GD14) showing sinusoidal curves in δ^{18}O values could indicate that the vast majority of the animals stayed around the same altitude throughout the year, or moved over small distances. Unlike at Jarmo, most of the molars are likely to derive from goat, since they make up 94 % of the caprines (Zeder 2008, 261). This implies that humans kept the goats close to the site, possibly limiting their potential seasonal migration.

The mean of the δ^{13}C values is -9.5‰, between a maximum of -5.3 ‰ and minimum of -13.7 ‰ (Table 2). No consistent pattern between differences in δ^{13}C values and δ^{18}O values is evidently visible (Figures 9,10). Since not all samples survived the pre-treatment, not all molars displayed a full year.

No coinciding peaks in δ^{13}C and δ^{18}O are visible in the molars of the specimens of Ganj Dareh (Figure 10). While the average of is δ^{13}C, similar to Bestansur and Ganj Dareh, the range of the δ^{13}C values is wider and the higher δ^{13}C values do not occur during the summer months (Table 2, Figure 9, 10). In contrast to Bestansur and Jarmo, Ganj Dareh is located in the high Zagros. So, the variation in δ^{13}C could be related to different plant availability in the high Zagros, movement of the animals to a higher elevation during summer, as well as winter foddering. C_4 grasses have been found in low abundance in phytolith assemblages of Ganj Dareh (Yeomans *et al.* 2021), indicating the availability of these plant types, which could influence the different patterns in δ^{13}C values.

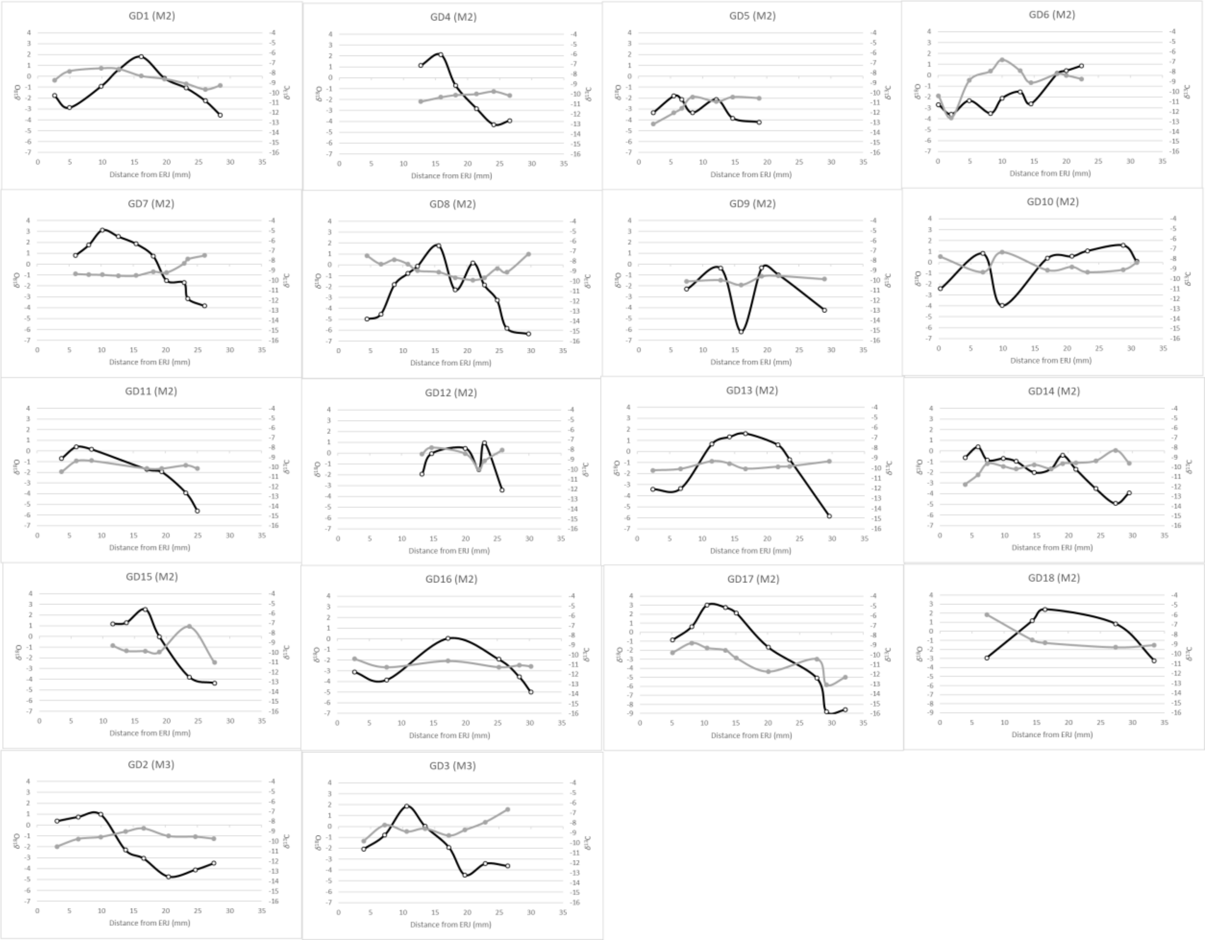

Figure 9: Sequential carbon (grey) and oxygen (black) isotope data from Ganj Dareh

The lower average δ^{18}O values at Bestansur compared to Jarmo and Ganj Dareh is curious since the site is located on a lower elevation where δ^{18}O of meteoric values would expected to be higher (Table 2; Figure 9). It is possible this is related to differences between sheep and goat, since the majority of caprines at Bestansur are sheep and the majority at Ganj Dareh are goat. However, at PN Jarmo the molars sampled are likely to be a mixture between sheep and goat and the δ^{18}O values of Bestansur are still lower. It is possible that this was related to water sources close to Bestansur, which could have been springs or streams directly coming from the high Zagros.

Table 2: averages and minima and maxima of the isotopic values per site

Site	average ‰ δ^{13}C	‰ 1 s.d. ,	Minimum ‰ δ^{13}C	Maximum δ^{13}C	Average ‰ δ^{18}O	‰ (1 s.d.),	Minimum ‰ δ^{18}O	Maximum ‰ δ^{18}O
Jarmo	-9.9	0.9	-12.4	-7.6	-2.2	2.2	-6.9	4.4
Ganj Dareh	-9.5	1.2	-13.7	-6.0	-1.6	2.4	-8.8	3.1
Bestansur	-10.0	0.9	-12.8	-7.7	-4.7	1.6	-7.9	-1.3

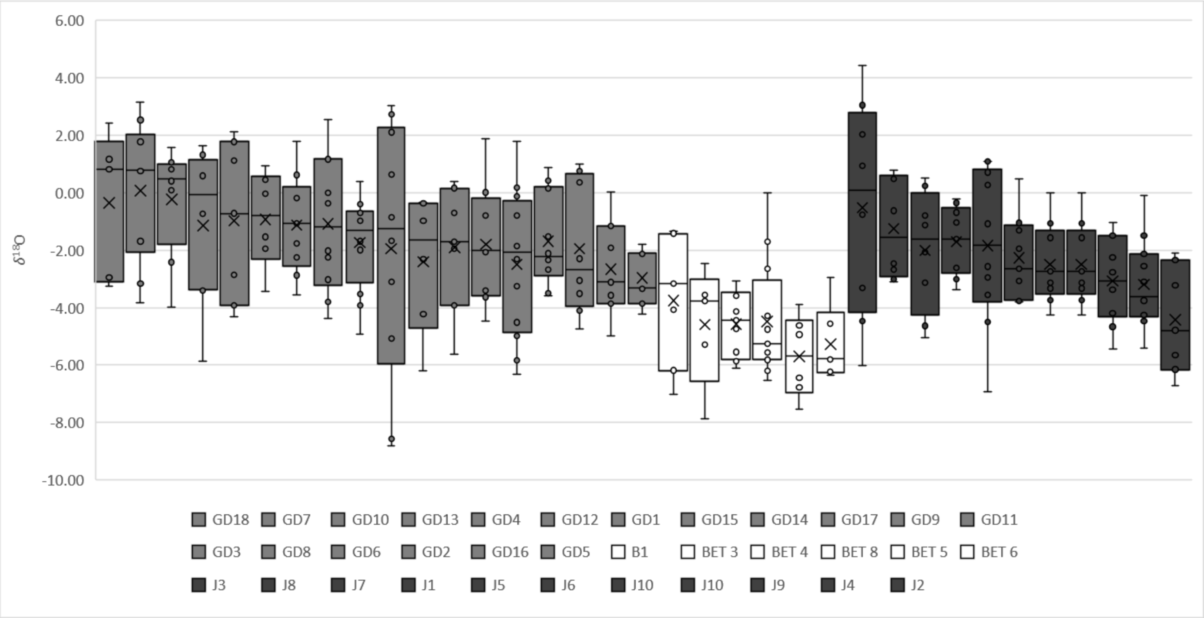

Figure 10: Boxplot of the δ^{18}O values (all sequences with more than 5 datapoints included, light grey = Ganj Dareh, white=Bestansur, dark grey= Jarmo

5 Discussion

Caprines are the most abundant animal group at Bestansur, Jarmo and Ganj Dareh, so they were certainly of significant dietary value at all three sites. Evidence indicates that goats were closely managed at Ganj Dareh. The kill off patterns show strong evidence for young male cull (Zeder 2008). The isotopic data indicates that either the animals were moved over summer or foddered during winter. Since Ganj Dareh is located in the high Zagros, moving animals to higher elevations during summer seems unlikely. The goat were possibly kept close to the sites, and may have been given ^{13}C enriched fodder. The presence of goat on site at Ganj Dareh is supported by analysis that showed the presence of foetal goat bones and shed deciduous teeth, as well as penning deposits and high concentrations of dung spherulites on site (Yeomans *et al.* 2021). Evidence for goat management is supported by recent aDNA analysis of goat, which shows genomes in two distinct clusters: those with domestic affinity and a minority group with stronger wild affinity, indicating that managed goats were genetically distinct from wild goats at this early horizon in Ganj Dareh. However, no genomes related to morphological change seen in later domesticated goat were present (Daly *et al.* 2021).

At the lowland site of Bestansur, sheep were more abundant than goat, but based on the kill-off pattern there is no evidence for management of sheep. While the inhabitants of Ganj Dareh seem to have relied heavily on managed goat, undomesticated sheep would have been a bigger contribution to the diet at Bestansur. Due to the modest sample size, it is difficult to determine whether there was a young male cull at Bestansur, but a larger amount of younger goat are found than sheep, so this cannot be ruled out. Herbivore faecal material was found in occupational areas (Elliott 2020) as well as a shed goat milk tooth (Bendrey *et al.* 2020, 321), indicating that managed animals might have been present on the site. The isotopic samples do not give evidence for systematic transhumance, although small vertical movement might have been carried out. Furthermore, micromorphological analysis at Bestansur indicates that dung was used as a source of fuel (Elliott 2020). Dung types found in oven areas primarily derived from herbivores (Elliott 2020, 391), so dung might have been an important resource from caprines too. It is possible that given the abundance of the wild animals and the possible management of goat, people did not need resources they could derive from sheep management.

At Jarmo the young male cull management pattern is less evident than at Ganj Dareh but still visible, which might be due to recovery bias against unfused bones (Figures 3, 5; Table 1). At Jarmo there is no evidence for use of dung or penning deposits, but this could be because this aspect has not been studied in detail, because micromorphology and the study of dung markers are more recent developments not practised when Jarmo was excavated.

At all three sites there is no clear evidence for a sheep management strategy involving young male cull (Figures 4, 6; Table 3). Wild sheep were likely abundant in the environment around Jarmo and Bestansur, yet there is no evidence to indicate clear management of them prior to the ceramic Neolithic. The presence of sheep does not mean they were most likely domesticated. The managed sheep at Jarmo are significantly smaller than the unmanaged sheep at Bestansur and Ganj Dareh (section 4.1). Also, the sheep at Jarmo are smaller than both wild female and male sheep from the Zagros area, so this small size cannot be explained by sexual dimorphism alone. Overall body size reduction is not a marker for initial management, so the sudden reduction in size of sheep at Jarmo possibly indicates the introduction of domesticated sheep.

6 Conclusion

This research has given new insights into animal management practices in the Neolithic of the Zagros region. A form of goat management seems to have been practiced at Bestansur based on spherulites, dung and shed deciduous teeth. At Ganj Dareh there is evidence for quite intensive human management, keeping animals close to the site. Based on isotopic evidence it is possible that animals were foddered during the winter, and that humans were keeping control over the breeding population. At Early Neolithic Jarmo, goat were managed, and smaller, domestic sheep were likely introduced during the ceramic Neolithic.

Further research could include ZOOMS to distinguish isotopic signals of sheep and goat, since it impossible to determine at the moment what differences in isotopic values are related to species difference.

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Competing interest statement

Authors have no competing interests to declare.

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Supplementary information

SI A: Species abundance and references from sites in Southwest Asia.

Site	Environment	*Ovis / Capra*	*Ovis*	*Capra*	*Sus*	*Bos*	Large cervid	Small cervid	Gazelle	*Equus hemionus*	*Vulpes*	other mammal	total	Reference
Bestansur	Piedmont	415	157	68	331	64	167	10	28		7	7	1265	This study
Palegawra	Piedmont	29	10	9	15	3	74		74	164	31		409	Asouti *et al. 2020*
Karim Shahir	Piedmont	93	28	3	19	9	19		11		9		191	Stampfli 1983
East Chia Sabz	Piedmont	246	174	77	16	7	0	0	11			11	542	Darabi *et al.* 2012
Jarmo PPN	Piedmont	884	72	82	33	126	35		83	72	12	14	1413	Price and Arbuckle 2015
Jarmo PN	Piedmont	2401	117	294	241	103	89	2	136	13	8	24	3428	Price and Arbuckle 2015
Nemrik I-III	Steppe	1	10	2	7	3	1		68			60	152	Lasota-Moskalewska 1994
Nemrik IV	Steppe	11	15	12	24	94			111			44	311	Lasota-Moskalewska 1994
Nemrik V	Steppe	18	140	75	220	721	16		453			259	1902	Lasota-Moskalewska 1994
Shimshara	Piedmont	37	28	21	163	9	9	4			3		274	Bendrey *et al.* 2020
Qermez Dere	Steppe	38	42			12			1174	4	1677	49	2996	Dobney *et al.* 1999
M'lefaat	Steppe		50		7	2			73		6		138	Turnbull 1983
Sheik-e Abad	High Zagros	56	5	48		2	12				1	1	127	Bendrey *et al.* 2013
Ganj Dareh	High Zagros	21731	547	4689	308	174	63		5		579	13	28109	Hesse 1978

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SI B: The measurements of goat bones from Bestansur.

Humerus									fusion	
BoneID_auto	Context Number	Bd	BT				LSI BD			
7116	1950	37.7	35.9				0.18			
7548	2129	36.2	33.6				0.16			
7549	2129	35.3	33.4				0.15			
8215	2458	37	35.6				0.17			
Radius										
BoneID_auto	Context Number	Bp	Bfp	Bd			LSI BP			
7354	2117	35.1	32.3				0.09			
7550	2129	39.6	33.1				0.15			
7854	2133			28.5						
Metcarpal										
BoneID_auto	Context Number	GL	Bp	Sd		Bd				
1217	1216					28.6				
Tibia										
BoneID_auto	Context Number	GL	Bp	SD	Bd	Dd	LSI Bd			
3358	1412				32.7	24.2	0.10			
Metatarsal										
BoneID_auto	Context Number	Bp		Bd						
7330	2117			28.3						
Phalanx 1										

BoneID_ auto	Context Number	Glpe	Bp	SD	Bd		LSI GL	LSI Bd		LSI BP
2312	1243			9.9	12.3			0.05		
2883	1402	44.4	14.1	11.4	13.7		0.12	0.10		0.08
3372	1336	38	13.3	11.4	12.9		0.05	0.07		0.06
4162	1409			9.6	12			0.04		
5142	1350		12.4						uf	0.03
5329	1549		10.9	8.5	11.2			0.01		-0.03
6290	1528	41.8	14.1	10.1	12.7		0.09	0.06		0.08
7046	2023			8.2	10.3			-0.03		
7117	1950	41.5	12.3	9.9	11.6		0.09	0.02		0.03
7631	2129	46.7	14.6	10.8	13		0.14	0.07		0.10
7632	2129	47.5	15.6	11.4	13.6		0.15	0.09		0.13
7673	1938	44.2	14.2	10.5	13.4		0.12	0.09		0.09
7726	2101	50.4	15.3	11.8	14.6		0.17	0.12		0.12
7795	2280	41.1	12	9.9	11.6		0.08	0.02		0.01
Phalanx 2										
BoneID_ auto	Context Number	Glpe	Bp	SD	Bd					
7508	2135	25.3	14.5	11.6	11.4					

SI C: The measurements of sheep bones from Bestansur.

Humerus							fusion	
Bone_id	Context	Bd	BT	HT	HTC			LSI Bd
4126	1331			22.3	16.4			
6051	1528	32.9		19.9	15.5			0.03
7603	2127	33.6	31.2					0.04
7973	2255	33.1						0.03
Radius								
BoneID_auto	Context Number	Bp	Bfp	Bd				LSI Bp
3281	1412	34.4	32					0.04
3759	1423	35.5	34.4					0.06
4061	1412			28.3				
4933	1555	36.8	33.6					0.07
7272	2103			39.5			unfused	
7197	1976	35.1	33.3					0.05
7429	2122			33.1				
8023	2396			32				
Metacarpal								

BoneID_auto	Context Number	Bp	Sd		Bd			LSI Bd
1007	1096				26.8			0.08
2771	1330	27.6						
3186	1402	30.8						
3235	1414	29.2						
4127	1331				26			0.06
5557	1343				28.1			0.10
7346	2117				29.3			0.12
7499	2135				27.3			0.09
7430	2122	28.2	16.6					
7450	2122				30.1			0.13
7529	2129							
7111	1950	28.2						
Tibia								
BoneID_auto	Context Number	Bd						LSI Bd
2744	1340	24.2						-0.03
4652	1347							
5555	1343	21.7						-0.08
Astragalus								
BoneID_auto	Context Number	GLl	GLm	Dl	Dm	Bd		LSI Bd
1023	1037	34	33.4	19.7	20.9	22.9		0.06
1237	1217	32.4	29.8	18.4	18.5	21.2		0.03
2067	1243	32.9	30.1	18.5		20.4		0.01
2722	1333	35.8	33.9	20.4	21.3	23.9		0.08
3299	1412	32	18.3	31.4		21		0.02
3343	1386					20.6		0.02
4062	1412	32.3	30.3	18.1	18	19.2		-0.01
4464	1354		30					
5031	1538		31.6					
7300	2117	33.4	32.5					
7399	2103	34.3	31	20.4	21	21.7		0.04
7045	1772	27.4	25.8	13.1		16		-0.09
7200	1976	34.1	32.2					
7530	2129	34.5	32	20.6	20.7	22.4		0.05
7113	1950	35.5	33.1			22.9		0.06
7648	2142	31.5		17.7	18.8			
7965	2259	28.7	27.1	15.2	6.1	18		-0.04
8114	2390	31.6				21.8		0.04
8133	2468	33.7	31.8	19.3	21	20.7		0.02

Calcaneus		GL	GB	BS		GLde		
BoneID_auto	Context Number	74.6	24.7	21		28.2		LSI GB
3236	1414	70.8	20.4					0.02
7398	2103	71.2	21					-0.06
7528	2129	66.9	21.6					-0.05
7605	2127			20.6				-0.04
7112	1950							
Metatarsal		Bp	Sd		Bd			
BoneID_auto	Context Number				26.1			LSI Bd
2727	1340				28.6			0.01
3865	1409		23.9					0.05
4112	1331				26.4			
4465	1354		24.4					0.02
5556	1343							
7191	1976							
7451	2122				28.6			
7657	2129				28.2			0.05
7843	2133							0.05
Phalanx 1		Glpe	Bp	SD	Bd			
BoneID_auto	Context Number	44.4	12.9	10.6	12			LSI GL
2726	1340	49	0	0	14.9			0.02
2833	1333	45.9	14.9	11.3	14.3			0.07
3150	1344			10.9	13.2			0.04
4090	1331				13			
4640	1347	46.3	14.8	11.8	13.7			
7507	2135	49.4	14.4	11	13.6			0.04
7452	2122	45.7	14.6	11.8	14.9			0.07
7506	2135	47.3	12.9	10.2	12.3			0.04
7847	2133	45.5	14.1	10.7	12.9			0.05
7848	2133	42.5	14.3		12.7			0.03
7938	2259							0.00
Phalanx 2		Glpe	Bp	SD	Bd			
BoneID_auto	Context Number		9.4					
5236	1539	29.2	14.1	10.3	11.1			
7453	2122	25.2	12.4	8.4	9.1			0.08
7454	2122	25.9	14.2	10	10.3			0.02
7563	2129	11.6	13.4	9.1	9.4			0.03
7849	2133	27.8	13.5	9.5	9.8			
7850	2133							0.06

SID: Method section isotopic analysis.

Samples for stable isotopic analyses were taken and processed at the University of Reading, School for Archaeology, Geography and Environmental Science, partly carried out by author and partly for a master thesis project. The protocol for sampling teeth is adapted from Balasse *et al.* (2002), but involved only one acid step. Sequential sampling was performed from the tip to the basis of the crown, perpendicularly to the tooth growth axis specify distance between samples. Samples were taken using a diamond-coated drill, as evenly spaced as possible over the crown height and through the whole enamel thickness. Samples of Bestansur taken by Coogan were pre-treated in diluted H202 for 24 hours and analysed at KU Leuven in the Thermal Delta V Advantage Isotope Ratio Mass Spectrometer. Samples for this study were treated with acetic s 0.1 M, since research showed this does not change the isotopic composition of the tooth remains (Snoeck and Pellegrini 2015; Pellegrini and Snoeck 2016) and analysed at the University of Reading on a Thermo Scientific Delta Plus Isotope Ratio Mass Spectrometer coupled to a GasBench II. Analytical error (± 1 s.d.) determined by repeat analysis of international and internal standards, was max $\delta^{13}C$ 0.1 and d $\delta^{18}O$ 0.46; an internal powdered tooth enamel reference gave an error of Std. Deviation $\delta^{13}C$ 0.15 and $\delta^{18}O$ 0.31

References SI methods.

Balasse, M., 2002. Reconstructing dietary and environmental history from enamel isotopic analysis: time resolution of intra-tooth sequential sampling. *International Journal of Osteoarchaeology* 12(3), 155-165.

Pellegrini, M., Snoeck, C., 2016. Comparing bioapatite carbonate pre-treatments for isotopic measurements: Part 2—Impact on carbon and oxygen isotope compositions. *Chemical Geology* 420, 88-96.

Snoeck, C., Pellegrini, M., 2015. Comparing bioapatite carbonate pre-treatments for isotopic measurements: Part 1—Impact on structure and chemical composition. *Chemical Geology* 417, 394-403.

Chapter 6: The Epipalaeolithic-Neolithic Transition in Northeastern Iran: New Zooarchaeological Evidence from the Southern Shores of the Caspian Sea

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Abstract

This research sheds new light on sheep/goat management and domestication during the Epipalaeolithic-Neolithic transition on the Caspian Sea littoral through analysis of new zooarchaeological data from the recently re-excavated Hotu cave.

Gazelle dominates the zooarchaeological assemblage of the Epipalaeolithic levels, while sheep/goat are most abundant in the Neolithic. A high amount of perinatal remains of sheep/goat is found in the Early Neolithic layers as well, indicating they were kept in or close to the site. There is clear evidence that the community at Hotu cave managed sheep and goat during the Early Neolithic.

1 Introduction

The domestication of plants and animals is one of the most pivotal events in the history of humankind. Domestication and the transition from hunting gathering to farming was a slow and complex process, which took place in multiple places in Southwest Asia independently from ca. 9500 BC, rather than a revolutionary change subsequently spreading from a single core zone (Fuller *et al.* 2011; Zeder 2011). In addition, management, domestication and adoption of different livestock and plant species was a highly localized process, influenced by both cultural and environmental factors (Fuller *et al.* 2011; Arbuckle 2014). It is unclear whether local hunter-gatherers in Iran, beyond the Zagros, developed their own transition to farming or whether it was introduced from other regions (Matthews &Fazeli Nashli 2022), as traditionally the Zagros region has been subject to greater archaeological investigation (Weeks 2013, 56; Vahdati Nasab *et al.* 2019).

The Caspian Sea littoral of northeastern Iran is an ecologically diverse area, with climatic conditions supporting a broad variety of plant and animal food resources (Leroy *et al.* 2019), which could have been favourable for a local transition from hunter gathering to farming. The idea of local domestication of animals in this region was first suggested by Coon (1951, 1952) based on excavations at the cave site, Hotu, on the Caspian southern shore. The cave yielded a long sequence of occupation with Epipalaeolithic and Neolithic layers. Coon claimed to identify an increase in young goat in the late Epipalaeolithic horizons, which he interpreted as evidence for the start of goat husbandry in this period (Coon 1951, 50). He also suggested that domesticated sheep, pig, dog and cattle were present in the Neolithic layers of the site (Coon 1951, 1957). No analysis has been published to verify these statements (Harris and Coolidge 2010, 57), however, and only a selection of the zooarchaeological assemblage was published. Therefore, it remains unclear whether the sheep and goat were locally domesticated, imported, or a combination of introduced domesticates subsequently mixed with local wild animals.

This research sheds new light on sheep/goat management and domestication, and on the introduction of caprines during the Epipalaeolithic-Neolithic transition on the Caspian Sea littoral through analysis of new zooarchaeological data from the recently re-excavated Hotu cave. The complete zooarchaeological assemblage as well as other findings of the 2021 excavations at Hotu cave will be published separately.

2 The Site: Hotu cave

Hotu cave is situated in a cliff on the slope of the Alborz Mountains (Figure 1) and is approximately 30 m × 20 m in area. The cave was first excavated in 1951 and 1952 over the course of two field seasons of nine weeks, but with a lack of rigour in the recording of the finds (Harris & Coolidge 2010, 57; Leroy *et al.* 2019, 350) and only part of the zooarchaeological assemblage has been published (Coon 1951). The site was re-excavated in 2021 by a team directed by Hassan Fazeli Nashli from the University of Tehran.

The re-excavation of the site uncovered 124 stratigraphical layers, with archaeological layers spanning from the Epipalaeolithic to the Parthian period (Figure 2). Based on the excavation stratigraphy and archaeological finds, distinct phases for the site have been proposed (Figure 2). Seven samples from Epipalaeolithic and Neolithic layers have been radiocarbon dated, giving a range from ca 12,000 to 6300 BC (Table 1; all dates given as calibrated BC). These dates confirm earlier dating of the site which placed the Epipalaeolithic layers between 12,800 and 8900 BC (Harris and Coolidge 2010, 56), and later layers between 7500-4000 BC (Leroy *et al.* 2019, 350).

It is not yet clear how continuous the occupation of the site was during the Epipalaeolithic Neolithic transition, and whether there was a hiatus in occupation between the

Epipalaeolithic and the Early Neolithic. The Early Neolithic is understood to start from Context 99, and the radiocarbon dates suggest that the site was occupied intensively in the Early Neolithic (Table 1). The earliest pottery, Caspian Neolithic Soft Ware, was recovered from Context 75, directly above a layer containing gravel (Context 76) interpreted as an episode of cave collapse and abandonment (Figure 2; Table 1).

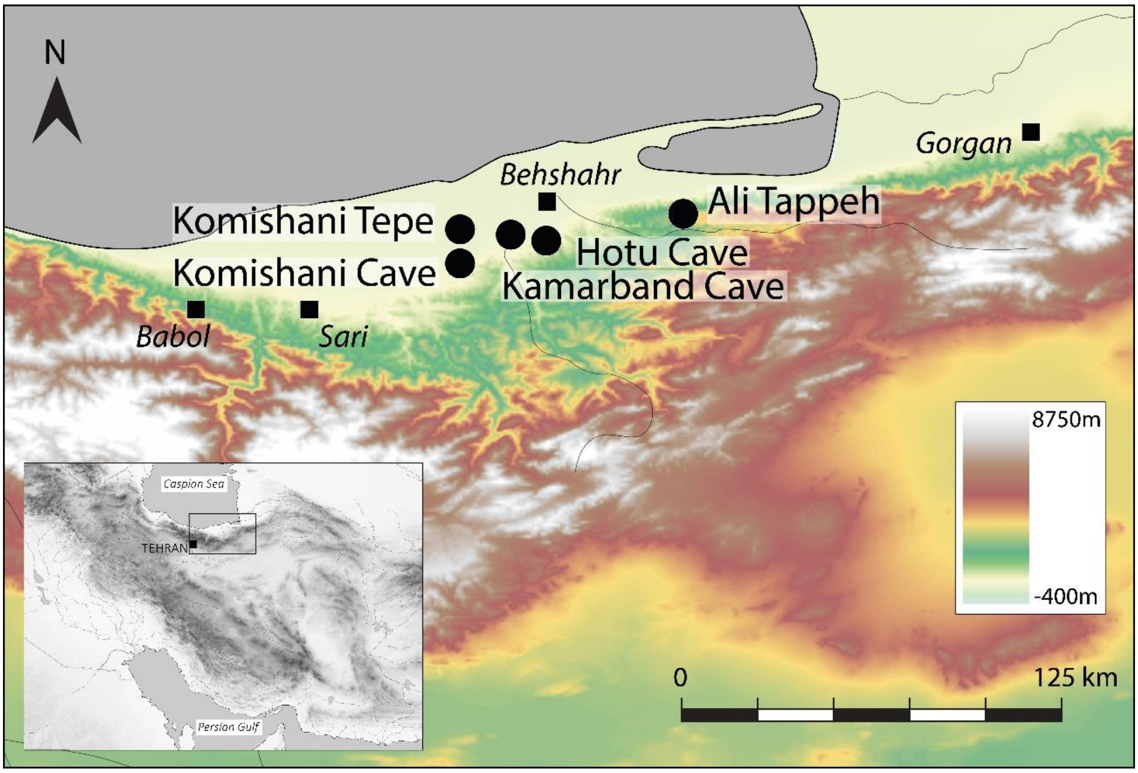


Figure 1: Location of Hotu cave and other Epipalaeolithic and Neolithic sites in the region.

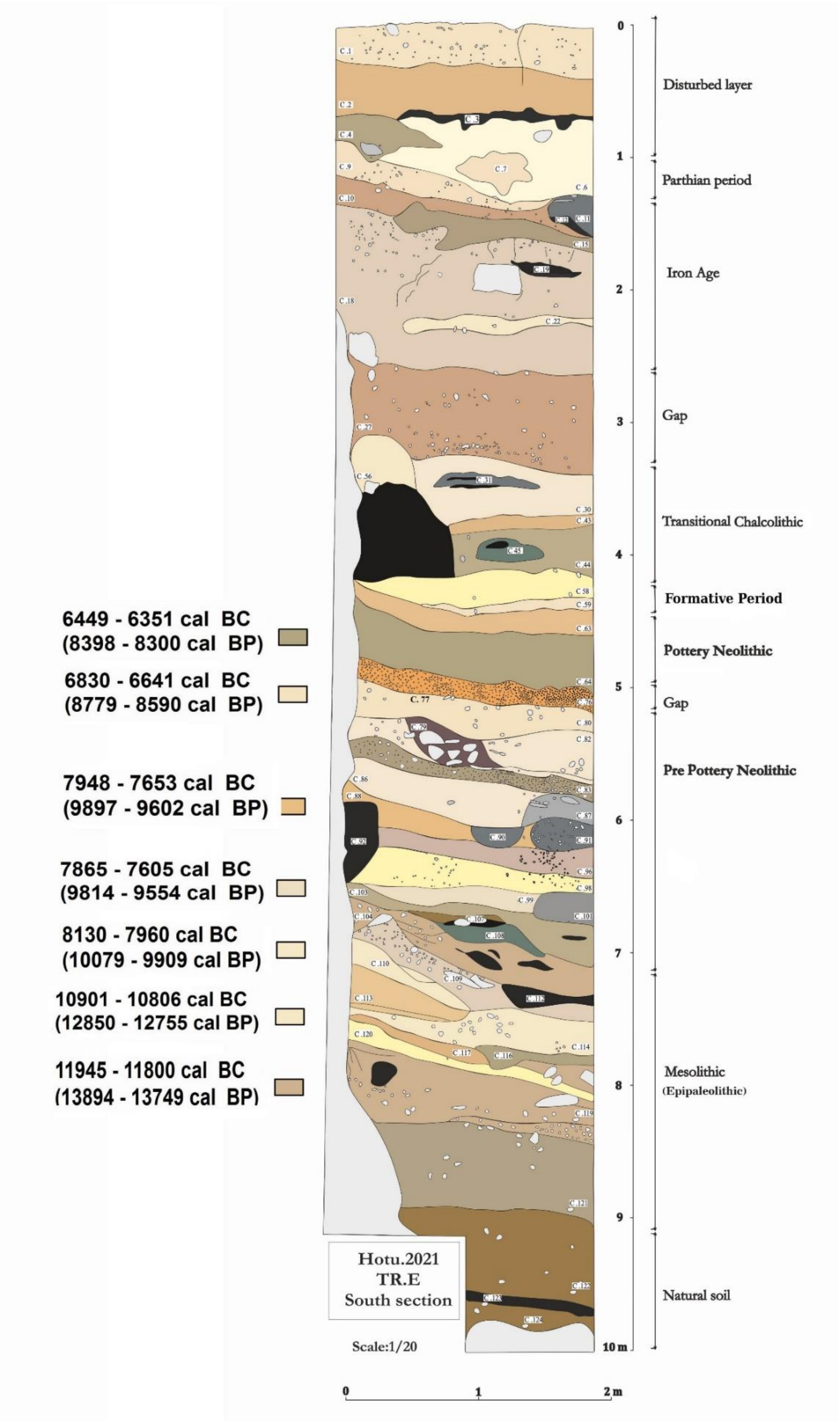


Figure 2: The stratigraphic layers of Hotu Cave.

Table 1: New radiocarbon dates of Hotu Cave.

Lab no.	Sample code no.	Context	Material	date uncal BP	date cal BC
Beta - 621449	Hotu_FN1435	63	Charcoal	7520±30	6449 - 6351
Beta - 621450	Hotu_FN1505	77	Charcoal	7880±30	6830 - 6641
Beta - 621451	Hotu_FN1762	88	Charcoal	8760±30	7948 - 7653
Beta - 621452	Hotu_FN1818	99	Charcoal	8740±30	7865 - 7605
Beta - 621447	Hotu_FN2901	111	Human bone	8930±30	8130 - 7960
Beta - 621448	Hotu_FN2902	115	Human bone	10920±30	10901 - 10806
Beta - 621453	Hotu_FN2844	121	Charcoal	11950±40	11945 - 11800

3 Regional context

Other Epipalaeolithic and Neolithic sites on the Caspian littoral located close to Hotu cave have varied zooarchaeological assemblages. The prehistoric layers from Ali Tappeh are all Epipalaeolithic, with radiocarbon dates ranging from 11,200-9750 BC. Gazelle is the most abundant species in the zooarchaeological assemblage of all layers, although the relative abundance of gazelle decreases over time and the presence of seals sharply increases (Harris & Coolidge 2010, 55-6). Other animals exploited were onager, wild sheep, aurochs, wild boar and fox as well as birds. The peak of sheep and goat exploration was during the latest two stratigraphic phases of the Epipalaeolithic occupation (McBurney 1969).

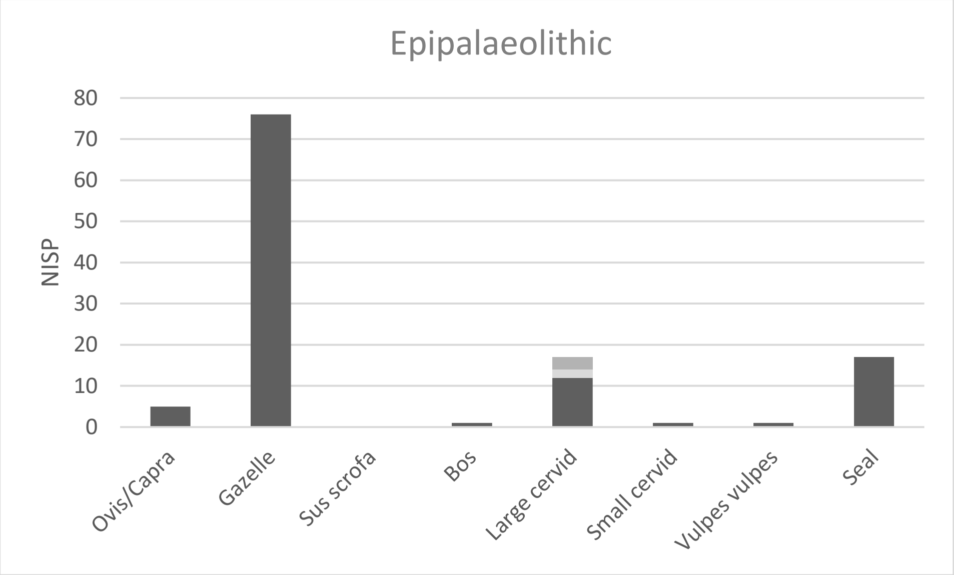
Komishani cave and Komishani Tepe are both sites on the Caspian Sea shores that have been recently excavated. Komishani cave had highly disturbed and potentially looted stratigraphic levels containing mixtures of Iron Age, Bronze Age, plus Chalcolithic pottery and Neolithic flint tools, but an undisturbed Epipalaeolithic layer. Radiocarbon dates from these layers provide ranges from ca. 12,100 -11,800 BC and 10,800-10,700 BC (Vahdati Nasab *et al.* 2011). Only the animal bones from the Epipalaeolithic layers have been studied, since the analysis of unstratified looted layers would not generate valuable information. Gazelle is the most abundant taxon and no sheep/goat and seals have been found at the site. Wild boar, fox and birds have also been identified (Mashkour *et al.* 2010; Vahdati Nasab *et al.* 2020). Komishani Tepe, situated on the plain in front of Komishani cave was excavated in 2017. The horizons of the site span from the Late Epipalaeolithic into Early Neolithic dating from between ca. 14,350-14,200 and 9200-8200 BC (Leroy *et al.* 2019). Few animal bones were found at the site, but sheep and goat are the most abundant species in both the Epipalaeolithic and the Neolithic layers. Wild boar, aurochs, fox, and deer are also present as well as a large variety of water birds, although there is no evidence for the exploitation of marine resources. The zooarchaeological assemblage of the Late Epipalaeolithic and Neolithic does not differ in terms of species found. Stable carbon and nitrogen isotope analysis of sheep and goat bones does not show notable differences in diet between the Epipalaeolithic and the Neolithic levels (Leroy *et al.* 2019, SI).

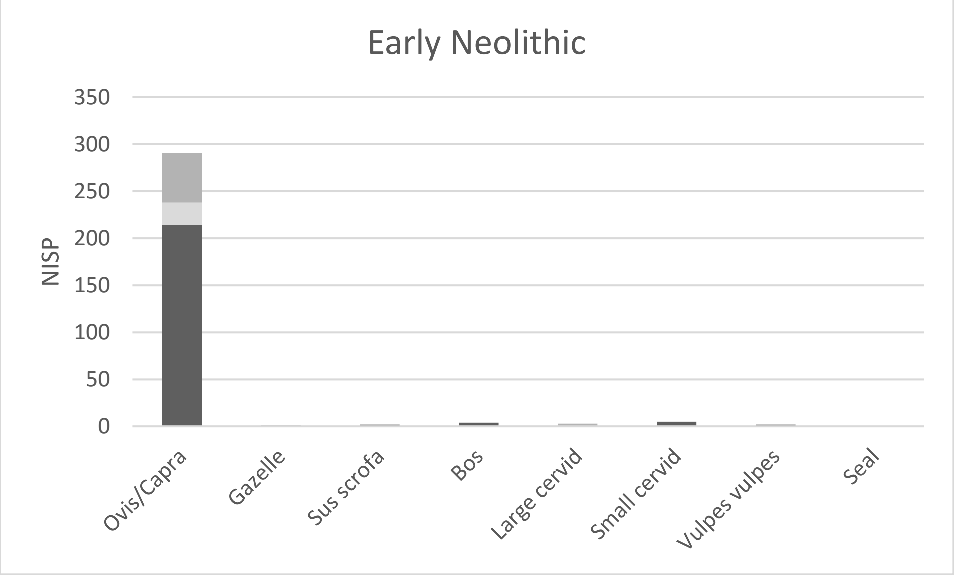
Kamarband cave (also known as Belt cave) was originally excavated at the same time as Hotu cave (Coon 1951; 1952). Kamarband has both Epipalaeolithic and Neolithic layers, but an aceramic phase of the Neolithic was not identified in the early excavations (McBurney 1969). The Epipalaeolithic layers from Kamarband date to ca. 11,350 BC, and the Neolithic occupation begins between ca. 8000-6000 BC (Leroy *et al.* 2019; McBurney 1969). Seal and gazelle were the dominant species during the Epipalaeolithic, but sheep/goat were present too in the later Epipalaeolithic layers as well as aurochs and deer (McBurney 1969). In the Neolithic, sheep/goat are the most abundant species, making up the vast majority of the zooarchaeological assemblage (McBurney 1969). New excavations in 2022 at Kamarband cave, directed by Hassan Fazeli Nashli, have recovered significant materials, including zooarchaeological remains, from levels of Epipalaeolithic and Early (aceramic) Neolithic date, which will be the subject of future research.

The changes in species abundancy in the zooarchaeological assemblages during the Epipalaeolithic of the region have been attributed to sea-level changes of the Caspian Sea (McBurney 1969; Leroy *et al.* 2019), but little is known about the transition to the Early Neolithic, which is the focus of the current article.

4 Results

This study includes animal remains of the Epipalaeolithic and Early Neolithic layers of Hotu cave from the 2021 field season. Methods used to analyse the assemblage can be found in the Supplementary information. The zooarchaeological assemblage at Hotu cave changes significantly across the Epipalaeolithic and Early Neolithic levels (Figure 3). The Epipalaeolithic levels are dominated by gazelle at 65% of total NISP of identified mammals, with significant representations of large cervid and seal. Sheep and goat appear widely in the assemblage from Context 99 onwards, while no gazelle or seals appear in the assemblage from this stage on. This evidence suggests a major shift in animal exploitation practices by the occupants of the cave at the start of the Early Neolithic in the early 8th millennium BC. Goat outnumber sheep in both the Early Neolithic and the Pottery Neolithic levels in a ca. 2:1 ratio. Pig, possibly domesticated, appears in the later layers of the Pottery Neolithic.


Epipalaeolithic
NISP
80
70
60
50
40
30
20
10
0
Ovis/Capra
Gazelle
Sus scrofa
Bos
Large cervid
Small cervid
Vulpes vulpes
Seal


Early Neolithic
NISP
350
300
250
200
150
100
50
0
Ovis/Capra
Gazelle
Sus scrofa
Bos
Large cervid
Small cervid
Vulpes vulpes
Seal

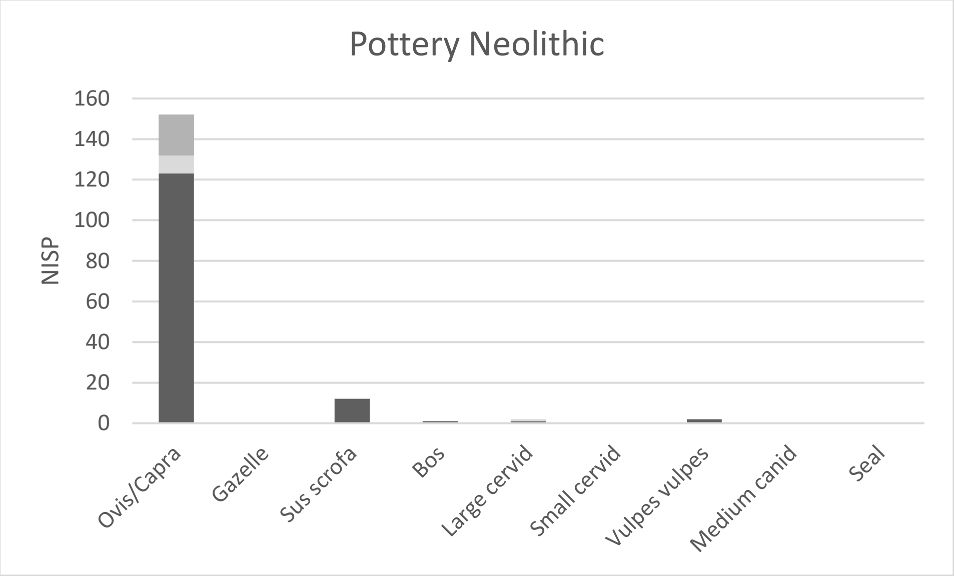

Pottery Neolithic
NISP
160
140
120
100
80
60
40
20
0
Ovis/Capra
Gazelle
Sus scrofa
Bos
Large cervid
Small cervid
Vulpes vulpes
Medium canid
Seal

Figure 3: the NISP of the zooarchaeological per period, in Ovis/Capra, black is sheep/goat, light grey is sheep, and dark grey is goat. In large cervid black is any large cervid, light grey is Cervus elaphus and dark grey is Dama dama (see SI for NISP=n and percentages per phase).

A significant amount of perinatal remains occur in the assemblage, not all elements of which could be identified since many of them were fragmentary (SI). Apart from the large amount of foetal and neonatal bones, sheep and goat generally died at a young age in the Early Neolithic (Table 2). The moderate size of the dataset makes it hard to compare the mortality profiles of sheep and goat, but both seem to have rarely reached an age older than 4 years. It is evident that once both sheep and goat passed the foetal and neonate stage, they generally seem to have reached an age older than one year. In the Pottery Neolithic perinatal remains are almost absent (SI, Table 3). Still the majority of the sheep/goat bones are unfused (Table 3).

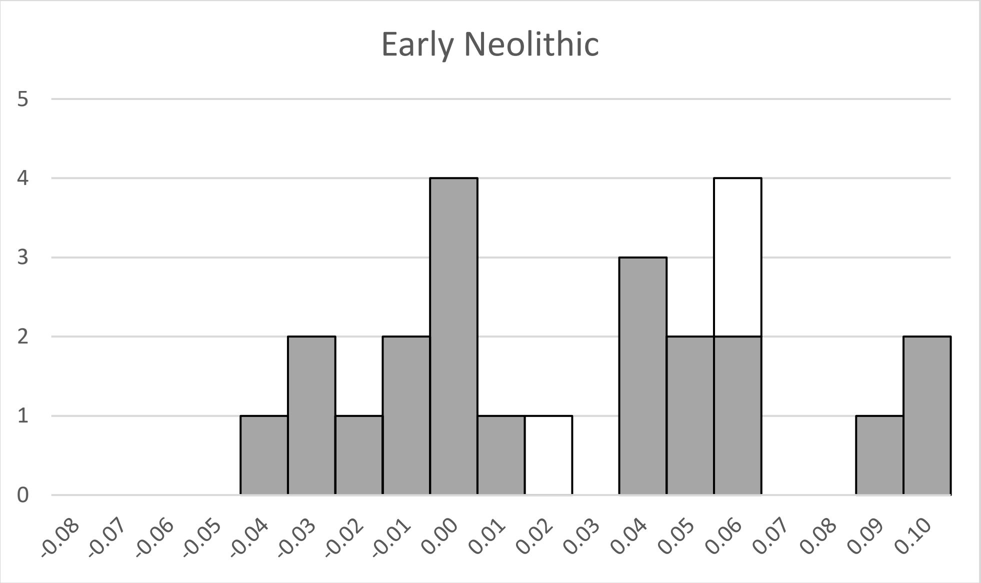
Table 2: Fusion data of sheep and goat of Early Neolithic Hotu, sheep/goat category includes sheep, goat and sheep/goat all added up together (following fusion ages of Zeder 2006).

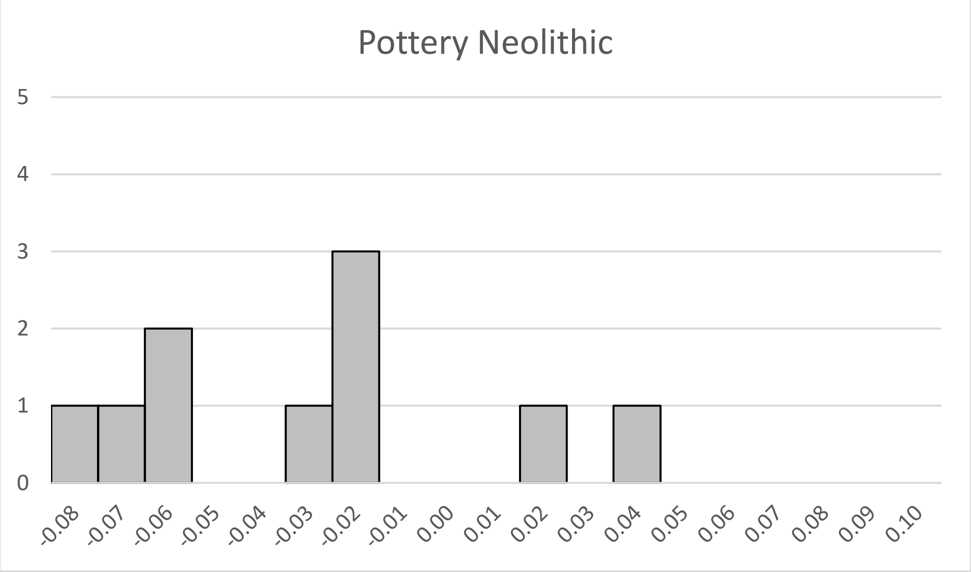
Age in months	Zeder age range	Element	unfused	fused	fusing	Total	
Goat							
	foetal/neonates		1			1	
0-6	A	Radius p.		5		5	
6-12	B	Humerus d.		2		2	
12-18	C	Phalanx 1	2	6	1	9	
12-18	C	Phalanx 2	2	5	1	8	
18-30	D	Metacarpal	1	1		2	
18-30	D	Metatarsal		1		1	
18-30	D	Tibia d.	2	1		3	
30-48	E	Radius d.	1			1	
30-48	E	Calcaneum	1	1		2	
Sheep							
0-6	A						
6-12	B	Humerus d.		2		2	
12-18	C	Phalanx 1		1		1	
12-18	C	Phalanx 2	1			1	
18-30	D	Metacarpal	1			1	
30-48	E	Calcaneum	1	2		3	
Sheep/goat							
			unfused	fused	fusing	total	% fused
foetal/neonates			**23**			23	
0-6	**A**	**radius p.**		**5**		**5**	**100**
6-12	**B**	**Humerus d.**		**7**		**7**	**100**
12-18	C	Phalanx 1	6	9	1		
12-18	C	Phalanx 2	4	5	1		
12-18	**C**	**Total C**	**10**	**14**	**2**	**26**	**53.8**
18-30	D	Metacarpal	5	1			
18-30	D	Metatarsal	3	1			
18-30	D	Metapodial	3				
18-30	D	Tibia d.	5	1			
	D	**Total D**	**16**	**3**		**19**	**15.8**
30-48	E	Radius d.	2			2	
30-48		Ulna p	2			2	
30-48		Calcaneum	2	3		5	
30-48	**E**	**Total E**	**6**	**5**		**9**	**33.3**

Table 3: Fusion data of sheep and goat of Pottery Neolithic Hotu, sheep/goat category includes sheep, goat and sheep/goat all added up together (following fusion ages of Zeder 2006).

Age in months	Zeder age range	element	unfused	fused	fusing	total	
Goat							
0-6	A	Radius p.		1		1	
12-18	C	Phalanx 1		2	1	3	
12-18	C	Phalanx 2	1		1	2	
Sheep							
6-12	B	Humerus d.		1		1	
18-30	D	Metacarpal		1		1	
Sheep/goat							
			unfused	fused	fusing	total	% fused
foetal/neonates		2				2	
0-6	**A**	**Radius p.**		**1**		**1**	**100**
6-12	**B**	**Humerus d.**	**1**	**2**		**3**	**66.7**
12-18	C	Phalanx 1	3	2	1		
12-18	C	Phalanx 2	1		1		
12-18	**C**	**Total C**	**5**	**5**	**2**	**12**	**41.7**
18-30	D	Metacarpal	2	1			
18-30	D	Metatarsal					
18-30	D	Metapodial	1				
18-30	**D**	**Total D**	**3**	**1**		**4**	**25**
48 +	**F**	**Humerus p.**	**1**	**1**		**2**	**50**

The LSI values of goat in the Early Neolithic show two peaks, which may be indication of sexual dimorphism (Figure 4). The graph is slightly skewed, while the kurtosis is negative (Skewness: 0.16, Kurtosis -0.85), meaning that the mean of the data is greater than the median and the graph is heavy tailed. The dataset from the Pottery Neolithic is smaller and the two peaks are less evident. The skewness of the graph is positive and the kurtosis negative (Skewness: 0.68, Kurtosis: -0.26). The goat bones in the Pottery Neolithic are significantly smaller than those of the Early Neolithic (Figure 4).


Early Neolithic
5
4
3
2
1
0
-0.08
-0.07
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10


Pottery Neolithic
5
4
3
2
1
0
-0.08
-0.07
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

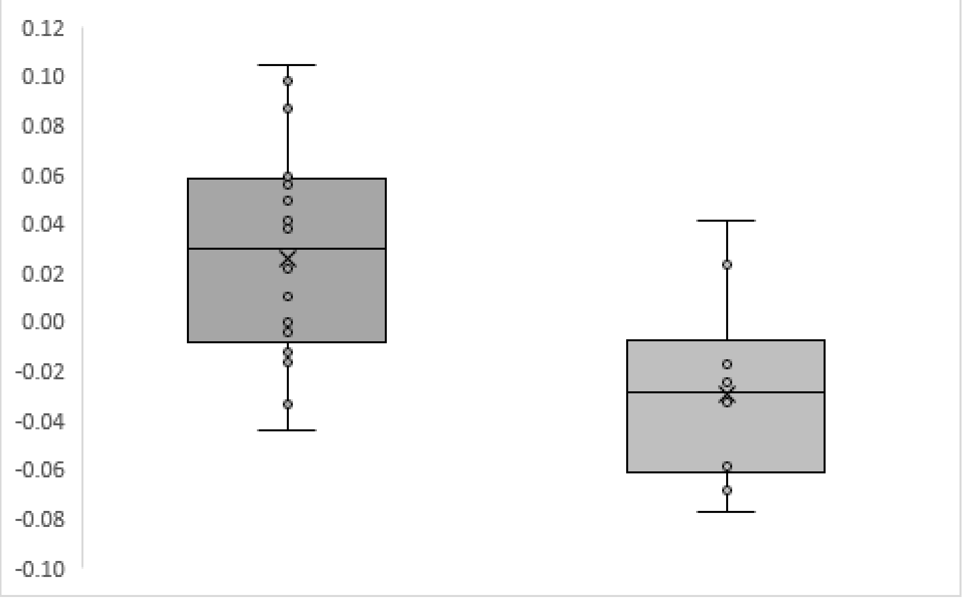

0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10

Figure 4: The LSI values of goat of Hotu, top Early Neolithic, middle Pottery Neolithic, and below boxplot of the Early Neolithic (left) and Pottery Neolithic (right), unfused elements in white. The Early Neolithic data include fused elements which fuse before an age 18 months (n=15), fused elements which fuse after an age of 18 months (n=1), elements which do not fuse (astralagus) n=5 and unfused elements n=3, the Pottery Neolithic include fused elements which fuse before 18 months (n=5) and fused elements which fuse after an age of 18 months (n=2).

The LSI of the Early Neolithic sheep show a flat curve, with a tail at the right (Skewness: -0.52; Kurtosis; 0.44) (Figure 5). Although the number of measurements of Pottery Neolithic sheep is modest, they are clearly smaller than the Early Neolithic sheep. The Pottery Neolithic sheep have a clear outlier on the right side of the graph (Figure 5), however the sample size is too small to draw definite conclusions.

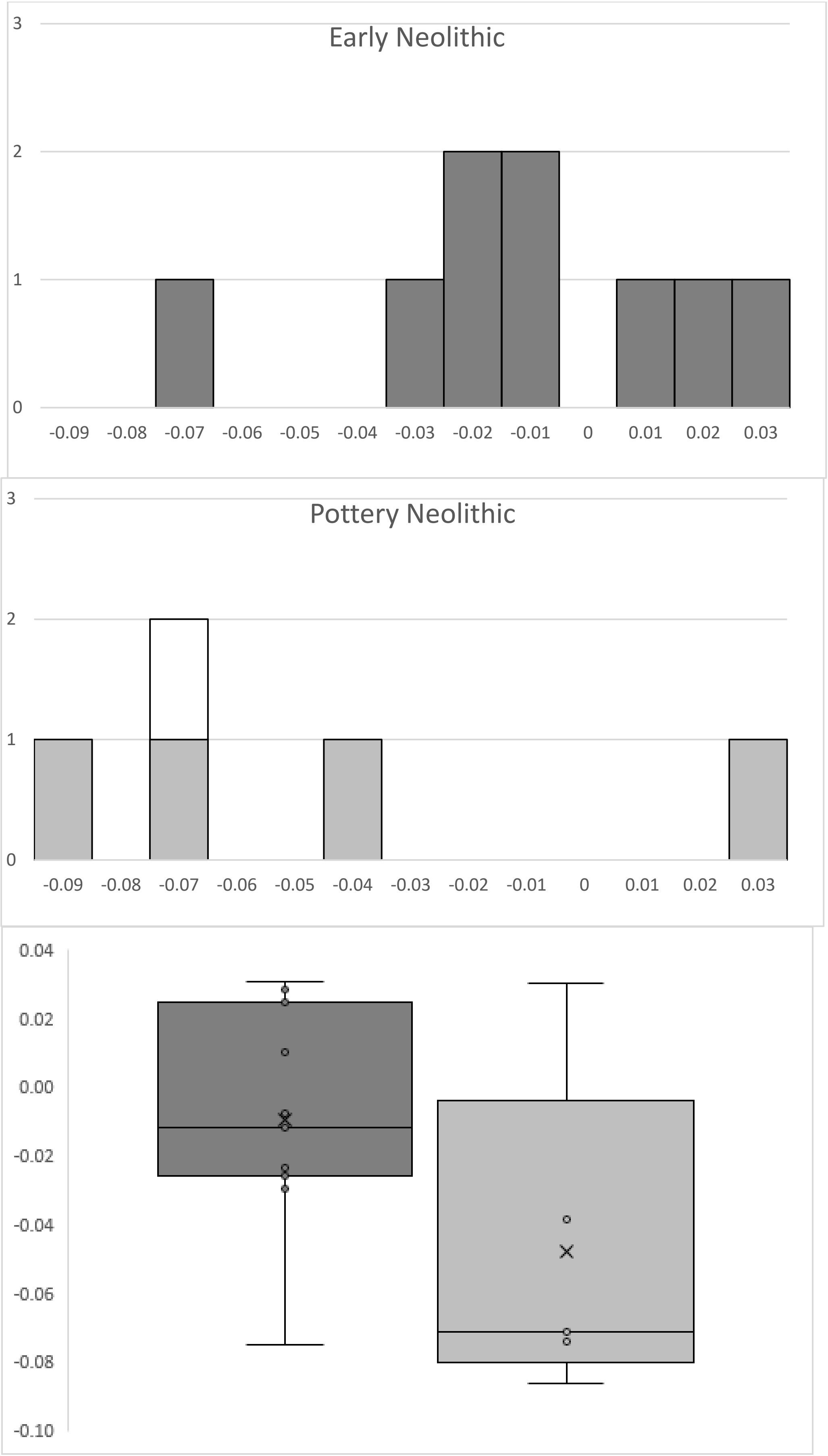

Early Neolithic
3
2
1
0
-0.09
-0.08
-0.07
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
Pottery Neolithic
3
2
1
0
-0.09
-0.08
-0.07
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10

Figure 5: The LSI values of the sheep of Hotu, top Early Neolithic, middle Pottery Neolithic, and below boxplot of the Early Neolithic (left) and Pottery Neolithic right, unfused elements in white. The Early Neolithic includes elements which do not fuse (astralagus) (n=9) and fused elements which fuse before an age of 18 months (n=2), the Pottery Neolithic includes fused elements which fuse before an age of 18 months (n=3) and which fuse after an age of 18 months (n=1) and unfused elements (n=1).

5 Discussion

The absence of sheep/goat in the Epipalaeolithic is in sharp contrast to their dominance of the zooarchaeological assemblage in later levels. At first sight this pattern might suggest a hiatus in occupation. There is no evidence for a gradual transition towards reliance on sheep and goat, rather than gazelle, cervidae and seal (Figure 3). This transition in the zooarchaeological assemblage could mean that a decline in gazelle, for unknown reasons, led local people to exploit sheep/goat instead. Both wild sheep and goat were present in the regional environment in the Epipalaeolithic, as attested at Komishani Tepe and Kamarband cave, and wild sheep were present at Ali Tappeh and in small amounts at Hotu cave, so it is likely that they were available in the Early Neolithic. Another possibility is that a new group of people came in, bringing domesticates or managed animals with them. One argument suggests that settlers from the Zagros region of western Iran, where Neolithic developments happen extremely early (management of goat from ca. 8000 BC), could have been the incomers who introduced the Neolithic lifestyle, travelling eastwards along the Great Khorasan Road on the northern edge of the central plateau of Iran (Harris and Coolidge 2010; Roustaei and Gratuze 2020; Matthews and Fazeli Nashli 2022). The presence of domesticated sheep at Obishir in southern Kyrgyzstan by 6000 BC (Taylor *et al.* 2021) suggests a relatively rapid spread of Neolithic herding practices eastwards across northeastern Iran and southern Turkmenistan. Intriguingly, aDNA from an individual from Hotu cave, found during the Coon excavations possibly from an Epipalaeolithic layer, shows genetic affinity with west Iranian farmers (Lazaridis *et al.* 2016).

The large amount of perinatal remains of sheep/goat in the Early Neolithic at Hotu (30 %, calculated against all bones of sheep goat which are included for ageing) indicates that they were kept at the cave or in close proximity to the cave. This association demonstrates that people were not solely hunting sheep/goat, but keeping control over their movement. Caves have been used as places to pen sheep and goat at various Neolithic sites around the world (Martín *et al.* 2016; Miracle 2006), and frequently infantile caprine bones have been found in such cave deposits (Boschin 2020; Tejedor-Rodríguez *et al.* 2021; Munro and Stiner 2015). It has been suggested that caves were used as locations for breeding flock (Martín *et al.* 2016). Pastoralist sheepherders nowadays often separate pregnant animals from the rest of the flock to give them extra care (Martín *et al.* 2016). It is uncertain whether all sheep/goat were kept in and close to the cave during the Early Neolithic, or whether the cave was mainly used as shelter for pregnant sheep/goat. The high number of foetal animals and neonates could be related to a separate flock kept in the cave. The ratio of spontaneous abortions in modern-day sheep and goat flocks varies. A survey among sheep/goat farmers in Jordan indicated a perinatal mortality in sheep of 7.5 % and an almost double perinatal mortality in goats of 13% (Aldomy *et al.* 2009). In case of infectious disease this figure can increase to 20–40% (Martín *et al.* 2016, 324). Non-infectious causes of spontaneous abortions and still-births in sheep and goat can be caused by various causes, such as trauma, which can be brought on by multiple factors such as long journeys, stays in unfamiliar accommodation, climatic changes, carnivore attacks, nutritional deficiencies, or the ingestion of toxic plants (Aldomy *et al.* 2009; Martin *et al.* 2016). Multiple infectious diseases, some of them infectious to humans, can lead to still-births and abortion (Aldomy *et al.* 2009; Fournié *et al.* 2017*).* Zoonotic diseases are likely to have increased during the Early Neolithic because humans brought animals together in larger, denser herds leading to increased contact with the animals (Fournié *et al.* 2017).

The LSI values of mature goat show two peaks, suggestive of sexual dimorphism (Figure 4). This pattern indicates that both male and female goat were kept or consumed at the cave site, since bones could all derive from relatively young or mature animals it not possible to determine whether male goat were slaughtered earlier than female goat. Apart from the perinatal remains, the goat were slaughtered at a young age during the Early Neolithic (Table 2). The mortality profile is very different from a hunted population where a focus on prime adults would be expected. The sample size of the Pottery Neolithic is small, but does show more and a tail at the right more suggestive for young male cull (Figure 4). The LSI graph of sheep in the Early Neolithic seems to be dominated by males (Figure 5). It might represent a focus on prime adults, but ageing pattern based on bone fusion sheep in the Early Neolithic, does not indicate a focus on prime adults (Table 2). In the Pottery Neolithic a large percentage of the sheep and goat population continued to be slaughtered at a young age (Table 3), but the percentage of perinatal remains is only 4% (Table 3). The sample size of the Pottery Neolithic is smaller, but both the sheep and goat LSI values have clearly decreased (Figure 4 and 5). It is possible that this is the result of a decrease in body size in animals or that smaller animals were introduced, but it could also be a change in management patterns. The large number of young animals in the assemblage could indicate that males were often culled before they reached 18 months of age (Table 3). A similar size decrease in both sheep and goat in the Pottery Neolithic has been observed in the Zagros region, which so far is unexplained (Zeder 2008). The data from Hotu cave do suggest that the sheep and goat were managed in the Early Neolithic. The sudden transition from a zooarchaeological assemblage dominated by gazelle to a zooarchaeological assemblage almost completely made up of sheep/goat is compelling. It is possible that the function of the cave changed, rather than the complete diet of humans. The cave could have been mainly used as a breeding site for sheep/goat, which could explain the high number of perinatal remains. Dung biomarkers and micromorphological analysis could give more insight on whether the animals were present in the cave, as has been attested at other Neolithic sites in Southwest Asia (Portillo *et al.* 2020; Tejedor-Rodríguez 2021; Yeomans *et al.* 2021). It is likely that zoonotic diseases were present among the sheep/goat if they were suddenly kept closer together and were more in contact with humans, causing abortions and still-births. Also, the high amount of abortions, still-births and neonatal deaths might be because the community was inexperienced and experimenting with sheep/goat management. The community at Hotu cave possibly managed both sheep and goat. Based on bone morphology it is impossible to make a distinction between foetal sheep and goat and it is often not possible for young animals (Martín & García-González 2015). The assemblage of Hotu is too small to draw a good comparison between the mortality profiles of sheep and goat, but both species were in general young (Table 2 and 3), indicating both were managed. It is common for modern day herders in the region to herd sheep and goat in the same flock (Ansari-Renani *et al.* 2013; Elliot *et al.* 2014).

It is unfortunate that the site mortality profiles, and size of the sheep and goat, cannot be compared with contemporary sites in the region to gain further understanding of sheep/goat management in the region. At Komishani Tepe both sheep and goat were present in the Epipalaeolithic and the Neolithic. However, the assemblage is too small to reconstruct mortality profiles or size patterns (Leroy *et al.* 2019).

6 Conclusions

There is clear evidence that the community at Hotu cave managed sheep and goat during the Early Neolithic. The high amount of perinatal remains of sheep/goat found in the Early Neolithic layers of Hotu cave indicates sheep/goat were kept in or close to the cave. Caves have been used to pen sheep and goat during the Neolithic in various places of the world. It is possible Hotu cave was used as a shelter for pregnant and young animals, which would explain the high number of perinatal remains. The high percentage of perinatal remains in the Early Neolithic might also be related to increased zoonotic diseases.

It is likely that both sheep and goat were managed during the Early Neolithic, since unfused young bones of both animals were present.

Both sheep and goat are also present in the Pottery Neolithic layers of the site. There is more evidence for a traditional young male cull management pattern in the Pottery Neolithic for both sheep and goat, but the sample size is limited. Based on stratigraphy there is a hiatus in occupation between the Early Neolithic and Pottery Neolithic, but not between the Epipalaeolithic and the Neolithic. The zooarchaeological assemblage, however, changes dramatically from dominated by gazelle in the Epipalaeolithic to heavily dominated by sheep/goat in the Early Neolithic (Figure 3). Whether this switch in the zooarchaeological profile indicates a hiatus in occupation between the Epipalaeolithic and the Neolithic levels, a shift in use of the cave from hunters' residence to herders' breeding stall, or the ingression of new peoples from the west bringing domesticated sheep/goat with them, remains to be established by further research. Such research should include enhanced identification of sheep versus goat using the ZooMS methodology (Pilaar Birch *et al.* 2019), characterisation of geographical origin and dietary history through stable isotope analysis, and situation of the aDNA of sheep/goat individuals from the Hotu assemblages within the wider context of Iran and beyond. Additional radiocarbon dates may also shed more light on the important developments from the Epipalaeolithic to the Neolithic at Hotu cave. Further work on zooarchaeological and other materials from Hotu and Kamarband caves has major potential to shed further light on the critical issue of local Neolithisation processes versus intrusion from outside of already well-developed practices of animal herding.

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Supplementary information

SI 1: Methods

Animal bones were collected using three different methods; hand-picking during excavation, dry sieving and flotation of excavated deposits. The entire heavy residue was collected and sieved to different sieve sizes and sorted with the naked eye for plant remains and other archaeological material, such as lithics, animal bones, beads and shells. Any plant remains found in heavy fractions were extracted and separated by size. Each float was dry-sieved in Endecott brass sieves into fractions of 1 mm and 250 µ. The relative abundance of the different species has been calculated based on NISP (number of identified specimens). All material was analysed at the University of Reading zooarchaeological lab, using the University of Reading osteological lab reference collection. Sheep and goat are osteologically very similar, so the criteria of Boessneck *et al.* (1964) were used to identify cranial bones, and Zeder and Lapham's (2010) criteria were used to distinguish post-cranial bones. When separation was not possible the bones were categorised as sheep/goat. No attempt was made to distinguish sheep and goat molars, since it has been shown to be unreliable (Zeder and Pilaar 2010). All possible anthropogenic modifications to the bones are recorded, as well as pathologies. Butchery marks were recorded following Binford (1981) and when necessary extra information was added. Measurements of the bones were taken following Von den Driesch (1976).

Age at death has been reconstructed based on bone fusion. Postcranial fusion ages from Zeder (2006) were followed for sheep and goat, since this system is based on caprines from Iran. The assemblage consisted of few mandibles suitable for a dentition-based age profile, so this approach was not included. The assemblage yielded a substantial amount of foetal and neonatal remains. These have been identified using the criteria of Prummel 1987a, 1987b, 1988. Martín and García-González (2015) presented a methodology for the identification of perinatal remains of sheep, which has been used for the perinatal remains of Ganj Dareh in combination with a foetal reference collection (Yeomans *et al.* 2021). The methods and pictures of Martín and García-González (2015) have been used to try to distinguish between foetal and neonate remains. Since the method is based on sheep only and the studied assemblage is likely to contain a mix of sheep and goat, and given the absence of an elaborate foetal remains reference collection, we did not attempt to ascertain gestation age.

To investigate possible young male kill-off, biometric data are used in addition to fusion-based age profiles. Goat exhibit a relatively high degree of sexual dimorphism while sheep are sexually dimorphic to a lesser extent. Therefore, male and female caprines can be distinguished based on the measurements of the long bones (Zeder & Hesse 2000). Considering the modest size of the dataset, the LSI (Logarithm Size Index) method is used to obtain a richer understanding of the size of the animals and the sex pattern. This is a logarithm to base 10 of the ratio between the measurement and its standard (Meadow 1999), which makes it possible to compare different elements, significantly increasing the dataset used for comparison. The standards published and commonly used in Near Eastern archaeology are the average measurements of goat from the Taurus mountains (Uerpmann & Uerpmann 1994) and modern wild sheep from Kermanshah, Iran (Zeder 2008, 263). Depth and breadth measurements are most influenced by sexual dimorphism (Zeder 2008), so those are plotted in the LSI diagrams. Skewness and kurtosis have been used to describe the shape of LSI diagrams. Skewness describes the asymmetry of the distribution of a variable, a skewness value of ‘0’ represents a normal distribution. Positive skewing shows a curve with a tail on the right of the mean, and negative skewing the opposite, a curve with a tail on the left. Kurtosis refers to the height of a distribution with positive values representing a tall peaked curve while negative values indicate a low peak in the distribution, and a value around zero would be a normal distribution (Arbuckle & Atici 2013, 223). The kill-off of young males is expected to be identified in results in the LSI data. A characteristic distribution for young male kill-off exhibits strong positive skewing and positive kurtosis (Arbuckle & Atici 2013, 223).

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SI 2: The NISP of the different animals per time period.

Animal	NISP Epipalaeolithic	% of total NISP	NISP of Early Neolithic	% of total NISP	NISP of Ceramic Neolithic	% of total NISP
Sheep/goat	5	4	214	69	123	72.8
Sheep	0	0	24	8	9	5.3
Goat	0	0	53	17	20	11.8
Gazelle	76	64	1	0	0	0.0
Wild boar/Pig	0	0	2	1	12	7.1
Aurochs/Cattle	1	1	4	1	1	0.6
Red deer	2	2	0	0	1	0.6
Fallow deer	3	3	3	1	1	0.6
Large cervid	12	10	0	0	0	0.0
Small cervid	1	1	5	2	0	0.0
Fox	1	1	2	1	2	1.2
Medium canid	0	0	0	0	0	0.0
Seal	17	14	0	0	0	0.0
Total	118		308		169	

Chapter 7: Discussion and Conclusion

7.1 Introduction – revisiting the aims and objectives

The first aim of this research was to obtain a fuller understanding of the initial steps towards animal management and how they led to animal domestication in the EFC. The second aim was to investigate whether and how animal management practices spread from the EFC eastwards to the Caspian littoral and beyond, or whether there was an autochthonous development of animal herding in this region. In this research I investigate how animal management practices varied locally and the possible reasons for any variation. To this end, changing human-animal interrelationships during the domestication process were investigated through analysis of biometry, kill-off patterns and stable isotopic analysis on zooarchaeological material. This integrated methodological approach enables the domestication process to be characterised with greater accuracy. My research has confirmed that the Neolithic transition and the first stages of animal management in the Zagros were regionally diverse (Arbuckle and Atici 2013; Arbuckle 2014). At the studied sites Ganj Dareh, Bestansur, Jarmo and Shimshara, management, domestication and adoption of different livestock species was a highly localized process. At the different sites management practices comprised penning, young male culling, as well as possible foddering and pasturing. These husbandry strategies, however, were not uniformly applied at all Neolithic sites in the Zagros region.

In this thesis the possible route of the spread of Neolithic lifeways from the Zagros eastwards, along the great High Road in the north between the central deserts to the south and the Alborz Mountains was also investigated. Analysis of the zooarchaeological assemblage of Hotu cave indicates that sheep/goat management was practiced in the Early Neolithic at *c.* 8000-7500 BC. It remains unclear whether these management practices were locally developed or whether domesticated or managed sheep/goat were introduced to the region from outside, for example from the Zagros region (Harris and Coolidge 2010).

In this Chapter, the evidence from each studied site will be discussed first, followed by a broader discussion of animal management and the transition to the Neolithic. I will first discuss my research on sites in the Zagros region, followed by sites in the Caspian Littoral. This Chapter will end with overall conclusions and recommendations for future research.

7.2 Neolithic animal management in the Zagros: discussion of the studied sites

Species abundancy at the studied sites in the Zagros is highly varied, as are possible management practices (Chapter 4, 5). At **Ganj Dareh**, caprines make up more than 90 percent of the NISP of the zooarchaeological assemblage, with goat outnumbering sheep on a 15:1 ratio. Analysis of the zooarchaeological assemblage shows focused kill-off of male goat between 1-2 years of age, while the females were kept alive for reproduction, which strongly suggests a managed herd (Hesse 1978; Zeder 1999; Zeder 2008). Male and female sheep, however, tend to reach an age well into maturity (Zeder 2008, 262), which supports the idea that these were hunted wild animals.

New re-excavations at Ganj Dareh and re-analysis of the zooarchaeological assemblage show the presence of foetal sheep/goat bones as well as hoofprints in mudbrick, providing further evidence for their presence on site (Darabi *et al.* 2019b, 51; Yeomans *et al.* 2021). In addition, dung spherulites are found in high abundancy (Yeomans *et al.* 2021, 6). Sequential analysis of oxygen isotopes in sheep/goat teeth from the site indicates that the sheep/goat were living in an area with strong seasonal changes, with cold and/or wet winters and hot summers with periods of drought (Chapter 5). This attribute is to be expected in the highlands of the Zagros Mountains. The fact that most molars give evidence for this strong seasonality indicates that no systematic transhumance took place, instead the goat were kept around the site year-round (Chapter 5). The range of the $\delta^{13}C$ values in the sampled molars of Ganj Dareh is also larger than at Jarmo and Bestansur (Chapter 5). This larger range in $\delta^{13}C$ values could indicate increased seasonality in the higher mountains, or a different type of grazing and browsing availability, as well as winter foddering. Phytolith analysis indicates the diet of the caprines mainly consisted of grasses (Yeomans *et al.* 2021, 7). C^4 grasses have been found in low abundance in phytolith assemblages of Ganj Dareh (Yeomans *et al.* 2021, 7), indicating the availability of these plant types, which could influence the patterns in $\delta^{13}C$. Inhabitants of Ganj Dareh closely managed the goat population and at least part of the flock of animals were penned on site. Pastoralist sheepherders nowadays often separate pregnant animals from the rest of the flock to give them extra care (Martín *et al.* 2016, 324). It is possible that only the pregnant and young animals were kept on site. However, based on the isotopic evidence and biometric data combined with mortality patterns it can be concluded that the overall flock was closely managed and likely kept in relative proximity to the site. There is no evidence the inhabitants of Ganj Dareh were experimenting with management of other animals.

At **Bestansur**, caprines are the most abundant in the zooarchaeological assemblage. However, based on NISP, in contrast to Ganj Dareh, sheep are more than twice as abundant as goat (Chapter 5). This feature is not exceptional for sites in the foothills of the Zagros

Mountains, where wild sheep were more abundant in the local environment than goat (Chapter 5). The bones suitable for LSI from goat at Bestansur came from animals which could have been young since the elements fuse at an early age. Therefore young male cull could not be ruled out. The goat at Bestansur are large on average and both male and female goat are present on site (Chapter 5). Based on bone fusion data a larger amount of younger goat have been found than sheep. Sheep all reached their full size and mainly prime adults seem to have been targeted (Chapter 5). Sheep of Bestansur are also large, and more males than females are present (Chapter 5), which indicates that they were unlikely to have been managed, rather prime adult large males appear to have been targeted. Preservation of bone collagen was not good enough for stable isotopic analysis and preservation of teeth enamel was only fair (Chapter 5). Therefore, there are not many complete sequences which could give an adequate representation of the diet of the caprines over the span of a year. However, the oxygen isotopic analysis from the samples of the better preserved teeth does indicate less severe seasonal changes at Bestansur than at Ganj Dareh. The stable carbon isotopic analysis combined with the oxygen isotope analysis indicates that the caprines stayed local throughout the year. These animals could be both caprines which were kept on site or close to the site by humans, as well as wild sheep, whose migration is dependent on food availability and shelter (Dwyer 2017, 204-5). Natural spring water sources at Bestansur could have been a favourable location for human settlement, as well as for wild sheep. However, it is quite likely some caprines, most likely goats, were kept on or close to the site by humans. Herbivore faecal material was found in occupational areas (Matthews *et al.* 2013; Elliott 2020), as well as a shed goat milk tooth (Bendrey *et al.* 2020, 321), indicating that goat may have been kept by humans on site or in close proximity to the site. After caprines, pigs are the most abundant animal in the zooarchaeological assemblage of Bestansur based on NISP (Chapter 5). As today, Bestansur was likely located close to a riverine forest during the Neolithic, which would have provided a favourable habitat for wild boar. The proximity to water sources associated with reeds and rushes would have been a favourable place where wild boar could shelter (Bendrey *et al.* 2020; Chapter 4).

The high abundance of pigs in the zooarchaeological record at Bestansur also indicates that they were of major dietary value. The bones of the pigs of Bestansur are very large compared to other sites, indicating they are morphologically wild. By contrast, many of the molars of the pigs of Bestansur are relatively small. The larger molars fall within the size range of the molars of Asiab, which are thought to be unmanaged wild boar (Chapter 4). However, the smaller group of molars are smaller than those of the Pottery Neolithic pigs of

Jarmo, where pigs are argued to be domesticated (Price and Arbuckle 2015). Teeth are less influenced by sexual dimorphism and decrease in size as a result of the domestication process earlier than postcranial elements (Rowley-Conwy *et al.* 2012; Zeder 2012; Zeder and Lemoine 2020, 7-8). Therefore, the small molars of the Bestansur pigs are likely to be an indication of early human management of pigs at Bestansur. The biological process behind the decrease in tooth size under domestication is unknown (Price and Hongo 2020, 22-3), so it is uncertain how human pig interaction at Bestansur could have caused this tooth size decrease (Chapter 4).

The kill-off pattern of the pigs from Bestansur is not representative of a managed population. In a managed herd it would be expected that most animals would be slaughtered before the age of two years (Hadjikoumis 2012). If people were actively keeping herds in the Neolithic, a larger part of the herd may have been kept alive, since the herds were usually smaller, and a greater percentage would be needed for reproduction, although an increase in juveniles in the archaeological record is still expected when a herd is managed (Chapter 4). Isotopic analysis of the pigs could not provide any further insights due to the poor preservation of the collagen (Chapter 4). Little is known about the diets of pigs at other sites, since, to date, no isotopic research has been conducted on Neolithic pig remains in Southwest Asia and collagen in bones in this area often does not survive.

It is striking that at Bestansur there are no young kill-off or no small body sized pigs, but that the pigs have small teeth. This association of attributes has not been attested at other Neolithic sites in the Zagros region. Faecal material of a pig has been found at Bestansur (Elliot 2020, 338), which indicates presence of a live pig at the settlement. So, even though the population at Bestansur does not show the young kill-off pattern associated with early management strategies, pigs were at least occasionally in close interaction with humans on site. Wild boar could have been attracted to the human settlement because of food availability, but it is possible this relationship developed further. Some animals might have been kept on site, but possibly they were still mixing with wild boar by the river or in marshlands. The pig/wild boar community might have been a hybrid community, as is still attested in different regions of the world nowadays (Price and Hongo 2020, 567).

Evidence indicates that the inhabitants of Bestansur were experimenting with animal management of goat and wild boar. Pigs at Bestansur clearly seem to be at a developmental stage in between wild and domestic. They have small teeth, but the inhabitants did not practice early kill-off and might have loosely managed the pigs.

Shimshara is the only Neolithic site known in the Zagros region where pigs are the most abundant animal in the zooarchaeological assemblage based on NISP (Chapter 4). It is probable that the environment around Shimshara, along the banks of the Lesser Zab, was even more favourable for wild boar than Bestansur (Chapter 4). Since the overall zooarchaeological assemblage of Shimshara is small, and limited data of the size and age of the pigs at Shimshara are available, it is hard to say more on the nature of the human-pig relationships at Shimshara. Also, little is known about the domestic status of the caprines, since the assemblage was too small to reconstruct reliable age or size patterns (Bendrey *et al.* 2020,).

Jarmo is the only site studied in the Zagros region with both pre-pottery and ceramic Neolithic phases. In both the Early Neolithic and ceramic Neolithic periods, goats were the dominant taxon in the zooarchaeological assemblage, followed by sheep. Young male cull of goat at Jarmo is practised in the Early Neolithic and ceramic Neolithic, however not to the same extent as at Ganj Dareh (Zeder 2008, 262). A shift towards young male cull for sheep is not seen until the ceramic Neolithic phase at Jarmo (Zeder 2008, 265). It is argued that sheep were unmanaged before then (Zeder 2008).

The molars from Jarmo sampled in this research could have derived from either sheep or goat. While the teeth enamel preservation was fair (Chapter 5), no bone collagen was preserved in sampled bones from Jarmo, so differences in stable isotopes ratios between the two species could not be studied. The combined oxygen and carbon stable isotope data indicate that most animals stayed in a similar environment year round, with no evidence for systematic practice of transhumance. At Jarmo there is no evidence for use of dung or penning deposits, so it is unclear if the animals were kept on site. The lack of evidence for dung and penning deposits is likely the result of the excavation strategy; micromorphology and the study of dung markers are more recent developments, not commonly practised when Jarmo was excavated in the 1940-60ies.

Wild boar remains made up 2% of the Early Neolithic assemblage at Jarmo, increasing to 7% NISP in the ceramic Neolithic at Jarmo. At Ceramic Neolithic Jarmo, 97% of the pigs were slaughtered before they reached an age of two years, suggesting that they were managed (Price and Arbuckle 2015, 444-5). The pigs at Jarmo are smaller than wild boar from earlier sites in the Zagros region, and they do not display the level of post-cranial and dental size diminution detected at later sites. However, the teeth from the specimens at Bestansur are smaller than those of Jarmo. At Jarmo, in contrast to Bestansur and Jarmo, even though pigs were managed in the ceramic Neolithic and possibly in the Early Neolithic (Price and Arbuckle 2015), they only made up a minor part of the food economy. These new data from recent excavations and the application of new methods to the previously studied assemblages of Jarmo and Ganj Dareh reinforce the interpretation that management practices and choice of species were not uniform throughout the Zagros region, but followed a highly localized process, dependent on environment as well as on cultural factors.

The evidence for localized animal management practices fits within former research of the region. At the early Neolithic site of Sheikh-e Abad (ca. 9800-9200 cal BC) goat were morphologically wild, but likely penned (Chapter 2). However, at the highland site of Asiab, slightly younger site than Sheikh-e Abad, no evidence for animal management has been found (Chapter 2). At the lowland site of Ali Kosh, the goats were managed, but this is management is only visible based on the kill-off pattern, where young males were culled (Zeder 1999, 2008). While, at lowland site Qermez Dere (ca. 8000 cal BC), no evidence for domestic animals or indications for management have been found (Dobney *et al.* 1999). This shows that during the initial stages animal management was developed at some sites (Figure 1.1), but did not homogenously occur in the Zagros region around and beyond at the same time.

7.3 Adaption of the Neolithic way of life, domestication and animal management on the Caspian Littoral

Little is known about the expansion of the Neolithic way of life from the Zagros eastwards, across the Iranian plateau, likely along the route between the central deserts to the south and the Alborz Mountains to the north, leading to northeast Iran, Turkmenistan and Central Asia. Few Neolithic sites of this region have been studied in detail (Chapter 2, 6), but the analysis of the re-excavated site of Hotu is shedding new light on the development of animal management on the Caspian littoral.

The studied site Hotu cave shows a clear transition in the zooarchaeological assemblage from the Epipalaeolithic to the Neolithic levels. The absence of sheep/goat in the Epipalaeolithic is in sharp contrast to their dominance of the zooarchaeological assemblage in later levels (Chapter 6, Figure 3). There is no evidence for a gradual transition towards reliance on sheep and goat, rather than gazelle, cervidae and seal, which were the most common species in the zooarchaeological assemblage in the Epipalaeolithic. The large amount of perinatal remains of sheep/goat in the Early Neolithic at Hotu indicates that they were kept at the cave or in close proximity to the cave. This association demonstrates that people were not solely hunting sheep/goat, but keeping control over their movement. Caves have been used as places to pen sheep and goat at various Neolithic sites around the world

(Martín *et al.* 2016; Miracle, 2006), and frequently infantile caprine bones have been found in such cave deposits (Boschin 2020; Tejedor-Rodríguez *et al.* 2021; Munro and Stiner 2015). It has been suggested that caves were used as locations for breeding flock (Martín *et al.* 2016, 323). Pastoralist sheepherders nowadays often separate pregnant animals from the rest of the flock to give them extra care (Martín *et al.* 2016, 324). It is uncertain whether all sheep/goat were kept in and close to the cave during the Early Neolithic, or whether the cave was mainly used as shelter for pregnant sheep/goat. The high number of foetal animals and neonates could be related to a separate flock kept in the cave. The high amount of neonatal sheep/goat found at Hotu cave is not attested at Ganj Dareh, Jarmo, Bestansur or any other Neolithic site in the Zagros region (Chapter 2, 5; Yeomans *et al.* 2021). The high amount of neonates at Hotu cave could be related to the cave mainly being used as a breeding site, but could also be because of increased zoonotic disease. Compared to the Neolithic sites in the Zagros, the caprines at Hotu cave might have been in closer proximity to humans because of restricted space in the cave site and diseases therefore could have spread more rapidly (Fournié *et al.* 2017).

The size of the sheep and goat indicate males and females were present in the zooarchaeological assemblage, so the cave does not seem to have been solely used for breeding flocks. Apart from the perinatal remains, the sheep and goat were slaughtered at a young age during the Early Neolithic. The mortality profile is very different from a hunted population where a focus on prime adults would be expected.

These data do suggest that the sheep and goat were managed in the Early Neolithic. The sudden transition from a zooarchaeological assemblage dominated by gazelle to a zooarchaeological assemblage almost completely made up of sheep/goat is compelling. This transition in the zooarchaeological assemblage could mean that a decline in gazelle, for unknown reasons but possibly because of over-hunting, led local people to exploit sheep/goat instead. Both wild sheep and goat were present in the regional environment in the Epipalaeolithic, as attested at Komishani Tepe and Kamarband cave, and wild sheep were present at Ali Tappeh and in small amounts at Hotu cave, so it is likely that they were available in the Early Neolithic (Chapter 6).

It is unfortunate that the mortality profiles, and size of the sheep and goat of Hotu cave, cannot be compared with contemporary sites in the region to gain further understanding of sheep/goat management in the region. At Komishani Tepe both sheep and goat were present in the Epipalaeolithic and the Neolithic. However, the assemblage is too small to reconstruct mortality profiles or size patterns (Leroy *et al.* 2019, SI). Because of this it is harder to say whether local management practices were developed.

The adaption of management practices was not uniform throughout the Zagros region so might also not have been along the Caspian coast. In contrast to Hotu cave, at Komishani Tepe, in the zooarchaeological assemblage sheep/goat are the most abundant animals in the Epipalaeolithic and the Neolithic. Stable carbon and nitrogen isotope analysis of sheep and goat bones does not show notable differences in diet between the Epipalaeolithic and the Neolithic levels (Leroy *et al.* 2019, SI). Few animal bones were found, so it was not possible to investigate changes in size and kill-off patterns.

At Kamarband cave, the species abundancy seems more similar to Hotu cave. Gazelle were the dominant species during the Epipalaeolithic, but sheep/goat were present too in the later Epipalaeolithic layers as well as aurochs and deer (McBurney 1969). In the Neolithic, sheep/goat are the most abundant species, making up the vast majority of the zooarchaeological assemblage (McBurney 1969). However, little is published about the kill-off patterns and size of the animals so it is unclear if they were managed. Wild sheep and goat were abundant in the local environment in the Epipalaeolithic (Chapter 2, 6), so it is possible local management developed in the region autochthonously (Leroy *et al.* 2019, 360), whereby local communities shaped their own transition from hunter-gatherer to farmer-herder. Another possibility is that a new group of people came in, bringing domesticates or managed animals with them. One argument suggests that settlers from the Zagros region could have been the incomers who introduced the Neolithic lifestyle, travelling eastwards along the Great Khorasan Road on the northern edge of the central plateau of Iran (Harris and Coolidge 2010; Roustaei and Gratuze 2020, 1; Matthews and Fazeli Nashli 2022,85-9). The presence of domesticated sheep at Obishir in southern Kyrgyzstan by 6000 cal BC (Taylor *et al.* 2021) suggests a relatively rapid spread of Neolithic herding practices eastwards across northeastern Iran and southern Turkmenistan. Intriguingly, aDNA from an individual from Hotu cave, found during the Coon excavations possibly from an Epipalaeolithic layer, shows genetic affinity with west Iranian farmers (Lazaridis *et al.* 2016), supporting the possibility of a Zagros origin for early herders of the Caspian coast. It is also possible that people brought a small number of animals with them, which then subsequently mixed with local wild animals.

7.4 Animal domestication and management

Animal management practices indicate a very local level in the nature of subsistence practices. Part of the difference in species abundancy and management strategies between the studied sites is related to the differences in environments for each of the studied sites, as also has been attested in the differences in species abundancy in the wider region (Chapter 4, 5). As mentioned, wild goat would have been more abundant in the higher Zagros Mountains than in the foothills. The abundance of goat, and the young male cull management strategy, correspond with a large abundance of goat. Wild goat were probably less abundant in the foothill surroundings of Jarmo and Bestansur. However, at Jarmo young male cull of goat was practiced as a management pattern, while it is not certain whether it was practiced at Bestansur. At both sites wild sheep seem to have been abundant and there is no evidence that they were managed. At ceramic Neolithic Jarmo, sheep management was practiced as one of the earliest sites in the Zagros region (Zeder 2008). Bestansur and Shimshara were favourable locations for wild boar, which could have encouraged the inhabitants of Bestansur and possibly Shimshara to experiment with wild boar/pig management strategies. However, at Jarmo, where pig management was practiced, the location was favourable too. Wild boar/pigs did not make up an important source of the food economy. The difference in relative abundance of pigs between Shimshara, Bestansur and Jarmo does not solely seem to be related to differences in environment.

Animal management strategies between sites in relatively similar environments may vary considerably. This point raises questions about the uneven pace of the spread of Neolithic technologies and practices. Differences in animal management practices were not solely related to differences in environment, but also to social and cultural factors. It is unclear whether people felt a sense of ownership over the animals they managed, either individually or as a community and if there would have been any exchange or trade in animals. Even though early animal management was a local process, we know from other evidence that Neolithic people were not living in isolation from each other. Material evidence from Neolithic sites of the region includes architecture, ground stone and chipped stone tools as well as special items that have clearly been traded or exchanged over considerable distances, such as beads of carnelian and seashell, and tools of obsidian (Connan 1999; Matthews *et al.* 2016, 221; Matthews *et al.* 2020; Richardson 2021).

At Hotu cave the Neolithic way of life may have been brought in by Neolithic communities from the Zagros region. However, the management strategies of sheep and goat at Hotu cave are different from those found in the Zagros. There is little evidence for Neolithic communities in the Zagros occupying caves or rock shelters (Chapter 2), except for Tang-e Bolagi in Fars (Matthews and Fazeli Nashli 2022, 62), while at the Caspian littoral this trait was common practice in the Epipalaeolithic as well as the Neolithic (Chapter 2, 6). So even if the animals and people came directly from the Zagros region, they developed their own practices of animal management in the Caspian littoral.

This local development of animal management practices fits well in the human niche construction as a framework for domestication, in which humans established resource catchment zones, with a more varied utilization of plant and animal species. Communities may have established ownership over resources and resource-catchment territories. Co-evolutionary relationships in niche construction activities do not necessarily lead to domestication. For niche construction to result in domestication a multi-generational relationship must develop. The maintenance of this relationship long term requires that both partners undergo modifications (Zeder 2016, 328). This multi-generational relationship between humans and animals seems to have occurred at Ganj Dareh, Jarmo, Bestansur and Hotu cave.

7.5 Concluding remarks and suggestions for further research

This research has shown that it remains essential to study each site in its own right to further our understanding of the transition from hunting to herding, and the extent to which local environments and cultural traditions influenced early management and domestication practices and processes. Some form of goat management seems to have been practiced at Bestansur based on spherulites, dung and shed deciduous teeth. The data of Bestansur suggest that the relationship between pigs and humans was possibly different from a strict hunter/prey relationship. The animals are very large but do have small molars relative to their body size. Most pigs were slaughtered above an age of two years old, so there is no culling of young animals, which might be expected in a managed herd. It is possible that the pigs were wild, but some experimentation with management strategies seems to have been underway. Young pigs were present at the site and the evidence for pig faecal material indicates that they were probably brought to the site alive or kept there. Also, pigs could have been attracted to the human settlement. Domestication may take several millennia, and these site assemblages could represent examples where the animals are somewhere within this process.

At Ganj Dareh there is evidence for quite intensive human management of goat, keeping animals close to the site and maintaining control over the breeding population. At Jarmo there is also some young male culling of goat visible, but it is not as pronounced as at Ganj Dareh, although this might be due to a recovery bias. At Jarmo, early pig management seems to have been practiced too, however, no clear evidence for pig management is found before the ceramic Neolithic period (Price and Arbuckle 2015). Also, in contrast to Bestansur pigs did not make up a large part of the food economy. Sheep did not seem to have been managed before the Ceramic either, as it has not been attested at any site in the Zagros region.

There is clear evidence for sheep/goat management at Hotu cave, based on mortality patterns. However, it is unclear whether these management practices were an autochthonous development or whether they were introduced. Additional radiocarbon dates may also shed more light on the important developments from the Epipalaeolithic to the Neolithic at Hotu cave. Further work on zooarchaeological and other materials from Hotu and Kamarband caves has major potential to shed further light on the critical issue of local Neolithisation processes versus intrusion from outside of already well-developed practices of animal herding.

Characterisation of geographical origin of animals and possible animal trade throughout the Zagros and the Caspian littoral could be further investigated by strontium and sulphur isotopic analysis, which has been successfully applied to research livestock mobility and trade in various other regions of the world (e.g. Thorton 2011, Madgwik *et al.* 2019; Sabatine *et al.* 2022). Sulphur and strontium isotopic analysis has not been widely applied in Southwest Asian archaeology, so isoscapes for the region have not yet been developed.

Further insights into animal management practices could be determined by identification of sheep versus goat using the ZooMS methodology (Collins *et al.* 2010; Pilaar Birch *et al.* 2019). Species identification of mandibles of caprines would enable us to reconstruct sheep/goat specific mortality profiles based on dental wear and eruption. In addition, it would make it possible to differentiate sheep and goat movement and diet based on sequential isotopic analysis on molars. This evidence would further the understanding of management practices considerably.

Also, the further development of aDNA could shed new light on the dispersal of domestic and managed animals. Initial research has demonstrated that multiple genetically different wild goat were domesticated in a dispersed process that resulted in genetically and geographically distinct Neolithic goat populations in the Fertile Crescent (Daley *et al.* 2018). Similar research at Iranian sites beyond the Zagros could possibly indicate whether domestication is an autochthonous development. At Ganj Dareh evidence for a duality in goat genomes that likely reflects diverged hunted and herded animals has been found (Daly *et al.* 2021). This type of aDNA analysis at multiple sites throughout the region could give more insight into animal management, hybridization and origin of populations.

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