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Wool they, won't they: Zooarchaeological perspectives on the political and subsistence economies of wool in northern Mesopotamia

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ABSTRACT

An important facet in the study of complex societies involves documenting how the extraction of resources to support political structures (the political economy) impacted the subsistence economy of everyday life. Caprine production was a central feature of ancient Mesopotamian subsistence, while ancient texts reveal that wool was centrally important to the region's political economies. It has long been thought that at some point in the Chalcolithic or Bronze Age (c. 4500–1500 BC) caprine husbandry was reorganized at the regional level to support the wool industry that was so dear to state finance and elite wealth. Here, we use kill-off patterns and biometrics to test whether caprine husbandry patterns across northern Mesopotamia underwent a regionwide transformation. We synthesize existing data and use Bayesian modeling to estimate average sheep size, male–female ratio, and harvesting patterns targeting older sheep. We confirm previous assessments that document an increase in sheep size in the 4th millennium BC. We find no pattern in male–female ratios. Diachronic kill-off data from across the region show subtle and local shifts in the slaughter of older caprines. While ambiguities in the data persist, there is no evidence of a dramatic shift toward intensive wool production at the regional level.

1. Introduction

In complex societies, the economy can be heuristically divided between the *political economy*, or the direction of surplus labor towards the accumulation and reproduction of power, and the *subsistence economy*, the expenditures of labor in activities that pattern and reproduce daily life (Johnson and Earle, 2000, pp. 11–15). The subsistence economy is usually organized through kinship and most often at the family or household level. The political economy draws surplus labor or its fruits from families. It feeds, in essence, off the subsistence economy.

A key issue in economic anthropology and history is how, specifically, the political economy relates to the subsistence economy. In the capitalist era, for example, the production of oil, plastics, and other petroleum-derived materials has revolutionized transportation, household labor, the packaging and availability of food, and many other aspects of subsistence. But oil production also figures in the political economy in profound ways: augmenting a class of billionaires, many with fingers inserted deep into political pies (e.g., the Koch family), and transforming once marginal polities into global players (e.g., the Gulf states) — all the while precipitating a global climate catastrophe that might bring the whole system crashing down on itself.

In the past, like oil today, animal fibers drew the political and subsistence economies into unique relations. The fibers of many species can be readily collected, spun, and woven into cloth. Clothing has an obvious use-value in the subsistence economy, but it also can materialize social identity (e.g., Costin, 1998), making it ripe for the political economy. In the Andes, textiles made from camelid fibers constituted a "technology of power" (Lechtman, 1993, p. 251), with the Inka state controlling herds, sequestering female weavers, taxing communities in textiles, and giving gifts of cloth to elites and subjects (Costin, 1998; Lechtman, 1993). On the other side of the world, in late medieval England and Europe, large-scale wool production and trade promoted the division of labor, technological innovation, wealth accumulation, the development of elaborate financial instruments, and the concentration of capital — thus laying much of the groundwork for industrial capitalism (e.g., Arrighi, 1994; Braudel, 1981; Gimpel, 1976). By the 19th century, to fuel the textile industry, the expansion to new "sheepscapes" (Gulliford, 2018) in the American Southwest and Australia went hand-in-glove with imperialism and settler colonial nation-building. An empirical question is how these and other political economic processes

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influenced the everyday herding strategies that underpinned pastoral subsistence.

As the cradle of sheep domestication, Greater Mesopotamia can lay claim to being the original “sheepscape.” It has been characterized as a “land of wool” (Breniquet and Michel, 2014, p. 1). Ancient texts reveal that wool was among the most important commodities in trade and that the large-scale production of woolen textiles by palaces and temples was a key component of state-building (e.g., Adams, 1981, p. 11; Algaze, 2008, p. 92; Michel, 2014, p. 233). As it did in England in the medieval period, and many other regions in other times, wool helped the Mesopotamian ruling class grow rich and extend its power.

Some have suggested that wool revolutionized both the political and subsistence economy in ancient Mesopotamia and beyond. Sherratt’s (1983, 1981) “secondary products revolution” posited that wool, milk, and traction power formed a unique package of products derived from living animals. Their production, so the model suggests, spurred on economic expansion by providing more efficient means of subsistence production, which in turn supported higher populations, while offering an avenue along which elites could profitably invest surplus labor (see also Greenfield, 1988; Halstead and Isaakidou, 2011). In another influential paper on wool production, McCorriston (1997) focused on the land-extensive and ostensibly male-dominated nature of animal husbandry in Mesopotamia. She alleged a shift in textile material from vegetable fibers (namely flax) to wool and hypothesized that this shift impacted gendered relations of production within the subsistence economy of households. These transformed gender relations subsequently set the conditions for alienated female labor to be exploited in a political economy which supported temples, elite manors, and palaces.

Decades of zooarchaeological work put us in a position to evaluate these hypotheses, which pertain to the impact upon the subsistence economy of the use of wool in the political economy. Zooarchaeological data complement the textual records. If texts by-and-large reveal elite preoccupations and managerial systems (in other words, they more directly reflect the political economy), zooarchaeology is more representative of general economic activity (the combination of the political and subsistence economies) (Halstead, 2003). Animal remains offer time-and space-averaged reflections of everyday herding activities, albeit ones impacted by taphonomic and depositional/aggregation factors. Thus, although the historical importance of animal fibers in the political economy of Mesopotamia cannot be denied, we do not know if or how it altered herding strategies. Similar questions have been asked concerning wool production in other contexts, especially the Aegean (Firth, 2014; Halstead, 2003, 1999).

Can we detect a general shift in which herders across the region adopted husbandry strategies more geared towards maximizing wool exploitation from their sheep? To begin to answer this question, we first offer a critical review of common zooarchaeological methods employed to investigate wool production, specifically age-at-death (or kill-off) and biometrical data. Second, we synthesize the published zooarchaeological data from Neolithic through Middle Bronze Age northern Mesopotamia to identify any widespread shift in caprine husbandry practices.

1.1. *Caprines through time: The northern Mesopotamian chronology*

The herding of sheep and goats (caprines) has long played an important role in the subsistence and political economies of northern Mesopotamian (Fig. 1; Table 1). Pre-Pottery Neolithic villagers across the Fertile Crescent domesticated sheep, goats, and other animals by around the 8th millennium BC (e.g., Arbuckle and Hammer, 2019; Peters et al., 2017). Sheep and goat remains regularly make up half or more of the faunal remains from archaeological sites from this time onwards (Arbuckle, 2014b, p. 67). Managing caprines was thus a major facet of the subsistence economy, one that offered diverse returns. Caprines not only converted grass into meat and milk, but also contributed their dung for manure and fuel (Düring, 2013, pp. 84–85; Miller, 1984; Styring et al., 2017). To encourage herd growth and mitigate against catastrophic loss, Neolithic herders must have carefully strategized herd

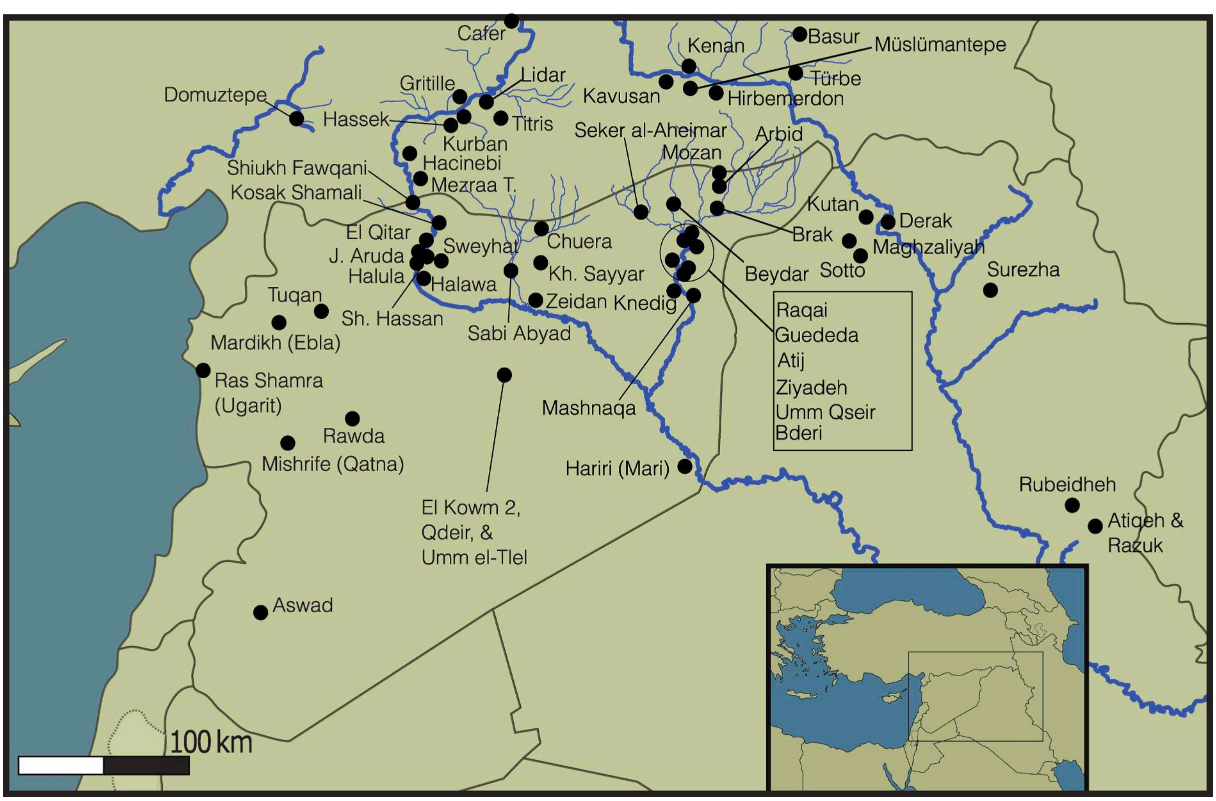

Fig. 1. Map of northern Mesopotamia with sites included in this study.

Table 1
Archaeological Periods in Northern Mesopotamia based on (Akkermans and Schwartz, 2003; Hole, 2001; Ur, 2010).

Period	Date BC (approx.)	Remarks	Analytical Grouping
Pre-Pottery Neolithic	9700–7000	Domestication of plants and animals; sheep and goat domestication by c. 8000 BC	Neolithic
Pottery Neolithic	7000–5900	Small agricultural villages	
Halaf	5900–5200	Egalitarian villages	Halaf
Ubaid	5200–4500	Emerging economic specialization and (in some places) inequality; no political centralization	Ubaid
LC 1	4500–4200		LC 1–3
LC 2	4200–3800	Political centralization; (Proto) urbanism	
LC 3	3800–3700		
LC 4	3700–3300	Uruk Expansion into North	LC 4–5
LC 5	3300–3100	Collapse of Uruk System; decentralization; earliest writing in the South	
EJ 0	3100–2900	Kura-Araxes Expansion into Upper Euphrates and Iran	Early Bronze Age (EBA)
EJ I	2900–2600	Ninevite V tradition in Khabur and northern Iraq	
EJ II	2600–2500	(Re)emergence of urbanism	
EJ III	2500–2300	Expansion of political power of N. Mesopotamian states; Ebla Palace G (and texts)	
EJ IV	2300–2100	Akkadian period	
EJ V	2100–2000	Post-Akkadian; abandonment/ contraction of some sites	
MB I	2000–1800	Old Assyrian merchant colonies at Kanesh	Middle Bronze Age (MBA)
MB II	1800–1600	Settlement size increase/ centralization; Zimri-Lim of Mari; Hammurabi of Babylon	
LBA	1600–1200	Middle Assyrian period; low levels of urbanization in northern Mesopotamia	

management. A common tactic involved killing off young males (less than 1–2 years old) in order to maximize the number of reproductive females supportable under existing labor and land resources (Arbuckle and Atici, 2013; Zeder, 2006). These strategies were successful. By the 7th millennium BC, domestic caprine husbandry had expanded across the Fertile Crescent and Anatolia, and had pushed into the Caucuses, Europe, Africa, and the Iranian Plateau (Arbuckle and Atici, 2013; Zeder, 2017).

It is unknown when people first exploited sheep or goats for their hair, but it likely began sometime between 7000 and 4000 BC. This period also saw significant sociopolitical change. In the Pottery Neolithic and Halaf periods (c.7000–5200 BC), more-or-less egalitarian villages practicing mixed agropastoralism, with a non-insignificant contribution of hunting, were spread across northern Mesopotamia (Frangipane, 2007; Grossman and Hinman, 2013). It is possible that exploitation of caprines for fibers was already part of the agropastoral subsistence economy. Some Late Neolithic sites, such as El Kowm 2 and Tell Halula have evidence for delayed kill-off (Saña and Tornero, 2012; Vigne and Helmer, 2007), while the presence of spindle whorls at Tell Sabi Abyad may provide another line of evidence for animal fiber exploitation (Rooijakkers, 2012). In the Ubaid and LC 1 periods (5200–4200 BC), two-tiered site hierarchies and craft specialization appeared in some parts of the region, but there is little clear evidence for leadership and limited evidence for differential wealth accumulation (Fisher, 2017; Stein, 2012). Woolen textiles may well have been part of an overall shift towards specialized craft production, one which would ultimately set the stage for elite accumulation. Occasional evidence for delayed kill-off (e.g., at Kosak Shamali; Gourichon and Helmer, 2003) and small spindle whorls (Price et al., 2021; Sudo, 2010) might indicate wool exploitation expanding at this time. Possible supporting evidence comes from an increase in sheep size in beginning around this time (Vila and Helmer, 2014).

Evidence for heritable wealth inequality, differentiated settlement patterns, economic specialization, and wool production is more obvious in contexts after about 4000 BC. Heritable status (e.g., prestige goods in child burials), large scale public architecture, and urban-sized settlements occurred across the region in the Late Chalcolithic 2 (LC 2) and LC 3 periods (Frangipane, 2018a; Lawrence and Wilkinson, 2015; McMahon, 2020; Stein, 2012; Ur, 2010). This relatively rapid formation of cities and states paralleled similar developments in southern Mesopotamia and Iran (Frangipane, 2018a). In the north, small spindle whorls, ideal for spinning wool, predominate over larger ones at archaeological sites (McMahon, 2020, p. 302).

By the middle of the 4th millennium BC (LC 4), southern Mesopotamian influence extended into the north — the so-called "Uruk Expansion." Southern Mesopotamian people ("colonists") established enclaves at Habuba Kabira, Area A of Hacinebi, and other places (Algaze, 1993; Stein, 1999). It has been hypothesized that these "colonists" may have been seeking either pasture for their sheep or access wool trade networks. Certainly, texts and glyptic evidence (cylinder seal design) indicate that the production of woolen textiles was a central concern of southern Mesopotamian political institutions (Algaze, 1993; Keith, 1998; Wright, 1989).

The beginning of the 3rd millennium BC saw deurbanization and the disappearance of southern Mesopotamian-related material culture in the north. Around 2600 BC, however, populations again nucleated in settlements across the region. In some cases, e.g., Tell Hamoukar in the Khabur region, rural settlements declined as people moved to urban centers; in others, e.g., Titriş Höyük in the Karababa Basin, urbanism coincided with a growth in rural settlement, signaling immigration into previously marginal regions (Lawrence and Wilkinson, 2015). Some of these cities, such as Ebla and Nagar (Tell Brak) exerted considerable political control. And while pork constituted a heavy fraction of the diet, particularly in the largest cities located in the Khabur Drainage (Price, 2021, pp. 64–76), sheep and goats were the predominant livestock animal across the region.

Wool played a definitive role in the more fully urbanized political economies of the Early Bronze Age. Across Mesopotamia, cuneiform texts of the 4th and 3rd millennium BC depict large-scale production of woolen textiles — a production that relied on the surplus, and often unfree, labor of women and children (Corcoran-Tadd et al., 2023; McCorriston, 1997; Pollock, 1991; Zagarell, 1986). Admittedly, northern Mesopotamian sites have produced far fewer textual records than southern ones. However, the palace archives at Ebla (c. 2400 BC) indicate flocks of sheep and goats in the 10,000 s or even 100,000 s. Ebla's palace also organized and oversaw the production of woolen textiles (Biga, 2014; Peyronel, 2014).

The political economies of the Bronze Age can be described generally as "domain states" — that is, the secular and religious institutions of "the state," such as it was, owned flocks and land, which they worked with corvée and unfree labor or, later on, which they rented out to farmers/ herders (Jursa and Moreno García, 2015). There was not necessarily any coordination between different institutions, such as temples and elite manorial estates. Moreover, temples, palaces, and other elite institutions did not own *all* land and livestock; it is unclear what proportion they owned in different periods and regions across the Near East, although it was a significant percentage (e.g., Foster, 1981; Pruß and Sallaberger, 2004). In any event, caprines were key assets of the elite estates. Not only was wool given to dependent laborers for their subsistence and gifted to elites, but raw wool and textiles were often consigned to merchants to exchange for silver (Englund, 2012; Michel, 2014, p. 244). Wool represented a significant source of income. For example, at Umma in the Ur III period (2112–2004 BC), wool represented 25–50 % of the total value of goods consigned to merchants (Sallaberger, 2014, p. 98).

Urbanism in northern Mesopotamia peaked in the late 3rd millennium BC, after which occurred a period of at least partial deurbanization around 2200–2000 BC. Cities rebounded, but did not fully recover, in the early second millennium (Middle Bronze Age). Across Mesopotamia, the political economy of the Middle Bronze Age was different in other ways. Exploitation shifted from corvée obligations to taxation/tribute as temple and palace estates were increasingly rented to farmers (Hudson, 2000; Jursa and Moreno García, 2015). The period also saw the expansion of markets and the emergence of the Old Assyrian trading network that operated across northern Mesopotamia and Anatolia. Wool continued played a central, sometimes dominant, role in the political economy. Texts from Mari and the Old Assyrian merchant colony of Kanesh reveal a long-standing trade in wool and metals (Atici, 2014a; Michel, 2014). Indeed, the mercantile family firms of Assur built their wealth on the inter-regional counter-circulation of metals for woolen textiles, thereby cementing their positions at the top of the Assyrian oligarchy (see Aubet, 2013, pp. 293–295). They also dealt in raw wool produced locally in Anatolia, although they did not have a monopoly on the trade (Lassen, 2010).

1.2. Evaluating zooarchaeological documentation of intensive wool production

Several zooarchaeological methods can answer questions pertaining to the effect of the political economy on the subsistence economy. However, zooarchaeological data, while free of the biases that affect texts, are bound by their own set of limitations. It is important to stress that zooarchaeological datasets reflect the "death assemblage," not living herds (Meadow, 1980). The death assemblage is not equivalent to a census of the animals living in a herd at any one time and is subject to aggregation issues, potentially including different depositional locations for remains of young and old, male and female individuals. For example, if animals of several specialized herds (e.g., one for meat and one for wool) were brought to a central location for slaughter, the resulting death assemblage would be a homogenous mixture, making assessment of one particular strategy difficult.

It is also important to note that, contrary to what many non-specialists believe, these zooarchaeological methods cannot determine whether wool was or was not produced at a site, when people first exploited animal fibers, or when the mutation for a woolly undercoat first appeared in sheep. Rather, the zooarchaeological methods reviewed here indicate husbandry strategies. They can tell us when there was a shift to *intensive wool production in time- and space-average deposits*— that is, the general adoption of sheep management strategies that maximize the output of wool — at some point in the archaeological sequence.

1.2.1. Sheep-to-goat ratio

An early approach to wool production was the sheep-to-goat ratio. It assumes a shift in the composition of herds towards sheep in an archaeological sequence indicates a transition to intensive wool production and is usually calculated from the number of identified specimens (NISPs). For example, in Iran, Hole and Flannery (1967), Bökönyi (1977, p. 6), and Davis (1984) argued for wool production based on the higher relative number of sheep in the 6th millennium BC.

The strength of this approach is its ease-of-use. But equifinality limits its interpretive power. Raising more sheep may reflect a variety of cultural, dietary, or environmental processes (Redding, 1984). Moreover, in places where sheep have predominated since the Neolithic, the sheep-to-goat ratio is less useful. Northern Mesopotamia is one such place — therefore we do not utilize this approach here.

1.2.2. Age-at-death

Age-at-death (or kill-off) analysis is a "demographic" approach that gained particular traction after Payne and Deniz's pioneering ethnoarchaeological work on goat herders in Turkey (Deniz and Payne, 1982; Payne, 1973). Their work not only provided a method for ageing dental remains by their wear patterns and eruption sequences, but also demonstrated the age and sex composition of herds managed for specific products. When the goal is meat production, herd security, or milk production, herders tend to slaughter males as they approach adult size, which is around 1–3 years of age (Cribb, 1984; Hadjikoumis, 2017; see also Redding, 1981). Such a strategy maximizes resources available to reproductive females, the major factor affecting herd growth (e.g., Hadjikoumis, 2017; Payne, 1973). The result in the death assemblage is a kill-off profile skewed towards younger animals.

Herders seeking to increase the wool output of their flocks would be attracted to keeping more animals (especially males) into adulthood. They can accomplish this by castrating males. Castration has three important effects. First, it tempers male aggressive behavior. Second, since males are larger than females, wethers produce heavier fleeces than ewes. Third, castrates tend to have finer wool than ewes or rams (Halstead and Isaakidou, 2011, p. 68). Thus, herders engaged in the intensive production of wool often keep a high proportion of castrates well into adulthood, resulting in the kill-off profiles of death assemblages being skewed toward older animals. Indeed, zooarchaeologists working across SW Asia have interpreted old-skewed kill-off as wool production at a range of sites dating to the 5th through 3rd millennia BC (Arbuckle, 2014a; Bigelow, 2011, 1999; Gourichon and Helmer, 2003; Grigson, 1995; McMahon et al., 2007; Payne, 1988; Piro and Crabtree, 2017; Wattenmaker, 1987) and sometimes earlier (Helmer et al., 2007; Saña and Tornero, 2012).

Several analytical problems face the age-at-death analysis. First, kill-off is typically analyzed at the taxonomic level of caprines, rather than separated between sheep and goats, due to difficulties in separating the mandibles of the two species (Gillis et al., 2011; Zeder and Pilaar, 2010). Second, there is little standardization in the cleaning of data, such as "allocating" isolated teeth to age classes (Payne, 1973, p. 296), or how to interpret kill-off profiles in a statistically robust manner (Marom and Bar-Oz, 2009; Price et al., 2016). Finally, it is worth pointing out that several ethnographic studies have shown that herders focused on the production of wool might not adopt the wool-maximizing strategies outlined by Payne (1973), but tend to stick to strategies that would be classed by zooarchaeologists as following a "meat" or "milk" profile (Bates, 1973; Chang and Koster, 1986; Halstead and Isaakidou, 2011, p. 64).

1.2.3. Sex

Another way to get at the demographic parameters expected in a herd geared toward wool production is by estimating the sex ratio, with the assumption that such herds will have a high proportion of adult males. Caprines are sexually dimorphic in their pelves, horn cores, and in the general size of bones. Ratios of male and female pelves and horn cores can be assessed in large assemblages (e.g., Stein, 1988, pp. 186–187), but small samples limit their applicability. In recent decades, zooarchaeologists have attempted to work around this problem by conducting mixture modeling of biometrical data to estimate sex ratios (Arbuckle, 2014a; Price et al., 2021; Vila and Helmer, 2014). A problem with mixture modeling — one experienced by us and conveyed to us by colleagues — is that statistical software using maximum likelihood techniques often fails to detect a bimodal distribution in the data. In other cases, they produce results that "don't make sense" (e.g., where male and female means are too close to one another). This is likely due to the "noisiness" of biometrical data and sample sizes. More concerning, however, is that results that "don't make sense" usually go unreported (Wolfhagen, 2023). With only its successes published, mixture modeling appears sounder than it is.

1.3. Sheep size

A final approach is the use of biometrical data to identify different populations of sheep. One can assume that intensive wool production would eventually lead herders to adopt better wool-producing populations of sheep (Harding et al., 2023; Vila and Helmer, 2014; Zeder, 1994, p. 116). The success of the Merino sheep and its related varieties in the 19th century is case-in-point. In northern Mesopotamia, Vila and Helmer (2014) present astragalus measurements from 6th-3rd-millennium-BC sites. Detecting an uptick in body size in the 5th millennium BC and then a decline in the 3rd millennium, they speculate that these population-level size changes were linked to wool exploitation. One problem is that the association between new populations of sheep and wool-bearing qualities remains hypothetical, and that population-level size change may indicate any number of other processes (e.g., change in nutritional plane). Additionally, such approaches rely on accurate discrimination of sheep and goat remains, as well as differentiation within biometrical distributions of males and females.

2. Data and methods

We collected sheep/goat kill-off data and sheep biometrical data from northern Mesopotamian sites spanning the Pre-Pottery Neolithic through Middle Bronze Age, using published articles and Open Context (https://opencontext.org). All data and analytical scripts are available on GitHub (https://github.com/wolfhagenj/woolmixmod).

We relied only on caprine mandibular eruption and wear data. We did not include epiphyseal fusion data. Although some studies differentiated sheep and goat mandibles, due to the variability in methods of separation and their documentation, we did not treat sheep and goat kill-off separately. Most of the data were coded using Payne's (1987, 1973) tooth wear scheme, but some publications used Habermehl's (1975) method.

Payne's (1973) model of wool-focused herding strategy entails a survival rate of 40–50 % past four years (age class G) compared to c. 25 % for milk or meat. We therefore summarized each assemblage with a single metric (%GHI) representing the proportion of mandibles in age classes G, H, and I. This was equivalent to M3++ and M3+++ scores in Habermehl's (1975) method. In cases with non-integer mandible numbers (which can occur when "allocating" teeth (see Payne, 1973, pp. 295–296)), the value was rounded to the nearest whole number. Together, the dataset includes 77 assemblages, with sample sizes ranging from 12 to 644 mandibles (see Supplemental Table 1).

While we provide the empirical data, our analysis relied on Bayesian binomial regression models of %GHI for each assemblage to account for uncertainty due to sampling variation (see GitHub link for details). Additionally, it uses a multilevel structure to summarize variation in % GHI values within and between analytical periods. The multilevel structure produces estimates of the average and standard deviation of % GHI values for each site. These estimates are then used to estimate the expected frequency of "old-dominated" (i.e., %GHI ≥ 40 %) per period.

A higher relative frequency of old-skewed sites across the region in a particular time period can be taken as an indication that large-scale wool production impacted herding strategies; in other words, that the political economic significance of wool affected the subsistence economy such that wool production was maximized on a regional level. But there is an important caveat. In an urban system, one could expect villages and nomadic groups to "provision" cities and their religious/political institutions with young and prime-aged males (c. 6–36 months), while older animals are left in the villages and culled off (Stein, 1988; Zeder, 1991). This could lead to one of, or a combination of, two patterns: first, assemblages from urban sites may not be old-skewed, even if wool production were maximized on a regional level; second, villages may show old-skewed assemblages, that in fact consist of old females, not males, thus presenting a false signature of intensive wool production (Stein, 1988). The only opportunity our data afforded to examine a synchronous urban system was age-at-death data from four Early Bronze sites (Titriş, Kurban, Gritille, and Lidar Höyük) in the Karababa Basin in southern Turkey.

Our biometrical dataset consists of 3033 sheep (*Ovis aries*) measurements from 2363 specimens, across 32 assemblages (see Supplemental Table 2). Biometrical data were collected only those elements that show a high reliability of correct identification to sheep or goat (see also Wolfhagen and Price, 2017; based on Zeder and Lapham, 2010), and we collected thirteen measurements (following von den Driesch, 1976): distal breadth of metapodials (Bd), length and proximal breadth of first phalanges (Glpe, Bp), length and proximal breadth of second phalanges (GL, Bp), distal breadth of astragali (Bd), distal breadth and trochlear breadth of humeri (BT, Bd), proximal breadth of radii (Bp), and distal breadth of tibiae (Bd). The measurement data were converted to log-size index (LSI) values (Meadow, 1999; Wolfhagen, 2020), using the average size of male Soay sheep from Clutton-Brock et al. (1990), drawn from the "zoolog" R package (Pozo et al., 2023). Fig. 2 displays the LSI values for our biometrical dataset, showing substantial variation between sites and periods, prompting our use of mixture modeling to analyze this variation.

Following Wolfhagen's (2023) methodology, we modeled biometrical data as a mixture of immature, (adult-sized) female, and (adult-sized) male animals using a Bayesian multilevel mixture model. Even though unfused bones are rarely measured, immature animals (i.e., those not having reached adult size) can be included in a set of measurements when fused early-fusing bones are measured. The model allows the inclusion of non-metrical sex data (namely the ratio of male-to-female pelves) to be included in the estimate of sex ratio. Fig. 3 provides an example from Late Chalcolithic 1–3 Tell Surezha. Observed proportions of immature animals were derived from rates of unfused first and second phalanges of sheep/goats at each site (see Supplemental Table 3). These elements fuse between 12 and 18 months of age. Observed proportions of the adult sex ratio were re-derived from (caprine) pelvis bones with sex identifications (see Supplemental Table 3). We modified the Wolfhagen (2023) model to produce period-specific estimates of the mixture model parameters, allowing us to compare the average size of animals and the expected proportion of males in measurement assemblages from these periods.

3. Results

3.1. Sheep body size

Fig. 4 shows modeled average female body sizes averaged across analytical periods. The trend is non-linear. Size decreased between the Neolithic and Halaf periods, in line with expectations of domestication. There were no data available from the Ubaid period, but between the Halaf and the Late Chalcolithic 1–3 mean female LSI values *increased* from 0.031 to 0.095; this is a roughly 7 % increase in body size measurements. Mean female size increased further in the Late Chalcolithic 4–5 to 0.13. The Early Bronze Age is a key period for urban development and the political economic importance of wool. Average female body size decreased between the LC 4–5 and the Early Bronze Age. Body size appears to increase again in the Middle Bronze Age (mean female LSI = 0.12).

Site-specific estimates of female size are shown in Fig. 5. They corroborate the patterns in Fig. 4, but also show some variation between sites, especially in the Early and Middle Bronze Age. Our nine Early Bronze assemblages include urban settlements (e.g., Tell Mozan) and a few hinterland sites (e.g., Tell al-Raqa'i), although we do not have metrical data from complementary sites within the same urban system. The most notable of which is that sheep from Tell Mozan (mean female LSI = 0.00) were smaller than animals from contemporary sites (EBA mean female LSI = 0.08). Interestingly, although the raw data were not published and therefore could not be included in this study, Doll's (2010, p. 230) bar charts seem to indicate that around 75 % or more of caprines were culled after four years of age in every phase from the mid-3rd through early-2nd millennia BC. If so, this is an extremely old-skewed kill-off profile.

In the Middle Bronze Age, Fig. 5 shows that most of the sites with

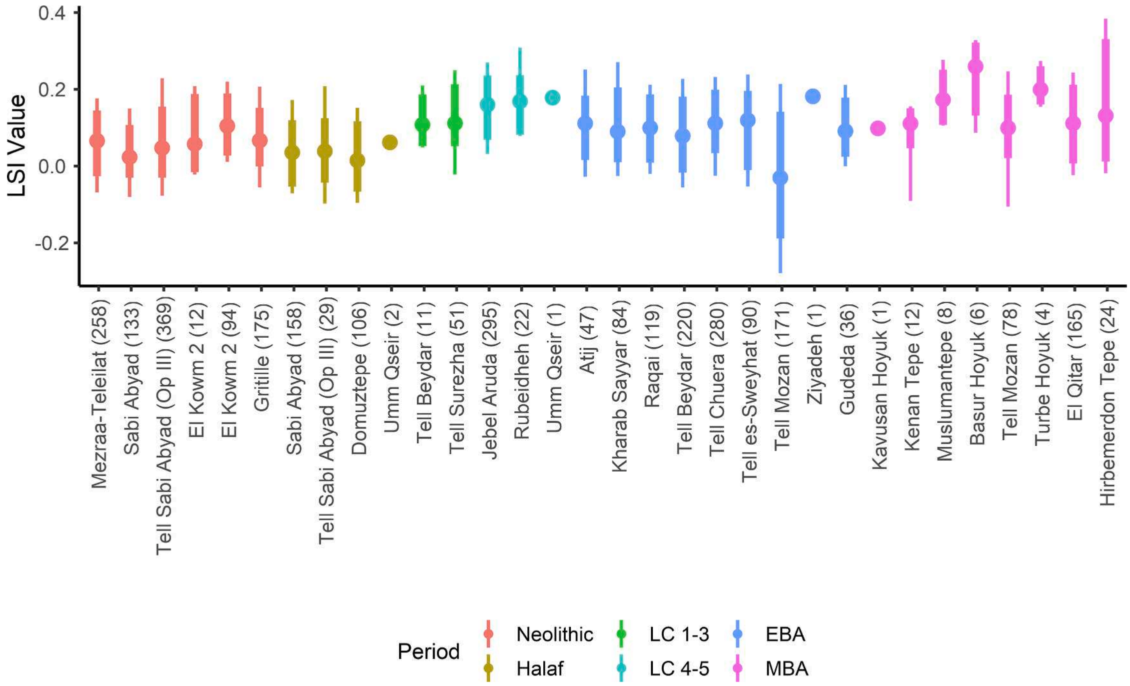

Fig. 2. LSI values for sheep measurements in the biometric dataset (in LSI_e scale), grouped by analytical period.

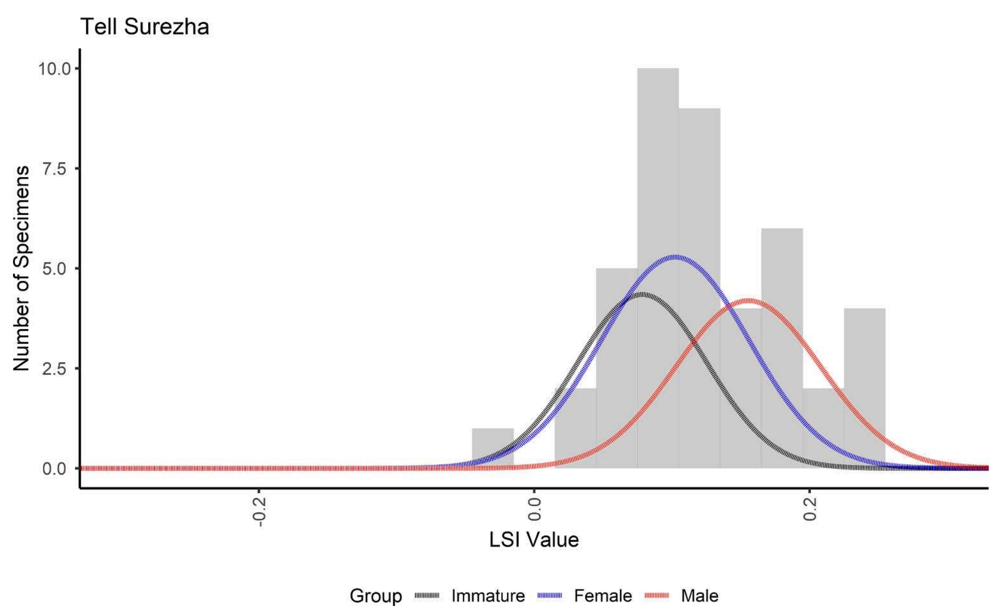

Fig. 3. Histogram of LSI_e values for sheep measurements from the Late Chalcolithic 1–3 site Tell Surezha with mixture modeling results. Curves show the relative probability distributions for specimens at a given LSI value being immature (black), female (blue), or male (red), based on the posterior means of the site-specific model parameters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

large sheep driving the pattern in Fig. 4 are located in the Upper Tigris (Hirbemerdon Tepe, Müslümantepe, Kavusan Höyük, Kenan Tepe, Türbe Höyük), a region unrepresented in other periods. This could suggest a geographic, rather than chronological, explanation for the size increase seen in the Middle Bronze sample. However, the Tell Mozan sheep, while smaller than those of the contemporary sites in the Upper Tigris, were larger than those from Early Bronze levels at the site. And the measurements from Middle Bronze El Qitar (mean female LSI = 0.11) on the Syrian Euphrates were slightly larger than those of nearby Early Bronze Tell es-Sweyhat (mean female LSI = 0.08).

3.2. Sex composition

The mixture modeling did not identify any major shift (or, indeed, much variation at all) in the adult sex ratio over time. For reasons that will be examined in the Discussion, the model generally predicted a higher-than-expected proportion of adult males in all assemblages. Males make up an average of 41–48 % of adults in each of the modeled sites (Fig. 6). Across periods, adult males typically accounted for 42–46 % of adults (Fig. 7).

Sex ratio estimates exhibited large standard deviations shown (Fig. 6). Thus, while the mean estimate of %males was below 50 % at all sites, the uncertainty in these estimates leaves high *meaningful*

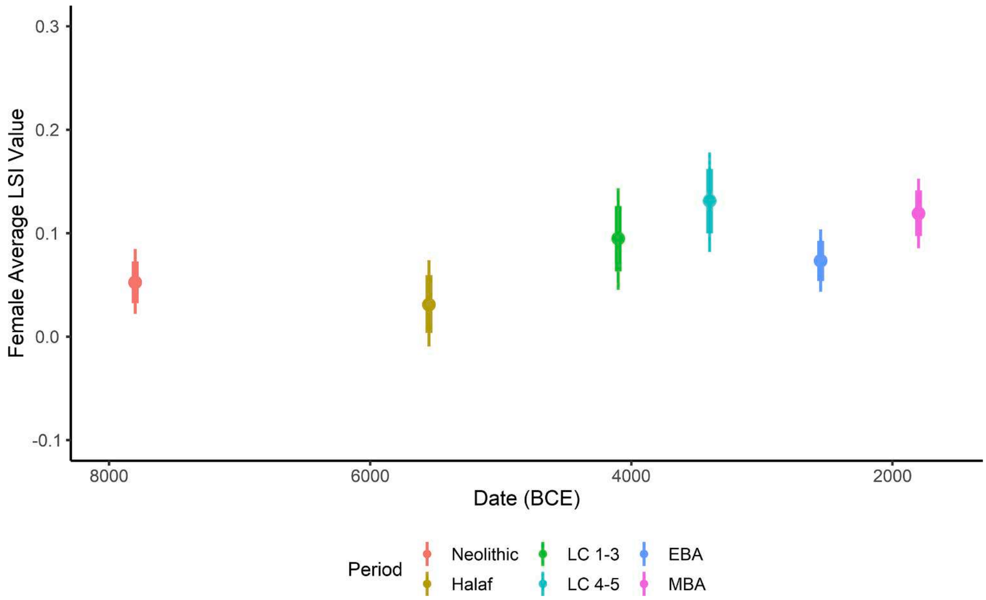

Fig. 4. Posterior distributions of modeled average female body size (in LSI_e scale) for each period. These averages account for variation in average LSI values across different sites (and element portions) within each period. Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals. Dates correspond to midpoints of periods in Table 1.

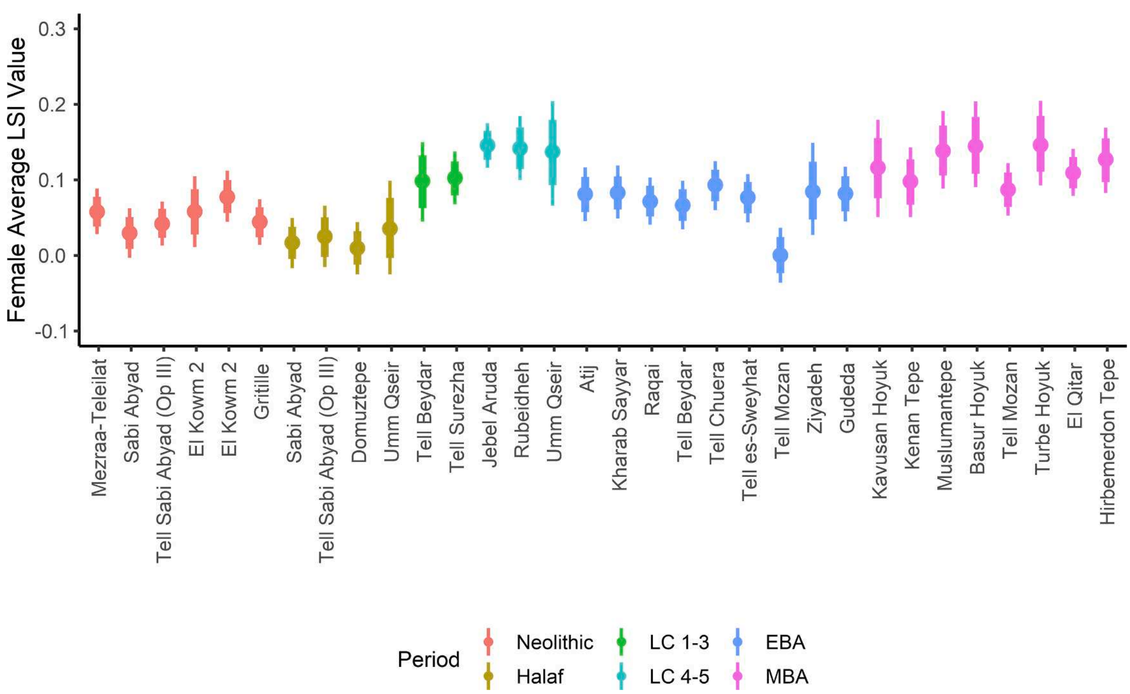

Fig. 5. Posterior distributions of modeled average female body size (in LSI_e scale) for each site, grouped by analytical period. These averages account for variation in average LSI values across different element portions. Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals.

probabilities that males outnumbered females in each assemblage. For example, there is a c. 17 % probability that males outnumbered females at MBA Tell Mozan, and c. 37 % probability at EBA Tell al-Raqai. These results highlight the difficulty of reconstructing sex ratios for zooarchaeological data, especially without relevant sex estimates from pelvis data. Only 9 of the 32 assemblages had reported or calculable sex ratio estimates.

3.3. Age-at-death

Fig. 8 shows the results (average and expected %GHI) of the Bayesian binomial regression model for mandibles by period. With the exception of a slight uptick in the LC 1–3, there appears to be little change over time. In each period, 25–30 % of caprines, on average, were culled after four years of age — percentages in line with Payne’s (1973) meat or milk (but not wool) strategies.

Fig. 9 shows the results of the Bayesian binomial regression model by individual assemblage. Analytical differences between authors likely account for some of the variation. Because no raw data were available (e.g., individual records of mandibles/loose teeth with eruption/wear observations), it was impossible to replicate or standardize the methods used to construct kill-off profiles. In any event, “old-skewed”

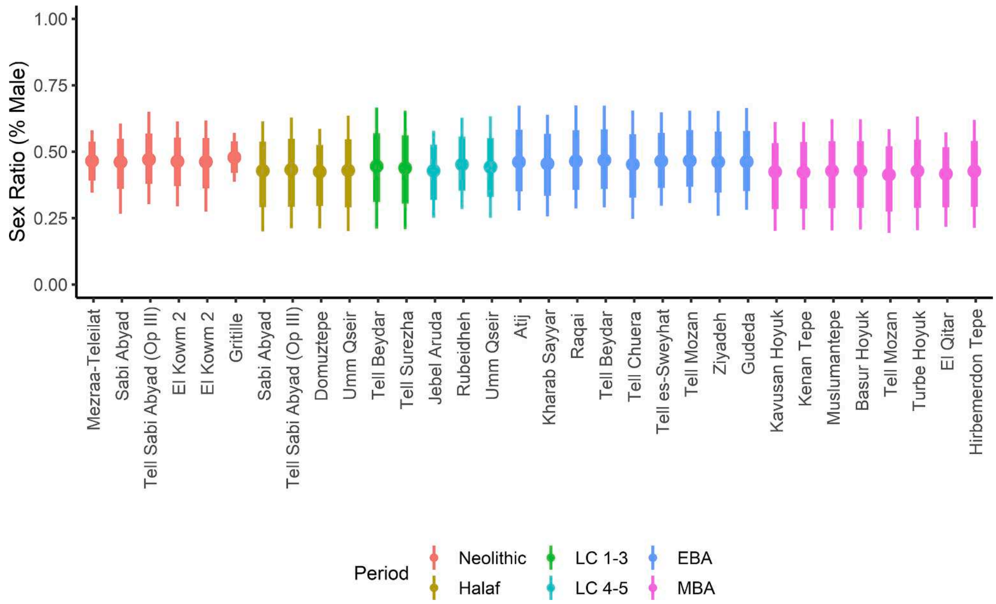

Fig. 6. Posterior distributions of modeled average adult sex ratios (% males out of adult females and adult males) for each site, grouped by analytical period. These averages account for variation across different element portions within each site. Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals.

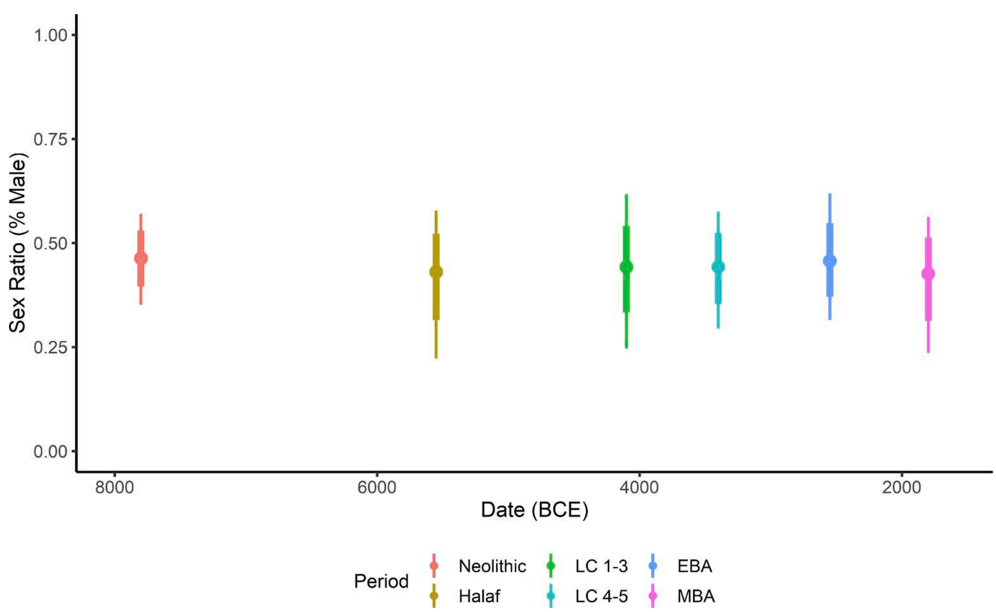

Fig. 7. Posterior distributions of modeled average adult sex ratios (% males out of adult females and adult males) for each period. These averages account for variation across different sites (and element portions) within each period. Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals. Dates correspond to midpoints of periods in Table 1.

assemblages with %GHI above 40 % are present in all periods (see also Table 2).

There is no major sea-change in any period, although there was a higher proportion of old-skewed sites in the Late Chalcolithic 4–5 and especially the Middle Bronze Age. In the small sample of Middle Bronze Age sites, the pattern is driven by Berthon's (2011) data from the Upper Tigris Basin, where two sites, Hirbemerdon Tepe and Kenan Tepe, were old-skewed. This region also had relatively larger sheep in the Middle Bronze (Fig. 5). The other old-skewed MB site was Tell Tuqan, a walled city in the vicinity of Ebla that was likewise old-skewed in the Early Bronze Age (EJ III-IV) (Minniti, 2014).

3.3.1. Karababa Basin urban system

To examine age-at-death data from settlements linked within an urban network, we turn to sites excavated in the 1980s-2000s in the Karababa Basin of southern Turkey. Unfortunately, biometrical data were not available to investigate male–female ratios in tandem with the age-at-death data, but the sites include a major center (Titriş Höyük), smaller towns (Lidar Höyük and Kurban Höyük), and a village (Gritille Höyük) contemporaneously occupied in the mid-late 3rd millennium BC (Algaze et al., 2001; Allentuck and Greenfield, 2010; Hauptmann, 1982; Kussinger, 1988; Stein, 1987; Wattenmaker and Stein, 1986; Wilkinson, 1990). Table 3 shows that the %GHI was highest at Gritille and Kurban Höyük. Next in line was Lidar Höyük, followed by Titriş Höyük.

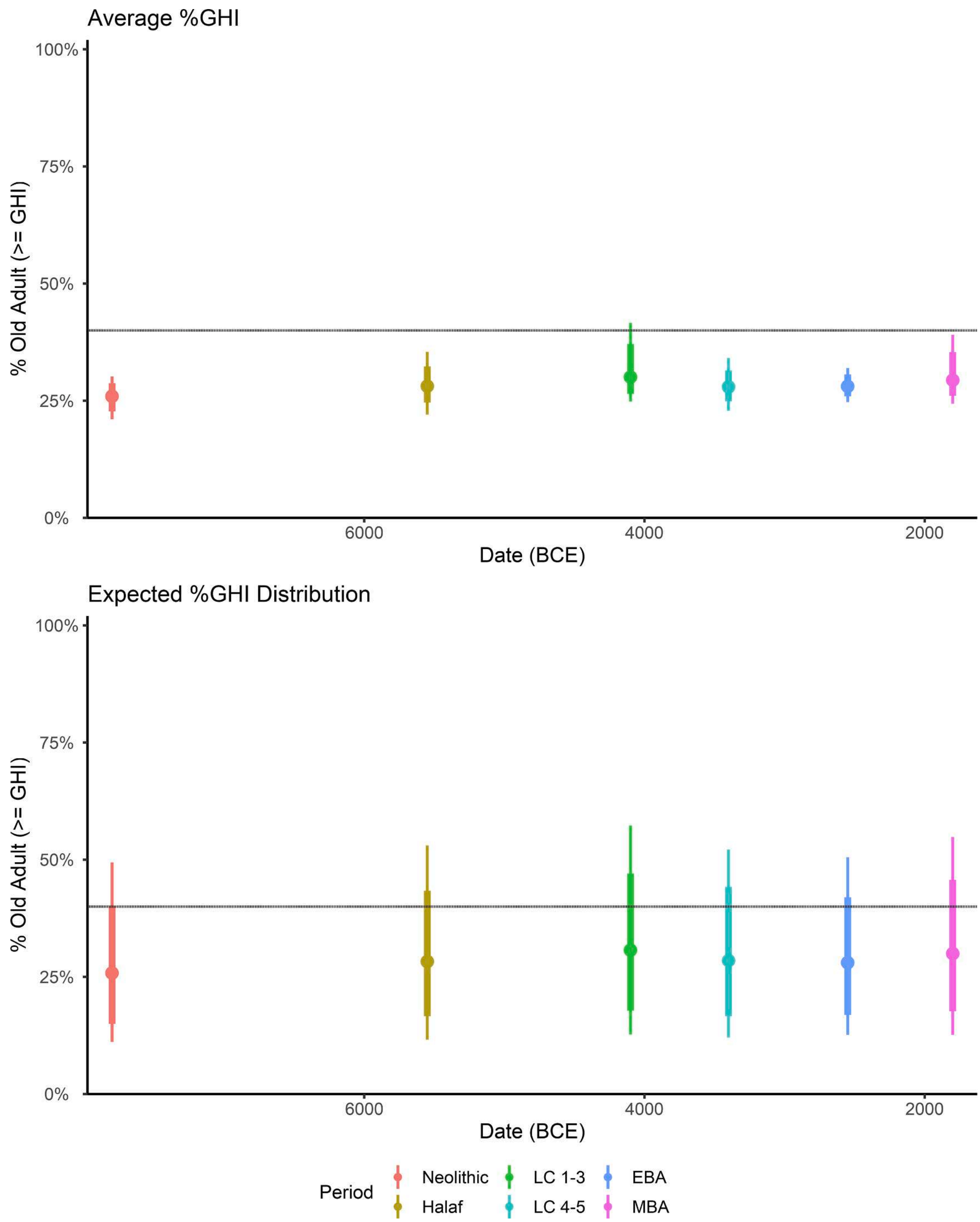

Fig. 8. Posterior distributions of the average proportion (top) and expected proportion (bottom) of old (%GHI) mandibles by analytical period. Expected proportions account for both the average (μ) and the variation among (σ) %GHI values for sites in each period. Horizontal lines at 40 % denote the lower end of the survival rate for a "wool profile" suggested by Payne (1973). Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals. Dates correspond to midpoints of periods in Table 1.

3.4. *Combining methods*

A major limitation of the current study is the patchiness of faunal data availability from northern Mesopotamian sites. While many sites had published biometrical or age-at-death data, few had both. Table 4 shows assemblages with a combination of datasets. There are no clear correlations. The proportion of males, as a fraction of mature sheep, not only shows little variation (something made clear already in Fig. 6), but also no pattern when organized by %GHI. Average female size also shows no correlation with %GHI values — of the six assemblages with large-sized sheep in Table 3, three of them have old-skewed kill-off (% GHI values over 40).

4. Discussion

4.1. *Sex ratios in sheep*

The lack of evidence for male-dominated sheep assemblages at any site in any period — or indeed much variation in the sex ratio at all — is striking. This remarkable consistency over time could indicate that there

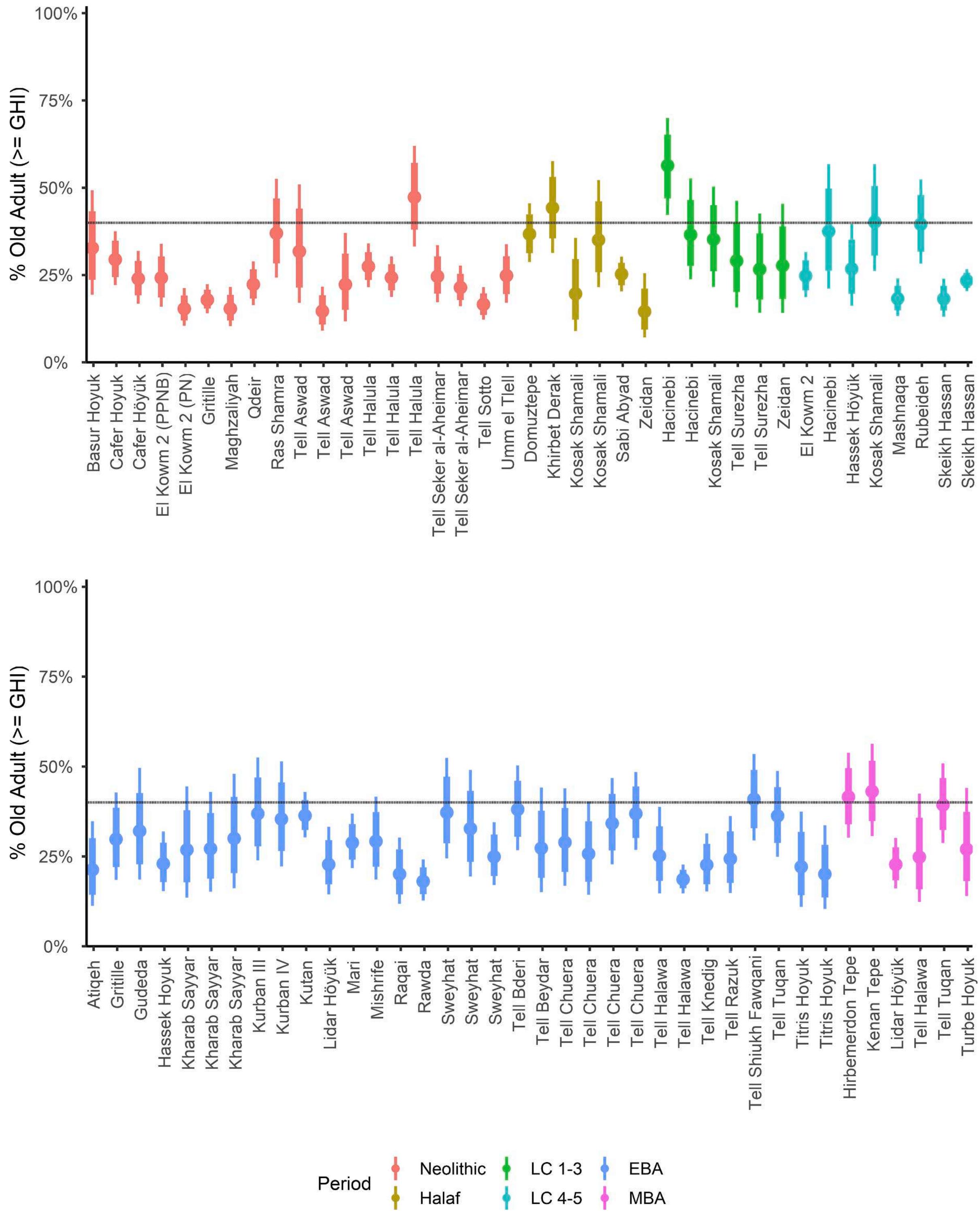

Fig. 9. Posterior distributions of the average proportion of old (% Payne GHI) mandibles per site, grouped by analytical period. Horizontal lines at 40 % denote the lower end of the survival rate for a "wool profile" suggested by Payne (1973). Points show the average value of each posterior distribution, alongside 80 % and 95 % credible intervals.

was no large-scale strategic shift to maximize the exploitation of wool by retaining more males. It might indicate that husbandry strategies were relatively stable over time and space with respect to sex ratio. Yet there is reason to be cautious given the relative lack of measurements from late-fusing elements (elements that fuse after c. 3 years of age).

In caprines, the sex ratio at birth is roughly 1:1. What distinguishes Payne's (1973) "wool" model from his other models is the high male-to-female ratio *among older animals* (>4 years). However, our measurements are primarily composed of elements that fuse at younger ages (e.g., proximal radius, c. 6 months). This is because later-fusing epiphyses tend to be less dense and thus do not preserve well (see e.g., Brain, 1980, p. 21; Lam et al., 2003); moreover, it is more difficult to reliably distinguishable between sheep and goats among them (Wolfhagen and Price, 2017; Zeder and Lapham, 2010). In our dataset, the only reliably

Table 2
Empirical and modeled frequencies of assemblages with at least 40 % old (Payne GHI) caprine mandibles. *Empirical percentage* is the simple proportion of sites with an observed %GHI over 40 % compared to the total number of sites in the period. *Modeled percentage* uses the site-specific estimates of %GHI (see Fig. 9) and takes account of sample sizes (number of mandibles in age classes GHI per assemblage, number of mandibles per assemblage, and number of assemblages per period). It answers the question: "Accounting for sampling bias, what is the estimated percentage of sites with %GHI > 40 in a given period?" Note that the presence of some sites with very high %GHI values impacts the estimate. *Expected percentage* of assemblages is based on period-specific estimates of the average %GHI for each period (see Fig. 8). It answers the question "What is the probability that a randomly selected new site will have %GHI > 40 %?".

Period	Empirical Percentage of Assemblages with > 40 % GHI (Number of Assemblages)	Modeled Percentage of Assemblages with > 40 % GHI	Expected probability that a site would have > 40 % GHI (model result)
Neolithic	16 (19)	8 (0–16)	.10
Halaf-Ubaid	33 (6)	21 (0–50)	.16
LC 1–3	33 (6)	30 (17–67)	.22
LC 4–5	38 (8)	17 (0–38)	.16
EBA	19 (32)	12 (3–22)	.13
MBA	50 (6)	31 (0–50)	.19

Table 3
Data from mid-late 3rd millennium BC Sites in Karababa Basin (Algaze et al., 2001; Kussinger, 1988b; Stein, 1988; Trella, 2010; Wattenmaker and Stein, 1986; Wilkinson, 1990).

Site	Size (ha)	Type	Empirical %GHI (N mand. in GHI / total mand.)	Modeled %GHI mean (±95 % credible interval)
Titriş Höyük	41	Center/ City	12–13 (2 / 15, 3 / 24)	21–23 (11–37)
Lidar Höyük	12	Town	21 (11 / 53)	23 (14–38)
Kurban Höyük	6	Town	43 (9 / 21)	35 (22–51)
Gritille Höyük	1.5	Village	31 (10 / 32)	30 (19–43)

distinguishable late-fusing elements were the distal radius and calcaneus; there were only 284 of these measurements out of 3122 total (9 %). The result is that our mixture models are potentially biased towards younger animals, meaning that they may reflect more closely the sex ratio at birth rather than at older age. While the Bayesian mixture modeling methodology adopted here attempts to mitigate this problem by identifying and separating "immature" animals from "mature" males and females based on size (Wolfhagen, 2023), the technique is imperfect.

One potential solution is to use geometric morphometrics (GMM) to separate male and female mandibles of known age classes. While this method has not yet been tested, several recent studies have shown success in using GMM to separate sheep from goat elements, including dentition (Gaastra et al., 2023; Harding et al., 2023; Haruda et al., 2019; Jeanjean et al., 2023, 2022). If similar methods could sort males from females, it would greatly assist in estimating the percentage of males surviving to different age classes.

4.2. Age at death in sheep/goats

The age-at-death data for combined sheep and goats show variation over time, some of which is potentially in line with expectations for an intensification of wool production on a general level. However, the data fail to show a radical shift in caprine herding strategies on a regional level. The relative frequency per period of caprines above four years of

Table 4
Assemblages with both biometrical and kill-off data. Gray shaded cells indicate "wooly" kill-off (%GHI > 40) and large-sized sheep (LSI > 0.1). %Males reflects values in Fig. 6.

Site	%GHI	% Male	Avg. Female LSI	Reference
Pre-Pottery Neolithic & Pottery Neolithic				
El Kowm 2 – PPN	24	46	0.058	Helmer, 2000; Helmer et al., 2007
Gritille Höyük	25	48	0.044	Monahan, 2000
El Kowm 2 – PN	58**	46	0.078	Helmer, 2000; Helmer et al., 2007
Halaf				
Umm Qseir	Low[1]	42	0.036	Zeder, 1994
Tell Sabi Abyad	25	47	0.025	Russell, 2010
Domuztepe	38	42	0.001	Lau, 2016
Late Chalcolithic				
Umm Qseir	Low[2]	44	0.137**	Zeder, 1994
Surezha	25	44	0.102**	Price et al., 2021
Tell Rubeidheh	44**	45	0.142**	Payne, 1988
Early Bronze Age				
Tell al-Raqa'i	16	47	0.072	Rufolo, 2011
Tell Beydar	27	47	0.066	Siracusano, 2014; Van Neer and De Cupere, 2000
Kharab Sayyar	28[3]	45	0.083	Vila, 2010
Tell Chuera	32[4]	45	0.093	Vila, 2010
Tell Gudeda	38	46	0.082	Rufolo, 2011
Tell es-Sweyhat	42[5] **	47	0.077	Weber, 2006
Tell Mozan	High[6] **	47	0.000	Doll, 2010
Middle Bronze Age				
Turbe Höyük	24	42	0.147**	Berthon, 2011
Başur Höyük	40**	42	0.145**	Berthon, 2011
Hirbemerdon Tepe	46**	42	0.127**	Berthon, 2011
Kenan Tepe	49**	42	0.098	Berthon, 2011
Tell Mozan	High[6] **	41	0.087	Doll, 2010

1 – No GHI data but Zeder (1994) indicates survivorship past four years is 13%.
2 – No GHI data but Zeder (1994) indicates past four years is 17%.
3 – Average; %GHI ranges 25–33% by context.
4 – Average; %GHI ranges 24–40% by context.
5 – Average; Main Phase (Phase 4, EB IV) = 44 %, post-Main (Phase 5, EB IV-MB I) = 38 %).
6 – No GHI data but kill-off is very old-skewed according to figure in Doll (2010, p. 230).

age (%GHI) was highest in the MBA and LC 4–5, while it was lowest in the Pre-Pottery and Pottery Neolithic. This would support the hypothesis that the political economic demand for wool reshaped general herding strategies on a regional level. However, the second-lowest period was the Early Bronze Age, the time during which texts from Sumer and Ebla document large-scale woolen textile production. This negates the hypothesis.

In fact, in every period, there were some assemblages in which over 40 % of the caprines were over four years old. The pattern of old-skewed kill-off in the Pottery Neolithic was raised by Helmer et al. (2007), who argued for intensive wool production. One can posit other explanations. Neolithic herders may have kept their sheep and goats to older ages because herd sizes were small, grass plentiful, and there existed a cultural sentiment against killing valuable stock early in life. In any case, old-skewed kill-off was by no means unique to the periods in which there is clear political economic development (Frangipane, 2018a; Stein, 2012) and those typically mentioned in the same breath as the "secondary products revolution" or "fiber revolution" (McCorriston, 1997; Sherratt, 1983).

Returning to the LC 4-5 and MBA, while they do not stand head-and-shoulders above the other periods, they displayed the highest proportion of sites with %GHI > 40 %. Both are interesting periods for the role of wool production in the political economy. The former saw the intrusion of southern Mesopotamian material culture and colonists into the north during the "Uruk Expansion." While it is likely that southern Mesopotamians installed enclaves to access a variety of materials, including copper and obsidian, the exploitation of northern pastures to supply elite-managed textile workshops with wool may have been an important component (Algaze, 1993; Keith, 1998; Wright, 1989). The Middle Bronze Age had the highest percentage of sites with old-skewed kill-off, primarily in the Upper Tigris. The Middle Bronze is notable for the presence of Assyrian merchant colonies in Anatolia, Kültepe-Kanesh being the most famous. Woolen textiles produced in Assyria (the area around modern Erbil and Mosul) and further south were an important component of this trade. But merchants also bought and sold raw or semi-processed wool produced in Anatolia (Atici, 2014b; Lassen, 2010; Michel, 2014). While the texts suggest that the region most productive in wool was in central Anatolia, around modern-day Konya (Lassen, 2010, p. 169), it is possible that the increased demand for wool in Anatolian/Assyrian markets pushed herders to adopt husbandry strategies to maximize its production in other regions, such as the Upper Tigris.

An important caveat to interpreting age-at-death data is that most of our Early Bronze Age assemblages derive from urban centers and walled "towns," not rural settlements. Not only do archaeologists more frequently excavate urban centers (conspicuous on the landscape as *tells*), but when exposures are made of rural sites, the faunal assemblages are usually too small for meaningful analysis of husbandry practices. For example, Hajji Ibrahim, an Early Bronze satellite of Tell es-Sweyhat on the Euphrates River, yielded only 96 identified sheep/goat remains (Weber, 2006, p. 150). Even when small sites yield larger assemblages, it is sometimes questionable how "rural" they were. For example, Tell Atij was a small early-mid-3rd millennium BC site in the Middle Khabur, but it contained monumental architecture (Fortin, 1995).

As mentioned above, in an urban system, rural sites are expected to provision urban centers with prime-aged and young male caprines (c. 6–36 months) (Gaastra et al., 2020; Stein, 1988; Zeder, 1991). In part, this is to meet the subsistence demands of concentrated populations. But it is also an important way in which the political economy feeds off the subsistence economy — a process often referred to as "staple finance" (D'Altroy and Earle, 1985; see also Frangipane, 2018b). A steady stream of livestock moving from the hinterland to cities supported feasts, provided sacrificial animals, and provisioned laborers — all key aspects of reproducing political power. More work needs to be done to determine the extent to which urban provisioning occurred in northern Mesopotamia, but for our purposes, if such provisioning existed, a dataset reliant on urban settlements might not detect intensive wool production. One would expect to find old-skewed kill-off in villages, while cities largely consumed young and prime-aged animals. There are two important implications. First, if urban provisioning did occur, then as long as temples, elite architecture, and urban centers attract the lion's share of excavation efforts, there will be bias against finding kill-off profiles matching Payne's (1973) wool strategy. Second, the old-skewed kill-off in villages *might* reflect intensive wool production; alternatively, it might reflect the population of ewes (minus the young males taken to cities) in meat- or milk-focused herds. In other words, within an urban network, the kill-off pattern is equifinal without sex data. Thus admonished, we turn to the data from the Karababa Basin, which offered the only opportunity to examine differential kill-off patterns across an urban system. The data do show evidence of old-skewed kill-off at rural sites (Kurban and Gritille Höyük) compared to the urban ones (Titriş and Lidar Höyük). Equifinal as it is, this provides our best, if tentative, evidence for intensive wool production at a regional level.

4.3. Sheep size

The variability in sheep size over time contrasts with the pattern of steady size decline seen in northern Mesopotamian pigs and cattle from the Neolithic through Bronze Age (Arbuckle et al., 2016; Price and Evin, 2019). In sheep, size reduction occurred in the Neolithic, followed by an increase in size in the Late Chalcolithic period, a decrease in the Early Bronze Age, and another increase in the Middle Bronze Age. Vila and Helmer's (2014) analysis of sheep astragalus measurements at 6th-3rd millennium BC sites in northern Mesopotamia had previously indicated this oscillating pattern. Vila and Helmer (2014) argued that the large sheep of the Late Chalcolithic were the hairy sheep depicted in 4th millennium artwork (e.g., the Warka Vase), while the smaller Early Bronze sheep were the wooly sheep depicted in 3rd millennium artwork (e.g., the Standard of Ur).

We can corroborate Vila and Helmer's (2014) pattern, but we note there is more variation in the Early Bronze Age sheep than previously observed. This is most notable at Tell Mozan, which has been identified as the ancient city of Urkesh (Buccellati and Kelly-Buccellati, 1998). There, average sheep size was much smaller than at contemporary sites. Although we cannot rule out other factors, such as nutritional differences, it is possible we are dealing with a different population of sheep at that site. The pattern of very old animals shown in graphical form by Doll (2010), but without raw data available, could suggest intensive wool production associated with this diminutive sheep population.

Vila and Helmer's (2014) hypothesis that size variation reflects different populations ("breeds" or, more likely, "landraces") relating to wool exploitation demands further testing. Texts from Sumer (southern Mesopotamia) in the late 3rd millennium BC do refer to at least three populations of sheep with variable wool qualities, including "fat-tailed sheep" (*udu* GUKKAL), "Sumerian sheep" (*udu eme-gi*), and "black sheep" (*udu gegge*) (Sallaberger, 2014, p. 104). Perhaps future research utilizing geometric morphometrics, stable isotopic analysis, or ancient DNA can more fully answer questions about ancient caprine populations.

4.4. The relationship between the political and subsistence economies

Rather strikingly, there is no evidence for a sea-change in regional caprine husbandry patterns in any of the datasets. Though there are perceptible changes over time, and there are some interesting patterns at local levels (e.g., the Titriş urban system), across the region, the magnitude of change is subtler than expected. Evidence for regional-scale intensive wool production is especially weak in the 3rd millennium BC, a period of rapid political economic expansion (Frangipane, 2018a; Lawrence and Wilkinson, 2015; Stein, 2012; Ur, 2010). The most notable change is in the average size of animals over time, suggesting population-level changes that may, or may not, be linked to fiber exploitation (Vila and Helmer, 2014).

In the preceding sections, we have offered a number of caveats to the interpretation of these patterns, including messy/incomplete zooarchaeological data, the limitations of mixture modeling, spotty publication of zooarchaeological data, and an over-abundance of excavations of settlements at or near the top of urban settlement hierarchies. Zooarchaeological data, by their nature, derive from time- and space-averaged deposits. They reflect the aggregated activities of a settlement, rather than individual-level behavior (Lyman, 2003; Makarewicz, 2016, p. 198). Such aggregation effects can mask distinctive economic strategies if culling decisions are responses to more immediate circumstances that fluctuate within the unit of stratigraphic resolution. As an example of the power of these confounding factors, consider that faunal biometrical data only demonstrate rather subtle changes over the18th and 19th centuries in England, a context in which abundant historical records attest to livestock improvement regimes (Thomas et al., 2013). It may be that the scale of studies such as ours, which attempt to find meaningful patterns over a large region, are too affected by local differences; *it is likely that more targeted, sub-regional analyses of diachronic patterns will be more fruitful in identifying major changes in animal husbandry vis-à-vis changing relationships between the political and subsistence economies*.

Those issues notwithstanding, we *tentatively reject* the hypothesis that the political economic importance of wool had a generalized impact on animal production regimes, and thus this element of the subsistence economy, in northern Mesopotamia. The zooarchaeological data considered here negate at least the strong versions of the "fiber revolution" hypothesis (McCorriston, 1997) and parts of the "secondary products revolution" (Sherratt, 1983). In fact, in another study, Grossman and Paulette (2020, p. 9) showed that while sheep and goats constitute the majority of animal remains in northern Mesopotamian faunal assemblages in all periods, the percentage of sites where sheep and goats predominated (over 75 % of domestic faunal remains by NISP) did not increase between the Late Chalcolithic and Early Bronze Age. This suggests that carpine herding did not expand faster than other sectors of the animal economy (pig and cattle husbandry), again pointing away from the conclusion that the pastoral sector of the susbsitence economy was radically reorganized to faciliate the intensification of wool production.

This is not to say that the political economy did not affect the subsistence economy. As the dataset from the Karababa Basin shows, when specific urban networks are examined in detail, we may be able to detect the political economy intruding upon caprine herding strategies. The Karababa pattern might reflect intensive wool production; or it might reflect provisioning of cities with prime-aged males. Either way, the data suggest that urban–rural dynamics, a facet of the political economy, did impact upon subsistence. In the southern Levant, caprine age-at-death data also tentatively indicate urban provisioning in the Early and Middle Bronze Age (Gaastra et al., 2020). It would be false, therefore, to claim that the political economy did not feed off the subsistence economy. The model of "staple finance" of early states is largely supported by the evidence (Frangipane, 2018b). But there does not appear to have a been a particularly strong influence on the subsistence economy from wool production, despite the textual evidence indicating wool played a critical role in the reproduction of political power.

Indeed, it might have been the case that wool production for the political economy did not require overhauling the subsistence economy. In ancient Mesopotamia, the limiting factor in textile production (and many other economic sectors) was almost certainly labor, not flock size. Extant herds and herding strategies may have been able to supply more than enough wool to households, palaces, and temples than they could process or exchange. Additionally, keeping large numbers of males might not have been necessary if herds were large enough to absorb the demand for wool, if grazing resources were plentiful, or if the finer wool of castrates were not in high demand. In such cases, there would be an incentive to stick to traditional slaughter patterns and husbandry strategies focused on culling most young males, which would ensure the maximum level of reproductivity and the greatest insurance against catastrophic loss. In fact, Bates's (1973) ethnographic work found that, while wool was the main source of income for Yörük pastoralists in SE Turkey, one that reproduced a political economy of rich herd owners and hired herders, the vast majority of males were slaughtered prior to one year old (Bates, 1973, p. 148).

The extraction of surplus from primary producers without fundamentally changing the nature of production practices is common to many economic sectors in non-capitalist modes of production (e.g., Haldon, 1993, p. 82; Wickham, 1985). Political economic pressure may galvanize the expansion of, or even revolutionize, certain key aspects of production. In Hawaii, for example, paramount chiefs compelled their subjects to pursue "capital improvements" such as terracing and irrigation, in order to increase agricultural yields that, in turn, could be mobilized in feasting and redistribution to non-producers (Johnson and Earle, 2000, p. 236). But in other cases, the impact of the political economy on subsistence production may be limited. In feudal Europe, for example,

> landlords did not often regard their demesnes as the places *par excellence* where they could closely direct the work-process of subjected labourers; peasants performed their labour-services according to the same locally-determined procedures that they used in cultivating their own land (Wickham, 1985, p. 168).

In Mesopotamia, political economic demands may have focused solely on the plucking, spinning, and weaving of wool. The concentration of specialist labor and economies of scale may even have increased productivity (m^2 of cloth produced per person-hour) — revolutionizing textile, but not pastoral, production. For caprine husbandry, the ruling class may have been content to skim the surplus without necessarily altering production by direct or indirect pressure. Such a scenario fits Mycenean Greece, where Halstead (2003) has shown that, even though Linear B documents indicate the importance of wool and other caprine products, the emergence of palace economies did not substantially alter sheep/goat husbandry:

> The development of a centralised redistributive economy may thus have had less impact on which animals were kept and how they were managed, than on who had rights to their carcasses, offspring and secondary products (Halstead, 2003, p. 260).

Elites took what they could get in the form of tribute, taxes, or corvée, but they were not necessarily inclined or able to invest a portion of that extracted surplus back into production or otherwise get involved in the messy business of growing crops or raising animals.

The model of a skimming elite, rather than an industrious one tinkering with husbandry or pressuring herders to adopt methods intended to maximize the production of wool, fits with some current models of early SW Asian states. For example, as Richardson (2017, 2012) has theorized, the political elite of ancient Mesopotamia, though projecting an appearance of hegemony, may have stood atop "low-power states," with quite limited ability to effect domination outside a few highly visible contexts (see also Grossman and Paulette, 2020). Indeed, of all the thousands of Mesopotamian texts dealing with caprines and herders, scribes took care to document receipts, transfers, birth, and losses of animals and animal products; they did *not* record everyday management, which was left to contracted herders (see e.g., Englund, 2004).

5. Conclusion

Heuristically dividing the mobilization of human labor into political economic and subsistence economic sectors provides a framework for understanding how the development and reproduction of political power impact the everyday activities that sustain life and cultural structures. We have investigated wool production in northern Mesopotamia as a way to view the relationship between these two sectors in a context defined by the development of institutionalized social inequality, urbanism, and state formation. Texts, visual art, and in some cases artifactual evidence (e.g., spindle whorls) strongly indicate that wool played a central role in these social processes. Wool was a major means by which political actors funded their power; it provided key commodities that could be mobilized in international trade, gifts to elites or allies, and as "rations" to dependents. But the production of sheep lay in the hands of non-elite herders, who adopted husbandry strategies with an eye towards several goals: supplying their elite patrons or overlords with enough wool, ensuring the long-term reproductive viability of herds, and extracting milk, meat, and wool for subsistence. The question we have asked is whether the elite demands for wool had a generalized impact on husbandry strategies across the region, an effect that would indicate political economic reorganization of subsistence production.

Like a case of "will they, won't they" on a TV series, there are possible hints of an impact, but nothing definitive. The zooarchaeological data indicate subtle and local changes in caprine husbandry over time. But there is no clearcut or dramatic shift towards wool production across northern Mesopotamia in terms of kill-off profiles or male-to-female ratios. The only clear region-wide pattern relates to sheep size, yet it remains unclear how the shift to larger sheep in the Late Chalcolithic, smaller sheep in the Early Bronze, and then back to larger sheep in the Middle Bronze Age relates to wool production. The results thus remain tentative. We have also stressed that commonly-employed faunal methods are bound by a set of limitations. Additional research may solve some of them, particularly research undertaken at smaller geographic scales, but a more immediate remedy is the publication of raw data collected by zooarchaeologists, especially from excavations in Syria from the 1990s until 2010. It would behoove archaeologists to remember that large-scale regional analyses such as this study are only as good as their data and methods, that they are vulnerable to inconsistencies in data publication. Without sober assessment of the limitations posed by methodology and data quality, such analyses have the potential to pull the wool over one's eyes.

CRediT authorship contribution statement

Max D. Price: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Jesse Wolfhagen:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Adams, R.M., 1981. Heartland of cities: surveys of ancient settlement and land use on the central floodplain of the euphrates. University of Chicago Press, Chicago.
Akkermans, P.M.M.G., Schwartz, G.M., 2003. The archaeology of Syria. Cambridge University Press, Cambridge.
Algaze, G., 1993. The uruk world system. University of Chicago Press, Chicago.
Algaze, G., 2008. Ancient Mesopotamia at the Dawn of civilization: the evolution of an urban landscape. University of Chicago Press, Chicago.
Algaze, G., Dinckan, G., Hartenberger, B., Matney, T., Pournelle, J., Rainville, L., Rosen, S., Rupley, E., Schlee, D., Vallet, R., 2001. Research at titris höyük in southeastern Turkey: the 1999 season. Anatolica 27, 23–106.
Allentuck, A., Greenfield, H.J., 2010. The Organization of Animal Production in an Early Urban Center: the Zooarchaeological evidence from Early bronze age titris höyük, Southeast Turkey. In: Campana, D., Crabtree, P.J., deFrance, S.D., Lev-Tov, J.S., Choyke, A.M. (Eds.), Anthropological Approaches to Zooarchaeology: Complexity, Colonialism, and Animal Transformations. Oxbow Books, Oxford, pp. 12–29.
Arbuckle, B., 2014a. Inequality and the origins of wool production in Central Anatolia. In: Arbuckle, B., McCarty, S.A. (Eds.), Animals and Inequality in the Ancient World. University of Colorado Press, Boulder, pp. 209–229.
Arbuckle, B., 2014b. Pace and process in the emergence of animal husbandry in neolithic Southwest Asia. Bioarchaeol. Near East 8, 53–81.
Arbuckle, B.S., Atici, L., 2013. Initial diversity in sheep and goat management in neolithic south-western Asia. Levant 45, 219–235.
Arbuckle, B., Hammer, E., 2019. The rise of pastoralism in the ancient near east. J. Archaeol. Res. 27, 391–449.
Arbuckle, B., Price, M.D., Hongo, H., Öksüz, B., 2016. Documenting the initial appearance of domestic cattle in the eastern fertile crescent (northern Iraq and Western Iran). J. Archaeol. Sci. 72, 1–9.
Arrighi, G., 1994. The long twentieth century: money, power, and the origins of our times. Verso, New York.
Atici, L., 2014a. The secondary products revolution in light of textual evidence from Kultepe-Kanesh, Central Turkey. In: Greenfield, H.J. (Ed.), Animal Secondary Products: Domestic Animal Exploitation in Prehistoric Europe, the near East and the Far East. Oxbow Books, Oxford, pp. 233–252.
Atici, L., 2014b. Tracing inequality from assur to kültepe/kanesh: merchants, donkeys, and clay tablets. In: Arbuckle, B.S., McCarty, S.A. (Eds.), Animals and Inequality in the Ancient World. Boulder, University of Colorado Press. University of Colorado Press, Boulder, pp. 233–252.
Aubet, M.E., 2013. Commerce and colonization in the ancient near east. Cambridge Univeristy Press, Cambridge.
Bates, D.D., 1973. Nomads and farmers: a study of the yörük of southeastern Turkey. University of Michigan Press, Ann Arbor.
Berthon, R., 2011. Animal exploitation in the upper Tigris River valley (Turkey) between the 3rd and 1st millennia BC. Christian-Albrechts Universität zu Kiel, Kiel.
Biga, M.G., 2014. Some aspects of the wool economy at ebla (Syria, 24th century BC). In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow Books, Oxford, pp. 139–150.
Bigelow, L., 1999. Zooarchaeological investigation of economic organization and ethnicity at late Chalcolithic Hacinebi: a preliminary report. Paléorient 25, 83–89.
Bigelow, L., 2011. Economic Specialization in Late Chalcolithic Animal Systems: The Fauna at Hacinebi Tepe, Turkey. Anthropology. Northwestern University, Evanston.
Bökönyi, S., 1977. The Animal Remains from Four Sites in the Kermanshah Valley, Iran: Asiab, Sarab, Dehsavar, and Siahib. BAR, Oxford.
Brain, C.K., 1980. The Hunters or the Hunted? An Introduction to African Cave Taphonomy. University of Chicago Press, Chicago.
Braudel, F., 1981. The Structures of Everyday Life: Civilization and Capitalism 15th-18th Century Volume 1. Fontana Press, London.
Breniquet, C., Michel, C., 2014. Wool economy in the ancient Near east and the Aegean. In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow Books, Oxford, pp. 1–11.
Buccellati, G., Kelly-Buccellati, M., 1998. Urkesh as tell mozan: profiles of the Ancient City. In: Buccellati, G., Kelly-Buccellati, M. (Eds.), Urkesh and the Hurrians: Studies in Honor of Lloyd Cotsen. Undena Publications, Malibu, pp. 11–34.
Chang, C., Koster, H.A., 1986. Beyond bones: Toward an anthropology of pastoralism. Adv. Archaeol. Method Theory 9, 97–148.
Clutton-Brock, J., Dennis-Bryan, K., Armitage, P.L., Jewell, P.A., 1990. Osteology of the soay sheep. Bull. Br. Museum. Nat. Hist. Zool. 56, 1–56.
Corcoran-Tadd, N., Price, M., Caramanica, A., 2023. The political economy of livestock in Early states. Cambridge Archaeol. J. 33, 119–136.
Costin, C.L., 1998. Housewives, chosen women, skilled men: cloth production and social identity in the late prehispanic andes. In: Costin, C.L., Wright, R. (Eds.), Craft and Social Identity. American Anthropological Association, Washington, DC, pp. 123–141.
Cribb, R., 1984. Computer simulation of herding strategies as an interpretive and heuristic device in the study of kill-off strategies. In: Clutton-Brock, J., Grigson, C. (Eds.), Animals in Archaeology. BAR, Oxford, pp. 161–170.
D'Altroy, T.N., Earle, T.K., 1985. Staple finance, wealth finance, and storage in the inka political economy. Curr. Anthropol. 26, 187–206.
Davis, S.J.M., 1984. The Advent of Milk and Wool Production in Western Iran: Some Speculations, in: Clutton-Brock, J., Grigson, C. (Eds.), Animals in Archaeology 3: Early Herders and Their Flocks. BAR International Series 202, Oxford, pp. 265–278.
Deniz, E., Payne, S., 1982. Eruption and Wear in the Mandibular Dentition as a Guide to Ageing Turkish Angora Goats, in: Wilson, B., Grigson, C., Payne, S. (Eds.), Ageing and Sexing Animal Bones from Archaeological Sites. BAR British Series 109, Oxford, pp. 155–205.
Doll, M., 2010. Meat, traction, wool: urban livestock in tell mozan. In: Deckers, K., Doll, M., Pfälzner, P., Riehl, S. (Eds.), Development of the Environment, Subsistence, and Settlement of the City of Urkes and Its Region. Harrassowitz Verlag, Weisbaden, pp. 191–360.
Driesch, A. von den, 1976. A Guide to the Measurements of Animal Bones from Archaeological Sites. Peabody Museum Bulletin 2, Cambridge (MA).
Düring, B.S., 2013. Breaking the bond: investigating the neolithic expansion in Asia minor in the seventh millennium BC. J. World Prehistory 26, 75–100.
Englund, R.K., 2004. Proto-cuneiform account-books and journals. In: Hudson, M.J., Wunsch, C. (Eds.), Creating Economic Order: Record-Keeping, Standardization, and the Development of Accounting in the Ancient near East. University of Maryland Press, Bethesda (MD), pp. 23–46.
Englund, R.K., 2012. Equivalency values and the command economy of the Ur III period in Mesopotamia. In: Papadopoulos, J.K., Urton, G. (Eds.), The Construction of Value in the Ancient World. Cotsen Institute of Archaeology, Los Angeles, pp. 427–458.
Firth, R., 2014. Considering the population statistics of the sheep listed in the East-West corridor Archive at Knossos, in: Gulizio, J., James, S.A., Dimitri Nakassis (Eds.), KE-RA-ME-JA Studies Presented to Cynthia W. Shelmerdine. INSTAP Academic Press, Philadelphia, pp. 293–304.
Fisher, M., 2017. The Late Chalcolithic 1 Period in Northern Mesopotamia: Tell Zeidan, Syria, in Regional Context. Near East. Lang. Civilizations, Univ. Chicago, Chicago. University of Chicago, Chicago.
Fortin, M., 1995. Rapport préliminaire sur la cinquieme campagne a tell Atij et la Quartrieme a tell gudeda (Printemps 1993). Syria 72, 23–53.
Foster, B., 1981. A new look at the Sumerian temple state. J. Econ. Soc. Hist. Orient 24, 225–241.
Frangipane, M., 2007. Different types of egalitarian societies and the development of inequality in early Mesopotamia. World Archaeol. 39, 151–176.
Frangipane, M., 2018a. Different trajectories in state formation in greater Mesopotamia: a view from arslantepe (Turkey). J. Archaeol. Res. 26, 3–63.
Frangipane, M., 2018b. From a subsistence economy to the production of wealth in ancient formative societies: a political economy perspective. Econ. Polit. 35, 677–689.

Gaastra, J.S., Greenfield, T.L., Greenfield, H.J., 2020. There and back again: a zooarchaeological perspective on early and middle bronze age urbanism in the southern levant. PLoS One 15, e0227255.
Gaastra, J.S., Greenfield, T.L., Greenfield, H.J., 2023. Domesticating details: 3D geometric morphometrics for the zooarchaeological discrimination of wild, domestic and proto-domestic sheep (Ovis aries) and goat (Capra hircus) populations. J. Archaeol. Sci. 153, 105768.
Gillis, R., Chaix, L., Vigne, J.-D., 2011. An assessment of morphological criteria for discriminating sheep and goat mandibles on a large prehistoric archaeological assemblage (Kerma, Sudan). J. Archaeol. Sci. 38, 2324–2339.
Gimpel, J., 1976. The medieval machine: the industrial revolution of the middle ages. Penguin Books, New York.
Gourichon, L., Helmer, D., 2003. Preliminary analysis of the faunal remains from tell kosak shamali (Syria): Squares AD5, AE5, AF5, BD6 and BE6. In: Nishiaki, Y., Matsutani, T. (Eds.), Tell Kosak Shamali: the Archaeological Investigations on the Upper Euphrates, Syria. The University Museum. The University of Tokyo, Tokyo, pp. 273–282.
Greenfield, H.J., 1988. The origins of milk and wool production in the old world: a Zooarchaeological perspective from the Central Balkans. Curr. Anthropol. 29, 573–593.
Grigson, C., 1995. Cattle keepers of the northern Negev: animal remains from the chalcolithic site of Grar. In: Gilead, I. (Ed.), Grar: A Chalcolithic Site in the Northern Negev. Ben-Gurion University of the Negev Press, Beersheva, pp. 377–452.
Grossman, K.M., Hinman, M., 2013. Rethinking halaf and ubaid animal economies: hunting and herding at tell zeidan (Syria). Paléorient 39, 201–219.
Grossman, K., Paulette, T., 2020. Wealth-on-the-hoof and the low-power state: caprines as capital in early Mesopotamia. J. Anthropol. Archaeol. 60, 101207.
Gulliford, A., 2018. The woolly west: Colorado's hidden history of sheepscapes. Texas A&M University Press, College Station.
Habermehl, K.H., 1975. Die altersbestimmung bei haus- und labortieren. Parey, Berlin.
Hadjikoumis, A., 2017. Age-at-death in traditional cypriot sheep and goat husbandry: implications for zooarchaeology. In: Rowley-Conwy, P., Serjeantson, D., Halstead, P. (Eds.), Economic Zooarchaeology: Studies in Hunting, Herding and Early Agriculture. Oxbow Books, Oxford, pp. 126–134.
Haldon, J., 1993. The state and the Tributary mode of production. Verso, London.
Halstead, P., 1999. Texts, bones and herders: approaches to animal husbandry in late bronze age Greece. Minos 33–24, 149–189.
Halstead, P., 2003. Texts and bones: contrasting Linear B and archaeozoological evidence for animal exploitation in Mycenaean southern Greece. Br. Sch. Athens Stud. 9, 257–261.
Halstead, P., Isaakidou, V., 2011. Revolutionary secondary products: the development and significance of milking, animal-traction and wool-gathering in later prehistoric Europe and the Near east. In: Wilkinson, T., Sherratt, S., Bennet, J. (Eds.), Interweaving Worlds: Systemic Interactions in Eurasia, 7th to 1st Millennia BC. Oxbow Books, Oxford, pp. 61–76.
Harding, S., Vermeersch, S., Ujma, C., Deonarain, G., Susnow, M., Shafir, R., Gilboa, A., Lehmann, G., Marom, N., 2023. Hoofprints in the sand: a study on domestic sheep (Ovis aries) from iron age southern Phoenicia using traditional biometric methods. Quat. Int.
Haruda, A.F., Varfolomeev, V., Goriachev, A., Yermolayeva, A., Outram, A.K., 2019. A new zooarchaeological application for geometric morphometric methods: distinguishing Ovis aries morphotypes to address connectivity and mobility of prehistoric central asian pastoralists. J. Archaeol. Sci. 107, 50–57.
Hauptmann, H., 1982. Lidar höyük, 1981. Anatol. Stud. 32, 17–18.
Helmer, D., 2000. Étude de la faune mammalienne d'el kowm 2. In: Stordeur, D. (Ed.), El Kowm 2: Une Île Dans Le Désert. CNRS Éditions, Paris, pp. 233–264.
Helmer, D., Gourichon, L., Vila, E., 2007. The development of the exploitation of products from Capra and Ovis (meat, milk, and fleece) from the PPNB to the Early bronze in the northern Near east (8700 to 2000 BC cal.). Anthropozoologica 42, 41–69.
Hole, F., 2001. A radiocarbon chronology for the middle khabur, Syria. Iraq 63, 67–98.
Hole, F., Flannery, K.V., 1967. The prehistory of south-western Iran: a preliminary report. Proc. Prehist. Soc. 33, 147–206.
Hudson, M., 2000. Mesopotamia and classical antiquity. In: Andelson, R.V. (Ed.), Land-Value Taxation around the World. Blackwell Publishers, Oxford, pp. 3–26.
Jeanjean, M., Haruda, A., Salvagno, L., Schafberg, R., Valenzuela-Lamas, S., Nieto-Espinet, A., Forest, V., Blaise, E., Vuillien, M., Mureau, C., Evin, A., 2022. Sorting the flock: quantitative identification of sheep and goat from isolated third lower molars and mandibles through geometric morphometrics. J. Archaeol. Sci. 141, 105580.
Jeanjean, M., McGrath, K., Valenzuela-Lamas, S., Nieto-Espinet, A., Schafberg, R., Parés-Casanova, P.M., Jiménez-Manchón, S., Guintard, C., Tekkouk, F., Ridouh, R., Mureau, C., Evin, A., 2023. ZooMS confirms geometric morphometrics species identification of ancient sheep and goat. R. Soc. Open Sci. 10, 230672.
Johnson, A.W., Earle, T.K., 2000. The evolution of human societies: from foraging group to Agrarian state. Stanford University Press, Stanford.
Jursa, M., Moreno García, J.C., 2015. The ancient Near east and Egypt. In: Monson, A., Scheidel, W. (Eds.), Fiscal Regimes and the Political Economy of Premodern States. Cambridge University Press, Cambridge, pp. 115–165.
Keith, K., 1998. Spindle whorls, gender, and ethnicity at late chalcolithic hacinebi tepe. J. f. Archaeol. 25, 497–515.
Kussinger, S., 1988b. Tierknochenfunde vom Lidar höyük in südostanatolien (Grabungen 1979–86). Ludwig-Maximilians-Universität, München.
Kussinger, S., 1988. Tierknochenfunde vom Lidar Höyük in Sudostanatolien (Grabungen 1979–86). Institüt für Palaeoanatomie, Domest. und Geschichte der Tiermedizin. Ludwig-Maximilians-Universität, Munich.
Lam, Y.M., Pearson, O.M., Marean, C.W., Chen, X., 2003. Bone density studies in zooarchaeology. J. Archaeol. Sci. 30, 1701–1708.
Lassen, A.W., 2010. The Trade in Wool in Old Assyrian Anatolia. Jaarber. "Ex Oriente Lux" 42, 159–179.
Lau, H., 2016. Mobility, Cooperation, and Emergent Social Complexity in the Late Neolithic Near East. Interdep. Archaeol. Grad. Progr. University of California, Los Angeles, Los Angeles.
Lawrence, D., Wilkinson, T., 2015. Hubs and Upstarts: pathways to urbanism in the northern fertile crescent. Antiquity 89, 328–344.
Lechtman, H., 1993. Technologies of power: the andean case. In: Henderson, J.S., Netherly, P. (Eds.), Configurations of Power. Cornell University Press, Ithaca, pp. 244–280.
Lyman, R.L., 2003. The influence of time averaging and space averaging on the application of foraging theory in zooarchaeology. J. Archaeol. Sci. 30, 595–610.
Makarewicz, C., 2016. Toward an integrated isotope Zooarchaeology. In: Gruope, G., McGlynn, G.C. (Eds.), Isotopic Landscapes in Bioarchaeology. Springer, Berlin, pp. 189–209.
Marom, N., Bar-Oz, G., 2009. Culling profiles: the indeterminacy of archaeozoological data to survivorship curve modelling of sheep and goat herd maintenance strategies. J. Archaeol. Sci. 36, 1184–1187.
McCorriston, J., 1997. The fiber revolution: textile extensification, alienation, and social stratification in ancient Mesopotamia. Curr. Anthropol. 38, 517–535.
McMahon, A., 2020. Early urbanism in northern Mesopotamia. J. Archaeol. Res. 28, 289–337.
McMahon, A., Oates, J., Al-Quntar, S., Charles, M., Colantoni, C., Hald, M.M., Karsgaard, P., Khalidi, L., Soltysiak, A., Stone, A., Weber, J., 2007. Excavations at tell Brak 2006–2007. Iraq 69, 145–171.
Meadow, R.H., 1980. Animal bones: problems for the archaeologist together with some possible solutions. Paléorient 6, 65–77.
Meadow, R.H., 1999. The use of size index scaling techniques for research on archaeozoological collections from the Middle East. In: Becker, C., Manhart, H., Peters, J., Schibler, J. (Eds.), Historia Animalium Ex Ossibus. Verlag Marie Leidorf, Rahden, pp. 285–300.
Michel, C., 2014. Wool trade in upper Mesopotamia and Syria according to old babyloninan and old assyrian texts. In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow Books, Oxford, pp. 232–254.
Miller, N.F., 1984. The use of dung as fuel: an ethnographic example and an archaeological application. Paléorient 10, 71–79.
Minniti, C., 2014. Reassessing animal exploitation in northern Syria from the early bronze age to the persian/hellenistic period: the evidence from tell tuqan. In: Baffi, F., Fiorentino, R., Peyronel, L. (Eds.), Tell Tuqan: Excavations and Regional Perspectives. Cultural Developments in Inner Syria from the Early Bronze Age to the Persian/Hellenistic Period, Congedo Editore, Lecce.
Monahan, B.H., 2000. The Organization of Domestication at Gritille, A Pre-Pottery Neolithic B Site in Southeastern Turkey. Anthropology. Northwestern University, Evanston.
Payne, S., 1973. Kill-off patterns in sheep and goats: the mandibles from aşvan kale. Anatol. Stud. 23, 281–303.
Payne, S., 1987. Reference codes for wear stages in the Mandibular cheek teeth of sheep, ovis, and goats, Capra. J. Archaeol. Sci. 14, 609–614.
Payne, S., 1988. Animal bones from tell rubeideh. In: Killick, R.G. (Ed.), Tell Rubeideh: an Uruk Village in the Jebel Hamrin. British School of Archaeology in Iraq, Baghdad, pp. 98–135.
Peters, J., Pöllath, N., Arbuckle, B.S., 2017. The emergence of livestock husbandry in early neolithic Anatolia. In: Albarella, U., Rizzetto, M., Russ, H., Vickers, K., Viner-Daniels, S. (Eds.), The Oxford Handbook of Zooarchaeology. Oxford University Press, Oxford, pp. 247–265.
Peyronel, L., 2014. From weighing wool to weaving tools. textile manufacture at ebla during the Early Syrian period in the light of archaeological evidence. In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow Books, Oxford, pp. 124–138.
Piro, J.J., Crabtree, P.J., 2017. Zooarchaeological evidence for patoralism in the early transcaucasian culture. In: Mashkour, M., Beech, M. (Eds.), Archaeozoology of the near East 9. Oxbow Books, Oxford, pp. 273–283.
Pollock, S., 1991. Of priestesses, princes and poor relations: the dead in the Royal Cemetery of Ur. Cambridge Archaeol. J. 1, 171–189.
Pozo, J.M., Trentacoste, A., Nieto-Espinet, A., Guimarães, S., Valenzuela-Lamas, S., 2023. Zoolog R package: Zooarchaeological analysis with log-ratios. Quat. Int. 662, 4–12.
Price, M.D., 2021. Evolution of a taboo: pigs and people in the ancient near east. Oxford University Press, New York.
Price, M.D., Evin, A., 2019. Long-term morphological changes and evolving human-pig relations in the northern Fertile Crescent from 11,000 to 2000 cal. BC. Archaeol. Anthropol. Sci. 11, 237–251.
Price, M.D., Wolfhagen, J., Otárola-Castillo, E., 2016. Confidence intervals in the analysis of mortality and survivorship curves in zooarchaeology. Am. Antiq. 81, 157–173.
Price, M.D., Fisher, M.T., Stein, G.J., 2021. Animal production and secondary products in the fifth millenium BC in northern Mesopotamia: new data from tell surezha (Iraqi Kurdistan). Paléorient 47, 9–41.
Pruß, A., Sallaberger, W., 2004. Tierhaltung in nabada / tell Beydar und die bilderwelt der terrakotten als spiegel von wirtschaft und umwelt. Arch. Für Orientforsch. 50, 293–307.
Redding, R., 1984. Theoretical determinants of a herder's decisions: modeling variation in the sheep/goat ratio. In: Clutton-Brock, J., Grigson, C. (Eds.), Animals and Archaeology. BAR, Oxford, pp. 223–241.

Redding, R., 1981. Decision Making in Subsistence Herding of Sheep and Goats in the Middle East. Anthropol. Biol. Sci. University of Michigan, Ann Arbor.
Richardson, S., 2012. Early Mesopotamia: the presumptive state. Past Present 215, 3–49.
Richardson, S., 2017. Before things worked: a 'low-power'model of early Mesopotamia. In: Ando, C., Richardson, S. (Eds.), Ancient States and Infrastructural Power: Europe, Asia, and America. University of Pennsylvania Press, Philadelphia, pp. 17–62.
Rooijakkers, C.T., 2012. Spinning animal fibres at late neolithic tell Sabi Abyad, Syria? Paléorient 38, 93–109.
Rufolo, S.J., 2011. Specialized Pastoralism and Urban Process in Third Millennium BC Northern Mesopotamia. Near East. Stud. Johns Hopkins, Baltimore.
Russell, A., 2010. Retracing the Steppes: A Zooarchaeological Analysis of Changing Subsistence Patterns in the Late Neolithic at Tell Sabi Abyad, Northern Syria, c. 6900 to 5900 BC. Archaeology. Leiden University, Leiden.
Sallaberger, W., 2014. The value of wool in Early bronze age Mesopotamia: on the control of sheep and the handling of wool in the Presargonic to the ur III periods (c. 2400–2000 BC). In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow Books, Oxford, pp. 94–114.
Saña, M., Tornero, C., 2012. Use of animal fibres during the neolithisation in the middle Euphrates Valley: an archaeozoological appraoch. Paléorient 38, 79–91.
Sherratt, A., 1981. Plough and pastoralism: aspects of the secondary products revolution. In: Hodder, I., Isaac, G., Hammond, N. (Eds.), Patterns of the past: Studies in Honour of David Clarke. Cambridge University Press, Cambridge, pp. 261–305.
Sherratt, A., 1983. The Secondary products revolution of animals in the Old World. World Archaeol. 15, 90–104.
Siracusano, G., 2014. Third millennium BC Fauna at tell Beydar. In: Milano, L., Lebeau, M. (Eds.), Tell Beydar: Environmental and Technical Studies. Brepols, Turnhuot, pp. 271–304.
Stein, G.J., 1987. Regional economic integration in early state societies: third millennium B.C. pastoral production at gritille, Southeast Turkey. Paléorient 13, 101–111.
Stein, G.J., 1999. Rethinking world systems: diasporas, colonies and Interaction in uruk mespotamia. Univerity of Arizona Press, Tuscon.
Stein, G.J., 2012. The development of indigenous social complexity in late chalcolithic upper Mesopotamia in the 5th-4th millennia BC – an initial assessment. Origini 34, 125–151.
Stein, G.J., 1988. Pastoral Production in Complex Societies: Mid-Late Third Millennium BC and Medieval Faunal Remains from Gritille Höyük in the Karababa Basin, Southeast Turkey. University of Pennsylvania, PhD Dissertation. Department of Anthropology. Philadelphia.
Styring, A.K., Charles, M., Fantone, F., Hald, M.M., McMahon, A., Meadow, R.H., Nicholls, G.K., Patel, A.K., Pitre, M.C., Smith, A., Sołtysiak, A., Stein, G., Weber, J.A., Weiss, H., Bogaard, A., 2017. Isotope evidence for agricultural extensification reveals how the world's first cities were fed. Nat. Plants 3 nplants201776.
Sudo, H., 2010. The development of wool exploitation in ubaid-period settlements of North Mesopotamia. In: Carter, R.A., Philip, G. (Eds.), Beyond the Ubaid. University of Chicago Press, Chicago, pp. 169–180.
Thomas, R., Holmes, M., Morris, J., 2013. "So bigge as bigge may be": tracking size and shape change in domestic livestock in London (AD 1220–1900). J. Archaeol. Sci. 40, 3309–3325.
Trella, P.A., 2010. Evaluating collapse: the disintegration of Urban-Base societies in third millennium B.C. Upper Mesopotamia. Anthropology. University of Virginia, Charlottesville.
Ur, J.A., 2010. Cycles of civilization in northern Mesopotamia, 4400–2000 BC. J. Archaeol. Res. 18, 387–431.
Van Neer, W., De Cupere, B., 2000. Faunal remains from tell Beydar (excavation seasons 1992–1997). In: Van Lerberghe, K., Voet, G. (Eds.), Tell Beydar: Environmental and Technical Studies. Turnhout (Belgium), Brepolis, pp. 69–115.
Vigne, J.-D., Helmer, D., 2007. Was milk a "secondary product" in the Old World neolithisation process? Its role in the domestication of cattle, sheep and goats. Anthropozoologica 42, 9–40.
Vila, E., Helmer, D., 2014. The expansion of sheep herding and the development of wool production in the ancient near east: an archaeozoological and iconographical approach. In: Breniquet, C., Michel, C. (Eds.), Wool Economy in the Ancient near East and the Aegean: from the Beginnings of Sheep Husbandry to Institutional Textile Industry. Oxbow, Oxford, pp. 22–40.
Vila, E., 2010. Étude de la faune mammalienne de Tell Chuera, secteurs H et K (2000-2007) et de Kharab Sayyar, secteur A (Bronze ancien, Syrie), in: Meyer, J.-W. (Ed.), Ausgrabungen auf dem Tell Chuera in Nordost-Syrien. Teil II. Vorbericht zu den Grabungsgampagnen 1998 bis 2005. Harrassowwitz Verlag, Weisbaden, pp. 223–292.
Wattenmaker, P., 1987. Town and village economies in an early state society. Paléorient 13, 113–122.
Wattenmaker, P., Stein, G.J., 1986. Early pastoral production in Southeast Anatolia: faunal remains from kurban höyük and gritille höyük. Anatolica 13, 90–96.
Weber, J.A., 2006. Economic developments of urban proportions: evolving systems of animal-product consumption and distribution in the early an middle bronze ages in syro-Mesopotamia. Anthropology. University of Pennsylvania, Philadelphia.
Wickham, C., 1985. The uniqueness of the east. J. Peasant Stud. 12, 166–196.
Wilkinson, T.J., 1990. Town and Country in Southeastern Anatolia. Vol. I: Settlement and land use at Kurban Höyük and other sites in the Lower Karababa Basin. Oriental Institute of the University of Chicago, volume 109, Chicago.
Wolfhagen, J., 2020. Re-examining the use of the LSI technique in zooarchaeology. J. Archaeol. Sci. 123, 105254.
Wolfhagen, J.L., 2023. Estimating the ontogenetic age and sex composition of faunal assemblages with bayesian multilevel mixture models. J. Archaeol. Method Theory.
Wolfhagen, J., Price, M.D., 2017. A probabilistic model for distinguishing between sheep and goat postcranial remains. J. Archaeol. Sci. Reports 12, 625–631.
Wright, R., 1989. Comment. Curr. Anthropol. 30, 599–600.
Zagarell, A., 1986. Trade, women, class, and society in ancient Western Asia. Curr. Anthropol. 27, 415–430.
Zeder, M.A., 1991. Feeding cities: specialized animal economy in the ancient near east. Smithsonian Institute Press, Washington, DC.
Zeder, M.A., 1994. After the revolution: post-neolithic subsistence in northern Mesopotamia. Am. Anthropol. 96, 97–126.
Zeder, M.A., 2006. A critical assessment of Markers of initial domestication in goats (Capra hircus). In: Zeder, M.A., Bradley, D.G., Emschwiller, E., Smith, B.D. (Eds.), Documenting Domestication: New Genetic and Archaeological Paradigms. University of California Press, Berkeley, pp. 181–208.
Zeder, M.A., 2017. Out of the Fertile Crescent: the dispersal of domestic livestock through Europe and Africa. In: Boivin, N., Crassard, R., Petraglia, M. (Eds.), Human Dispersal and Species Movement: from Prehistory to the Present. Cambridge University Press, Cambridge, pp. 261–303.
Zeder, M.A., Lapham, H.A., 2010. Assessing the reliability of criteria used to identify postcranial bones in sheep, Ovis, and goats, Capra. J. Archaeol. Sci. 37, 2887–2905.
Zeder, M.A., Pilaar, S.E., 2010. Assessing the reliability of criteria used to identify mandibles and Mandibular teeth in sheep, Ovis, and goats, Capra. J. Archaeol. Sci. 37, 225–242.