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Documenting the initial appearance of domestic cattle in the Eastern Fertile Crescent (northern Iraq and western Iran)

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A B S T R A C T

In this paper we address the timing of and mechanisms for the appearance of domestic cattle in the Eastern Fertile Crescent (EFC) region of SW Asia through the analysis of new and previously published species abundance and biometric data from 86 archaeofaunal assemblages. We find that *Bos* exploitation was a minor component of animal economies in the EFC in the late Pleistocene and early Holocene but increased dramatically in the sixth millennium BC. Moreover, biometric data indicate that small-sized *Bos*, likely representing domesticates, appear suddenly in the region without any transitional forms in the early to mid sixth millennium BC. This suggests that domestic cattle were imported into the EFC, possibly associated with the spread of the Halaf archaeological culture, several millennia after they first appear in the neighboring northern Levant.

1. Introduction

The domestication of cattle (*Bos taurus*) from wild aurochs (*Bos primigenius*) was one of the most important consequences of the Neolithic period in Southwest Asia. Providing a wide range of resources including meat, dairy, traction, hides, and horn cattle became a central part of agro-pastoral economies across Eurasia and supported the development of increasingly complex societies. Although the initial, precocious domestication of taurine cattle in the central portion of the Fertile Crescent, a region including the Syrian and Turkish parts of the Upper Euphrates basin, has been addressed in detail (Helmer et al., 2005; Peters et al., 2005) very little is known about the timing and mechanisms of the appearance of domestic cattle in the eastern wing of the Fertile Crescent (EFC). The EFC encompasses portions of the Tigris drainage, the Zagros Mountains of western Iran and the adjacent Piedmont zone of northern Iraq. Although the Neolithic of this region was the target of intensive study by archaeologists in the mid 20th century and again in the early 21st century (e.g., Alizadeh, 2008; Braidwood and Howe, 1960; Coon, 1951; Darabi, 2012; Kozlowski, 1989; Matthews et al., 2013; Matthews and Nashli, 2013), analysis of the role of cattle in the EFC has lagged despite renewed interest in the prehistory of this region. As a result, the timing and mechanisms for the appearance of domestic cattle in this core area of the Neolithic Revolution remain poorly understood.

In this paper we synthesize and assess published and unpublished zooarchaeological evidence for the hunting of aurochs (*Bos primigenius*) and management of taurine cattle (*Bos taurus*) in the EFC. We focus on biometric data and the abundance of cattle remains from 86 faunal assemblages in the region in order to 1) define patterns in the exploitation of *Bos* and 2) address the timing of and mechanisms behind the appearance of domestic cattle in the region.

1.1. Domestication of taurine cattle in the Fertile Crescent

Zooarchaeological research has identified the upper Euphrates basin and adjacent portions of the uppermost Tigris basin as the

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'hearth' of taurine cattle domestication (Helmer et al., 2005; Hongo et al., 2009; Peters et al., 2005). Here, zooarchaeological research has documented a long tradition of aurochs exploitation in the late Pleistocene and early Holocene which evolved into systems of early *Bos* management in the ninth millennium BC in northern Syria and southeastern Turkey (Helmer et al., 2005). Control over cattle populations at this time is further suggested by their appearance on Cyprus where they were transported by Neolithic seafaring colonists from mainland SW Asia in the late ninth millennium BC (Vigne, 2015; Vigne et al., 2011). Despite evidence for management, these earliest managed *Bos* populations exhibit phenotypes that are largely indistinguishable from aurochs.

A dramatic decline in the body size of both male and female *Bos*, often used as a proxy for the suite of biological and behavioral changes known as the 'domestication syndrome' associated with domesticated livestock (Arbuckle, 2005; Hammer, 1984; Price, 1984; Zeder, 2012), is first evident at sites along the Turkish Euphrates in the early eighth millennium BC including Mezraa-Teleilat and Gritille and slightly later at Gürcütepe and Akarçay (SE Turkey) (Peters et al., 2015; Sana and Tornero, 2008) and within a few centuries cattle management is evident along the Syrian Euphrates at Tell Halula (Sana and Tornero, 2013).

At the site of Çayönü Tepesi, located high in the Tigris drainage in Southeast Turkey, Hongo (Hongo et al., 2004, Hongo et al., 2009) has identified gradual changes in kill-off, body size and diet through the stratigraphic sequence which may represent a process of local domestication beginning in earnest during the so-called Channel phase occupation, dating to the late ninth millennium BC, and continuing through the end of the Pre-pottery Neolithic (early seventh millennium BC). Paralleling the situation in the Euphrates basin, despite evidence for early *Bos* management, it is not until the mid eighth millennium BC (Large Room subphase) that cattle with a domestic phenotype (i.e., small body size) are consistently evident at Çayönü.

The presence of a significant (>500 year) time lag between the initiation of cattle management and the appearance of recognizable 'domestic' morphologies emphasizes the complexity of identifying the earliest stages of cattle management with traditional zooarchaeological datasets. However, once domestic phenotypes are present in faunal assemblages dating to the eighth millennium cal BC they can be used effectively to follow the spread of domestic cattle into neighboring regions without traditions of local aurochs management (e.g., Arbuckle et al., 2014).

Following the initiation of cattle management and the appearance of domestic *Bos* phenotypes in the eighth millennium BC in the upper Euphrates basin, small-sized domestic cattle spread westward and southward into neighboring regions (Conolly et al., 2012). Cattle management was practiced in the Damascus basin at Tell Aswad in the eighth millennium BC (Helmer and Gourichon, 2008), but domestic cattle appear quite late in the rest of the southern Levant. Although the remains of aurochs are abundant in some early Neolithic sites, especially along the Mediterranean coastal plain and in the Jordan Valley, small sized domestic cattle are not evident in the southern Levant until the late seventh and early sixth millennium cal BC (Becker, 2002; Haber and Dayan, 2004; Horwitz and Ducos, 2005; Marom and Bar-Oz, 2013).

In Anatolia, small-sized domestic cattle appear outside of the Euphrates basin with the first Neolithic settlements in SW Turkey in the first half of the seventh millennium and spread into the NW a few centuries later (Arbuckle, 2013; Arbuckle et al., 2014; Çakırlar, 2012, 2013; Russell et al., 2013a). In central Anatolia, where Neolithic settlements are present from the late ninth millennium BC, morphologically wild cattle were exploited for more than a millennium at Boncuklu, Aşıklı Höyük and in the early levels at Çatalhöyük, with domesticates appearing only in the late seventh millennium BC (Arbuckle and Makarewicz, 2009; Baird, 2012; Russell et al., 2005, Russell et al., 2013a). In the mountainous Caucasus region, cattle management emerges in the early to mid sixth millennium BC (Badalyan et al., 2010; Hansen et al., 2006; Lyonnet et al., 2015).

Although traditions of aurochs hunting were present in both central Anatolia and parts of the southern Levant, there is little evidence to suggest that local aurochs populations were domesticated in either of these regions (although see von den Driesch and Wodtke, 1997). Instead, the zooarchaeological data suggest that domestic cattle, originally from the northern Levant, were transported by Neolithic colonists or were adopted by local agropastoralists in Anatolia, the Caucasus, and the southern Levant over an extended period from c. 7800–5500 BC.

1.2. Bos exploitation in the Eastern Fertile Crescent (EFC)

Despite playing an important role in the creation of archaeological narratives concerning the Neolithic Revolution in the mid 20th century (e.g., Braidwood and Reed, 1957), our understanding of the origins of domestic livestock in the EFC lags behind that in neighboring areas. Zeder's work (2001, 2005, Zeder and Hesse, 2000) on museum collections has resulted in a high resolution understanding of the timing and processes of goat domestication in western Iran and mapped the diffusion of domestic sheep into the EFC, while the recent reanalysis and dating of the pig remains from Qalat Jarmo has clarified the spatio-temporal patterns of the emergence of pig husbandry in the region (Price and Arbuckle, 2015). The situation for cattle, however, has not been similarly reassessed with Flannery's (Hole et al., 1969) work from the 1960s representing the most recent regional synthesis of evidence for cattle domestication in the EFC (see also Reed, 1960).

In a remarkably prescient study, Flannery (Hole et al., 1969) summarized archaezoological evidence from the five Neolithic sites available at the time in western Iran and northern Iraq including Jarmo, Tepe Guran, Banahilk, Tepe Sabz and Ali Kosh. Working with this small sample, Flannery observed that small sized cattle (i.e., smaller than European aurochs) appeared suddenly along with an increase in the abundance of *Bos* remains in the Sabz phase of the Deh Luran sequence, dated to the sixth millennium BC. Flannery concluded: "We can therefore point with some confidence to 5500 BC as a crucial date for the appearance of domestic cattle in the Zagros-Mesopotamian region" (Hole et al., 1969:303). In regards to the mechanism by which cattle appeared in western Iran he argued that domestic livestock were likely imported to the region "with no previous evidence of "incipient cattle domestication"" (Hole et al., 1969:303).

Following this seminal publication, very little has been done to confirm, test, or expand on these results and despite a significant increase in the data available from the region, the broad patterns of Neolithic *Bos* exploitation and domestication have not been addressed on a regional scale in the EFC. Moreover, recent research has suggested that the central Zagros, in particular, was home to an innovative and early Neolithic tradition that developed from local Epipaleolithic traditions and included autochthonous domestication processes (Matthews and Nashli, 2013). As a result, it remains unclear if the late appearance of domestic cattle Flannery observed on the Deh Luran plain is a local phenomenon or a characteristic feature of the EFC as a whole.

2. Material and methods

In this paper we synthesize and assess published zooarchaeological evidence for the hunting of aurochs (*Bos primigenius*) and management of taurine cattle (*Bos taurus*) in the eastern wing of the Fertile Crescent (EFC) (including western Iran, the Upper Tigris drainage, and the piedmont zone of northern Iraq) as well as unpublished data from the Neolithic sites Çayönü Tepesi, Salat Cami Yanı, and Sumaki Höyük (Upper Tigris, Turkey) and re-analyzed data Qalat Jarmo (northern Iraq). We focus on the abundance of cattle remains from 86 faunal assemblages in order to define regional patterns in the exploitation of *Bos* (Fig. 1; Table S1). The frequencies of *Bos* remains were calculated based on the total number of medium and large mammals identified in each assemblage ($NISP_{large\text{-}med\ mammal}$) since these data were most frequently available in published reports.

In addition, we have compiled new and published biometric data for *Bos* remains from 31 assemblages in the EFC dating from the Epipaleolithic to the Bronze Age in order to assess variations in body size and to address the nature of *Bos* exploitation and domestication over time in this region (Table S2). Biometric data are widely used in zooarchaeology to assess hunting strategies as well as to identify declines in body size associated with the process of animal domestication and the identification of the diffusion of domestic livestock (Arbuckle et al., 2014; Peters et al., 2005; Vigne,

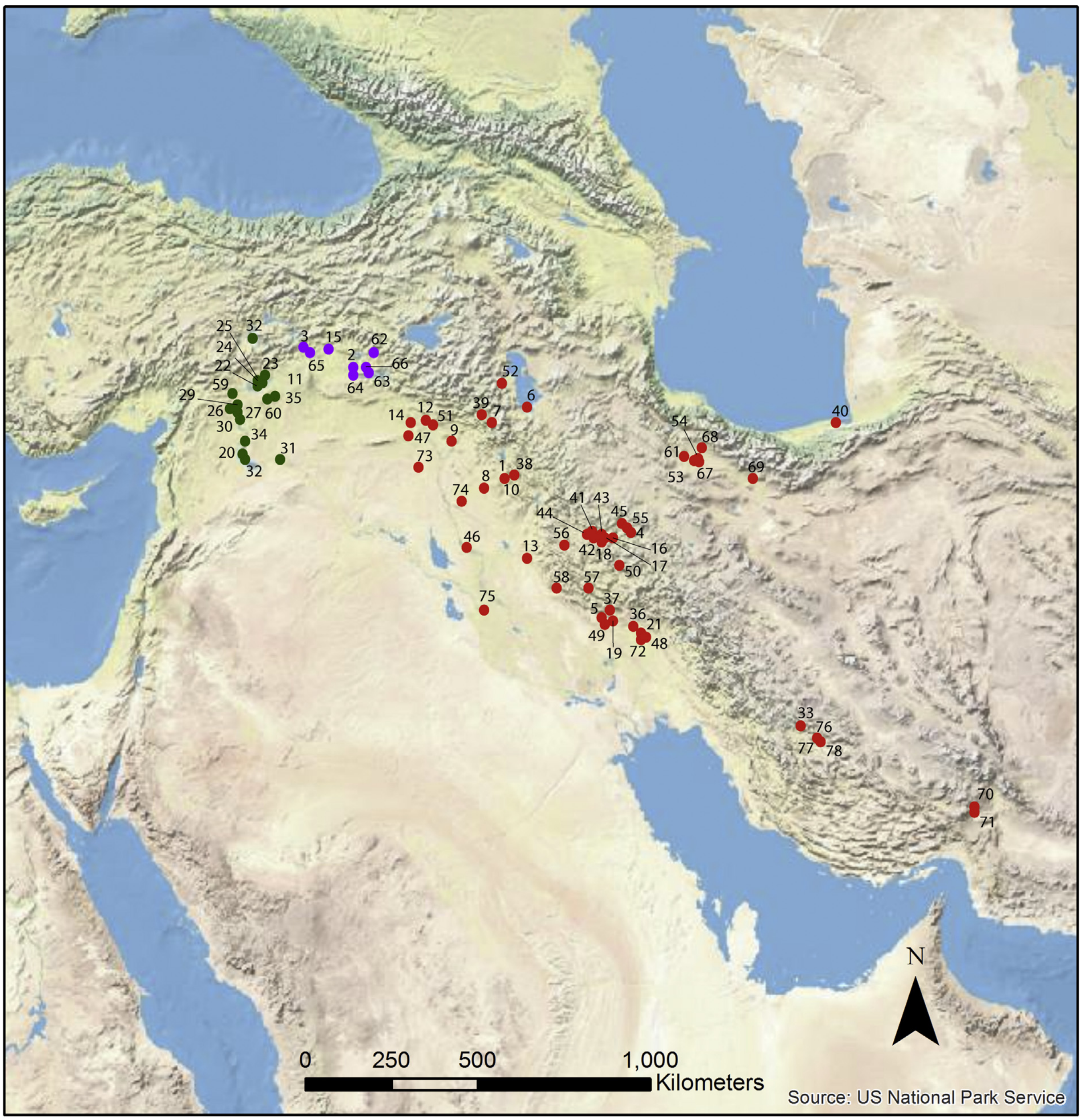

Fig. 1. Map with sites mentioned in the text. 1 – Jarmo; 2 – Körtik Tepe; 3 – Çayönü; 4 – Ganj Dareh; 5 – Tepe Sabz; 6 – Hajji Firuz; 7 – Banahilk; 8 – Matarrah; 9 – M'lefaat; 10 – Karim Shahir; 11 – Nevalı Çori; 12 – Nemrik; 13 – Choga Mami; 14 – Yarim Tepe; 15 – Girikihaciyan; 16 – Siahbid; 17 – Sarab; 18 – Dehsavar; 19 – Ali Kosh; 20 – Mureybet; 21 – Chogha Bonut; 22 – Çavi Tarlası; 23 – Hassek Höyük; 24 – Hayaz Höyük; 25 – Lidar Höyük; 26 – Tell Turlu; 27 – Fıstıkı Höyük; 28 – Arslantepe; 29 – Hacinebi; 30 – Tell Amarna; 31 – Tell Zeidan; 32 – Habuba Kabira; 33 – Tall i-Malyan; 34 – Tell Halula; 35 – Göbekli Tepe; 36 – Tepe Tula'I; 37 – Chogha Sefid; 38 – Palegawra; 39 – Zawi Çemi Shanidar; 40 – Belt Cave; 41 – Warwasi; 42 – Asiab; 43 – Bisitun; 44 – Kobeh; 45 – Ghar-i-Kar; 46 – Tell es-Sawwan; 47 – Qermez Dere; 48 – Sarafabad; 49 – Tepe Farukhabad; 50 – Yafteh; 51 – Hatara; 52 – Tamtama; 53 – Qabrestan; 54 – Zagheh; 55 – Godin Tepe; 56 – Tuwah Khoshkeh; 57 – East Chia Sabz; 58 – Chogha Golan; 59 – Mezraa Teleilat; 60 – Yeni Mahalle; 61 – Khaleseh; 62 – Hallan Çemi; 63 – Hasankeyf; 64 – Salat Cami Yani; 65 – Girikhaciyan; 66 – Sumaki; 67 – Chahar Boneh; 68 – Cheshmeh Ali; 69 – Ebrahimabid; 70 – Tepe Yahya; 71 – Gaz Tavila; 72 – Choga Mish; 73 – Umm Dabaghiyah; 74 – Tell Rubeideh; 75 – Ras Al Amiya; 76 – Tall i-Bakun; 77 – Tall i-Jari; 78 – Tall i-Mushki.

2015).

In this study, biometric data have been transformed using the Log Size Index (LSI) method in order to compare larger samples of breadth and depth measurements from multiple skeletal elements; analyzing log transformed measurements can also improve the comparability of biometric datasets (Meadow, 1999; Osborn, 2002; Vigne, 2015). LSI values are calculated using the formula, $Log_{10}(X-Y) = LSI$, in which X is an archaeological measurement (e.g., humerus Bd) and Y is the corresponding measurement from a 'standard animal'. We use the widely cited Ullerslev cow aurochs from Mesolithic Denmark as our standard animal following measurements published in Steppan (2001) (note: there are several differences in the measurements given by Steppen for the Ullerslev aurochs compared to those presented in the original description of this aurochs by Degerbøl and Fredskild (1970) and also in the frequently cited work by Grigson (1989)).

We also apply Gaussian Mixture Analysis to our biometric datasets (using PAST v.1.89 software) in order to address the biometric characteristics of both male and female *Bos* in our assemblages (Hammer et al., 2001; Monchot, 1999; Vigne, 2015). The PAST software uses an expectation maximization (EM) algorithm to determine the sizes of two component populations (k). Because we assume that sexual dimorphism accounts for much of the variation, we set $k = 2$. PAST runs 20 iterations of the algorithm and uses the Akaike Information Criterion to select the most appropriate model.

3. Results

3.1. Frequency of Bos in the EFC

The frequencies of *Bos* remains, including both aurochs and domestic cattle, provide a useful index of the importance of *Bos* exploitation and are presented in Fig. 2 for the EFC and the Euphrates basin. Frequency data show that *Bos* remains are generally represented in low frequencies (mean = 3.4% $NISP_{large\text{-}med\ mammal}$) in the EFC prior to the sixth millennium BC. This is in contrast to data from contemporary sites in both the Euphrates basin and at Çayönü Tepesi on the upper Tigris basin, where *Bos* remains are found in much higher frequencies ($Mean_{Euphrates} = 15.0\%\ NISP_{large\text{-}med\ mammal}$; $Mean_{Çayönü} = 16.2\%\ NISP_{large\text{-}med\ mammal}$). The frequency of *Bos* in the Neolithic EFC is low in all regions from which samples are available including the Turkish Tigris (south of Çayönü), the Iraqi Tigris valley, the Tigris piedmont, the central and southern Zagros, and northern Iran. The relative unimportance of *Bos* exploitation in the EFC extends from the Middle Paleolithic to the sixth millennium BC (late Neolithic), when the frequency of Bos increases dramatically (>10%) at sites including Banahilk in the Iraqi piedmont, Siahbid in the central Zagros, Tepe Sabz in the Deh Luran, Chogha Mish on the Susiana plain, Tepe Yahya in Southeast Iran, and Belt Cave, Chahar Boneh, and Ebrahimabid in northern Iran. The geographic distribution of these sites indicates that this increase in *Bos* exploitation occurred across multiple regions. However, even in the late Neolithic, interest in *Bos* was not universal and *Bos* remains are poorly represented (<10%) at many sites in the EFC including Haji Firuz, Tepe Khalaseh, Zagheh, Tell es-Sawwan and Gaz Tavila; a trend that continues into the Chalcolithic at many sites (Mashkour, 2002, 2006).

3.2. Biometric data

Comparing LSI values for *Bos* from the EFC and Euphrates regions, it is clear that median body size changes significantly over time (Kruska-Wallis test for equal medians, $H = 379.9$, $p < 0.001$) but the chronology of change in body size differs dramatically between regions (Fig. 3). In the Euphrates region, a large-scale decline in body size (reflected in median, maximum and minimum LSI values) is evident in the MPPNB levels of Mezraa-Teleilat dating to the early eighth millennium BC compared to the larger aurochs from tenth millennium BC Tell Mureybet (decline in mean LSI from 0.008 to −0.033; results of statistical comparison are presented in Table S3). This reduction in body size, reflecting the appearance of domestic cattle in the Euphrates valley, continues into the later phases at Mezraa-Teleilat (mean LSI = −0.051 in the PN) as well as the Pre-pottery Neolithic occupation at Gritille (mean LSI = −0.042) and into the Pottery Neolithic at Çavı Tarlası (−0.060), Tell Turlu (−0.044) and Chalcolithic Hassek Höyük (−0.069). In the Upper Tigris region, local aurochs are represented by LSI values from Körtik Tepe (mean LSI = 0.010) and the Round and Grill phases at Çayönü (−0.002 and −0.004) (late tenth and early ninth millennia BC). Here, newly phased biometric data from Çayönü show that mean body size is relatively constant through the Round, Grill, and Channel phases, followed by a decline in the Cobble phase (mean LSI = −0.022) dating to c.8000 BC. A more

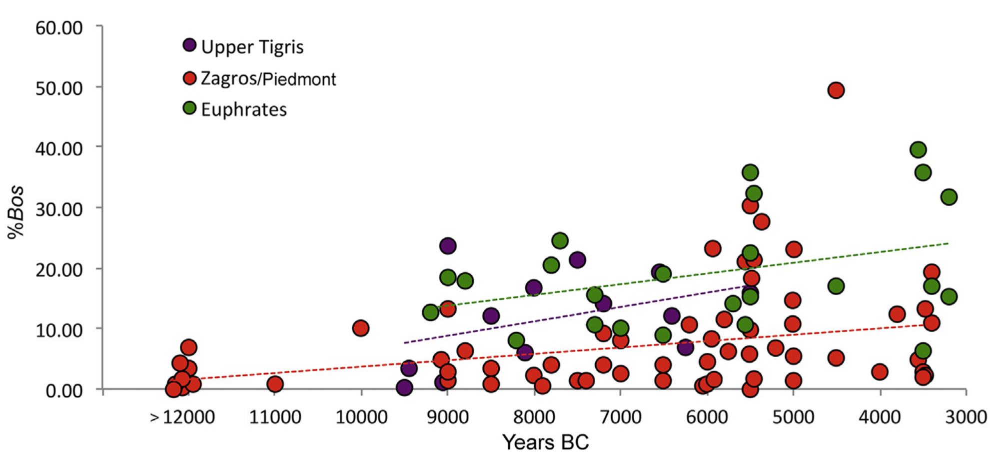

Fig. 2. Frequency of *Bos* remains through time in the EFC (red), Upper Tigris (purple), and Euphrates (green). EFC and Upper Tigris sites listed in caption of Fig. 1. Euphrates sites include Göbekli Tepe (Peters et al., 2005); Mureybet (Gourichon and Helmer, 2008); Yeni Mahalle (Çelik, 2011); Nevalı Çori (Peters et al., 2005); Halula (Sana Segui, 2000); Mezraa-Teleilat (Ilgezdi, 2008); Tell Turlu (Ducos, 1991); Çavı Tarlaşı (Schäffer and Boessneck, 1988); Tell Amarna (Sana, 2004); Fıstıklı (Orton, nd); Tell Zeidan (Grossman and Hinman, 2013); Arslantepe (Bartosiewicz, 1998); Habuba Kabira (von den Driesch, 1993); Hacınebi (Stein and Nicola, 1996); Hayaz Höyük (Buitenhuis, 1985); Hassek Höyük (Boessneck, 1992). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

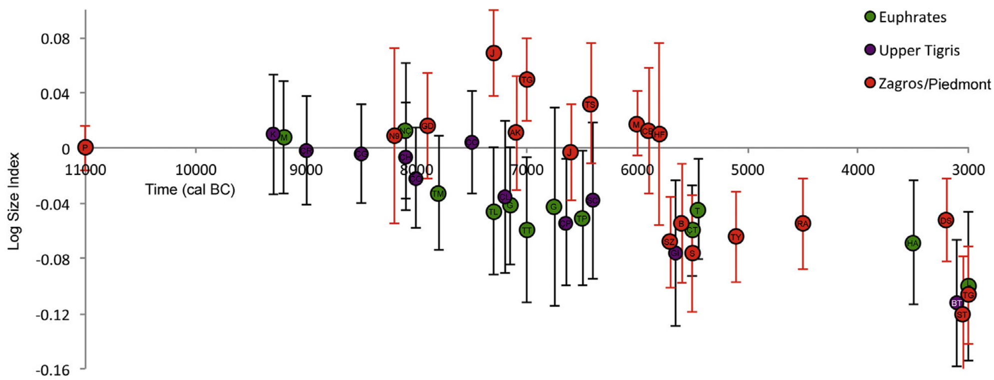

Fig. 3. Scatter plot of mean LSI values through time for sites in the EFC (red), Upper Tigris (purple), and Euphrates (green). Bars represent standard deviations. (From left to right) P = Palegawra; K = Körtik; M = Murebet; ÇR = Çayonü Round; ÇG = Çayonü Grill; N9 = Nemrik 9; NÇ = Nevalı Çori; ÇH = Çayonü Channel; ÇO = Çayonü Cobble; GD = Ganj Dareh; TM = Teleilat MPPNB; ÇC = Çayonü Cell; J = Jarmo PPN and PN; TL = Teleilat LPPNB; ÇL = Çayonü Large Room; G = Gritille MPPNB, LPPNB; AK = Ali Kosh; TG = Tepe Guran Neolithic; TT = Teleilat Transitional; ÇP = Çayonü Pottery Neolithic; TP = Teleilat Pottery Neolithic; SC = Salat Cami Yanı; TS = Tepe Sarab; M = Matarrah; CB = Chogha Bonut; HF = Haji Firuz; SZ; B = Banahilk; GI = Girikihacıyan; S = Tepe Sabz; ÇT = Çavı Tarlaşı; T = Turlu; TY = Tepe Yahya VII; RA = Ras al-Amiya; HA = Hassek Höyük; DS = Desavar; ST = Shah Tepe; TG = Tepe Guran Bronze Age; L = Lidar Höyük; BT = Bronze Age Tigris sites (from Berthon, 2011). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

dramatic (and highly significant, $p < 0.001$) decline in body size is evident in the Large Room subphase (mean LSI = −0.036) dating to the late eighth millennium BC where LSI values are similar to those from the Pottery Neolithic assemblage at Salat Cami Yanı (−0.038) (mid seventh millennium BC).

In the EFC, mean LSI values for sites dating to the ninth through seventh millennia BC are among the highest in SW Asia (Fig. 3) with Ganj Dareh (mean LSI = 0.015), Ali Kosh (0.011), Tepe Guran (0.049), PPN Jarmo (0.069), Tepe Sarab (0.032), PN Matarrah (0.017) and Chogha Bonut (0.012) all exhibiting mean values well above the standard animal. A dramatic (and highly statistically significant; see Table S3) decline in size is evident at sites in the mid sixth millennium including Banahilk (mean LSI = −0.055), Tepe Sabz (−0.068), Siahbid (−0.077) and slightly later at Tepe Yahya (−0.064). The *Bos* remains from these sixth millennium assemblages are comparable in size to those from Halaf assemblages in southeastern Turkey and also to those from later EFC Chalcolithic assemblages from Ras Al Amiya (mean LSI = −0.055) and Dehsavar (−0.052).

A combination of biometric data and species frequencies (Fig. 4) show that (with the exception of Çayönü) sites in the EFC dating from the ninth through seventh millennia BC are characterized by low frequencies of large-sized *Bos* remains, suggesting that aurochsen were a minor component of subsistence systems in this region in the early Holocene and that domestic cattle were absent. Among these early sites, Pre-pottery Neolithic Jarmo exhibits a relatively high frequency (9.1%) of *Bos* remains and the largest LSI mean (mean LSI = 0.069) indicating a focus on hunting large bull aurochs. This pattern is reversed in the Jarmo Pottery Neolithic assemblage where *Bos* is less frequent (4.0%) and the distribution of LSI values (mean LSI = −0.003) is skewed to the left suggesting the predominance of female aurochsen. The presence of one very small outlier at PN Jarmo (a fused proximal radius, Bp = 70.8 mm [LSI = −0.148], BFP = 65.4 mm [LSI = −0.139], assigned to trench J1, level3a; which is not reported in Stampfli's (1983) publication of the Jarmo fauna) is difficult to interpret. It may represent a single domestic animal imported into the settlement but, given its status as a statistical outlier, is unlikely to represent the appearance of domestic cattle management in the Iraqi piedmont.

In addition, the presence of a small number of small-sized cattle at Nemrik 9 (with LSI values from −0.103 to −0.188) (see Fig. 4) is difficult to interpret. These specimens are smaller than the Neolithic domestic cattle from the EFC and are comparable in size to Bronze Age domesticates from the Tigris valley. Given serious

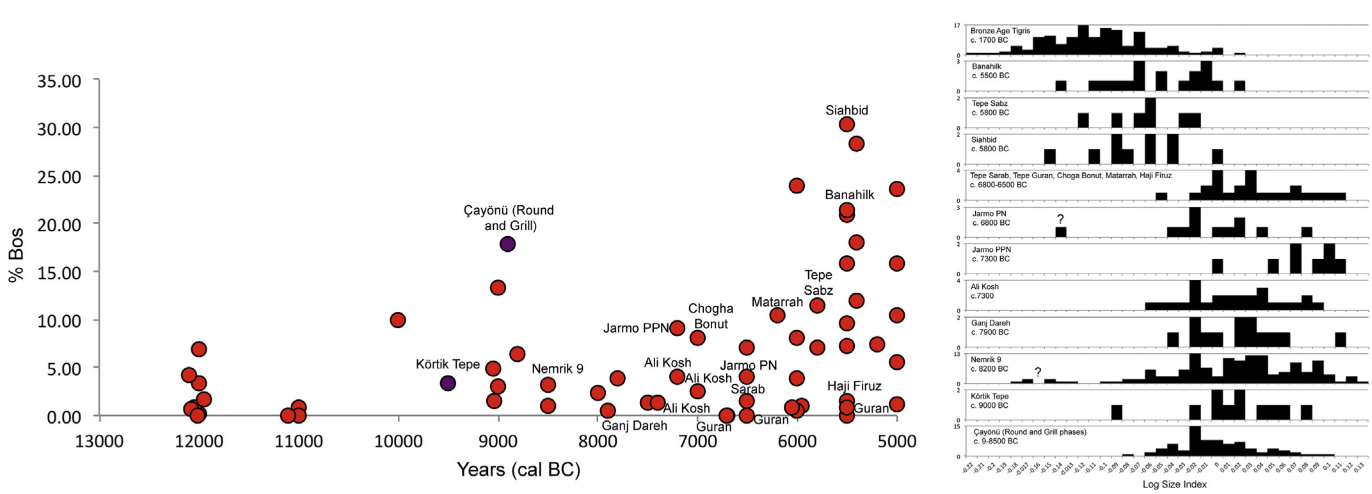

Fig. 4. A) Frequencies of *Bos* remains at EFC sites; b) histograms of LSI values at key sites in the EFC.

questions about the chronology of the settlement (Watkins, 1992) and the consistent lack of evidence for domestic cattle in the EFC prior to the sixth millennium BC, these remains likely reflect an intrusive element in the site's stratigraphy rather than the earliest domestic cattle in the EFC.

The biometric data show that a clear shift in the size of *Bos* occurs in the sixth millennium BC (mean LSI declines from 0.02 to −0.062) with the sudden appearance of small-sized domestic cattle as well as an increase in the frequency of these small cattle in faunal assemblages in the northern Iraqi Piedmont (Banahilk), and the central (Siahbid) and southern Zagros (Tepe Sabz) and slightly later in Southeast Iran (Tepe Yahya). The appearance of small-sized, domestic cattle in the EFC is rather sudden with no evidence for a gradual transition from local aurochs to domestic cattle in contrast to evidence from the Çayönü sequence and from the Euphrates basin.

Using mixture analysis to assign LSI values to a specific sex, we found that for the ninth through seventh millennia BC assemblages in the EFC the mean LSI values generated for female aurochs are consistent and comparable to those from Mureybet and the Round and Grill phases of Çayönü while values for males exhibit more variation but are still consistently larger than the standard animal (see Fig. 5). In most cases the mean LSI value is closer to the mean male size suggesting EFC hunters more frequently targeted bull aurochsen. Sixth millennium BC assemblages show a dramatic decline in both male and female size with mean LSI values much closer to the female average suggesting that domestic cows dominate in these assemblages. These estimates of the size of male and female *Bos* over time indicate that the decrease in LSI values evident in the sixth millennium BC is not simply the result of an increase in the frequency of female *Bos* pulling down average LSI values (also see Manning et al., 2015) but instead reflects a dramatic decline in the size of both male and female cattle—supporting the conclusion that domestic stock appeared suddenly in the region.

4. Discussion

The results of our analysis allow us to address the origins, chronology, and process of cattle domestication in the EFC. Small-sized cattle representing domestic individuals with phenotypes that diverged significantly from local aurochsen appear suddenly in the EFC in the sixth millennium BC. At the same time, the frequency of *Bos* increases dramatically at multiple sites in the northern Iraqi piedmont, the middle and southern Zagros, the Susiana plain and Southeast Iran. Although biometric data are not available from sites in northern Iran, it is likely that the relatively high frequencies of *Bos* at mid to late sixth millennium BC sites such as Belt Cave (21%), Chahar Boneh (18%), Ebrahimabid (12%), and Cheshmeh Ali (14%) represent the appearance of domesticates in that region (Young and Nashli, 2013). This combination of frequency data and biometrics from a large sample of assemblages supports Flannery's conclusion that the early to mid sixth millennium BC was the crucial period when domestic cattle appear in the EFC.

In addition, the appearance of small-sized, domestic cattle in the EFC occurs suddenly with no evidence for gradual shifts in body size over time as would be expected if local aurochsen populations were domesticated as part of an autochthonous process, as evidenced in the Euphrates region and perhaps also at Çayönü. This suggests that domesticates were imported into the region in the sixth millennium BC—likely from settlements in the Euphrates basin—again supporting Flannery's (Hole et al., 1969) interpretation of the mechanisms responsible for the emergence of cattle husbandry in the EFC.

Although zooarchaeological evidence from ninth millennium BC sites indicates that the intensive management of phenotypically wild animals preceded the appearance of changes in body size and horn shape by many centuries (Helmer, 2008; Peters et al., 2015; Vigne, 2011, 2015), there is currently no clear evidence for the management of morphologically wild *Bos* in Neolithic sites in the EFC prior to the sixth millennium BC, even in the central Zagros region where evidence for other aspects of the Neolithic transition, including goat management, are evident at an early date (Matthews and Nashli, 2013; Zeder and Hesse, 2000). Instead, the diffusion of domestic cattle into the EFC seems to coincide, at least chronologically, with the spread of Halaf influence into the region. Given similarities in the biometrics and frequencies of *Bos* from Halaf sites in the Euphrates and upper Tigris (e.g., Tell Turlu, Girikihaciyan, Fıstıklı, Çavı Tarlaşı, and Tell Halula) and those from sixth millennium sites in the EFC including Banahilk and Siahbid, as well as iconographic evidence for the importance of cattle in Halaf communities (e.g., McCarty, 2013; Nieuwenhuyse, 1997), the spread of Halaf ceramics and architectural forms may have also involved the movement of livestock and livestock management practices that had previous been absent in the EFC.

Our results raise questions as to why domestic cattle appear relatively late (sixth millennium BC) in the EFC despite its proximity to the earliest center of cattle domestication where domesticates are present by the end of the ninth millennium BC. Neolithic

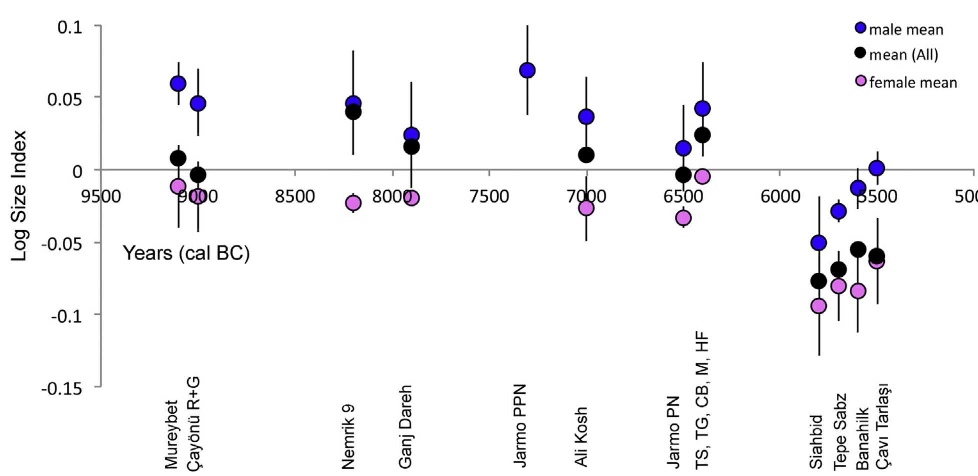

Fig. 5. Plots of male, female and mean LSI values from sites in the EFC calculated using mixture analysis (PAST). Bars represent standard deviations. TS = Tepe Sarab; TG = Tepe Guran; CB = Chogha Bonut; M = Matarrah; HF = Haji Firuz.

economies in SW Asia often show strong regional preferences for specific taxa which are highly conservative over long periods of time (Arbuckle, 2014; Arbuckle and Atici, 2013). From our survey of the available data, it is clear that aurochs exploitation was never an important part of Pleistocene and early Holocene animal economies in the EFC in contrast to neighboring regions with robust traditions of *Bos* exploitation including the upper Euphrates basin, Çayönü (upper Tigris basin), central Anatolia and the Levantine coastal plain and Jordan valley (Baird, 2012; Horwitz and Ducos, 2005; Ilgezdi, 2008) (Fig. 2). Instead, in the northern Iraqi piedmont zone, gazelle were the primary game animal, while in the Zagros goats and secondarily sheep were the focus of early animal economies (Dobney et al., 1999; Zeder, 2008). These long established animal practices, which become entangled within established social and ritual structures (Hodder, 2014; Russell, 2012) and are often highly resistant to change, may be partially responsible for the long-term disinterest in cattle management in the EFC region.

The low frequency of aurochs in EFC assemblages is undoubtedly related to the semi-arid climate of the region as well as the rugged topography of the Zagros which likely did not support large populations of aurochs. However, Connolly's (Conolly et al., 2012) recent analysis of *Bos* remains across Neolithic SW Asia suggest that aurochs are under-represented in the EFC compared to predictions based on environmental productivity, especially in the Iraqi piedmont regions. It is possible, therefore, that although the relative unimportance of *Bos* in EFC cultures was initially influenced by environmental factors (i.e., limited local availability), cultural factors may have also played a significant role. This is supported by dramatic differences in the use of *Bos* at Çayönü in the upper Tigris basin compared to sites located further downstream but in broadly similar (although not identical) environments. Çayönü, with its cultural affiliations with the Euphrates basin (Borrell et al., 2013; Kozlowski and Gebel, 1996; Özdoğan and Özdoğan, 1989), exhibits a strong tradition of aurochs hunting extending back into the Epipaleolithic which transformed into local system of cattle management. In contrast, *Bos* remains are rare and domesticates absent at Hallan Çemi, Körtik Tepe, and Hasankeyf (Arbuckle and Özkaya, 2007; Özkaya et al., 2011; Starkovich and Stiner, 2009), sites with material culture affiliations with the Epipaleolithic cultures of the Zagros (Peasnall, 2000). Given these differences, it is possible that settlements with Zagros material culture affiliations actively avoided, or limited their interaction with, aurochs as part of an established and widespread cultural tradition.

The fact that domestic cattle did not spread down the Tigris valley over a period of two millennia provides further support for the presence of a persistent cultural barrier between the Çayönü region of the upper Tigris basin and the Turkish and Iraqi Tigris south of the city of Diyarbakır which belongs to a distinctive EFC Epipaleolithic and Neolithic cultural tradition (Aurenche et al., 2004; Kozlowski and Gebel, 1996; Peasnall, 2000; Peters et al., 2015). However, this cultural barrier was not impenetrable. Although traditions of goat management may have developed locally in the EFC, domestic sheep and pigs were probably imported into the region from the northern Levant in the eighth and seventh millennia BC respectively although the specific mechanisms and routes for these dispersals remain unclear (Zeder, 2008).

Although surprising, the late appearance of domestic cattle and cattle management to the EFC is not unique in Neolithic SW Asia. Although domestic cattle appear early in the upper Euphrates basin and at Çayönü, their appearance in other parts of SW Asia is chronologically heterogeneous. Managed cattle were transported to Cyprus in the ninth millennium BC, and domestic cattle were part of the initial Neolithic colonization of southern and western Anatolia in the early seventh millennium BC and were imported into SE Europe in the mid seventh millennium BC. However, they are not present on the central Anatolian plateau until the second half of the seventh millennium despite two millennia of Neolithic agro-pastoralism and aurochs hunting in the region (Russell et al., 2013b). Moreover, although cattle management is evident at Tell Aswad in the eighth millennium BC (Helmer and Gourichon, 2008), domestic cattle are not widespread in the Jordan Valley and the coastal plain of the southern Levant nor in the mountainous Caucasus region until the sixth millennium BC providing parallel examples of the slow spread of cattle management in those regions (Hansen et al., 2006; Lyonnet et al., 2015). In contrast to the situation in the EFC, some regions of the southern Levant were characterized by traditions of intensive aurochs hunting (Horwitz and Ducos, 2005) and Marom and Bar-Oz (2013) have argued intensive overhunting by Neolithic agropastoralists preceded the appearance of domesticates, presumably acquired from northern Levantine neighbors. No such tradition of aurochs hunting is identifiable in the EFC (although for Çayönü see Hongo et al., 2009) where there is no evidence that the depression of aurochsen populations led to the uptake of domesticates.

5. Conclusions

Analysis of new and previously published species abundance and biometric data from 86 assemblages across the EFC have allowed us to identify regional patterns in the chronology of and mechanisms for the appearance of domestic cattle and cattle management in this region. In contrast to neighboring regions, *Bos* exploitation was a minor component of animal economies in the EFC in the late Pleistocene and early Holocene but increased dramatically in the sixth millennium BC. Moreover, biometric data indicate that the *Bos* remains from assemblages dating to the ninth through seventh millennia BC represent large bodied aurochs with mixture analysis suggesting that hunters often targeted large bulls. In the sixth millennium BC, small-sized *Bos* appears suddenly in the region without any transitional forms. This is in stark contrast to patterns from the upper Euphrates basin and also at Çayönü where gradual changes in body size indicate a local domestication process taking place as early as the ninth millennium BC. Together these datasets provide strong support for Flannery's hypothesis that the EFC was not a center of autochthonous aurochs domestication and that fully domestic cattle were imported into the region in the sixth millennium BC, perhaps associated with the spread of the Halaf tradition, more than two millennia after their initial domestication in the upper Tigris and Euphrates regions.

These results show that despite its proximity to an early center of cattle domestication, the EFC was one of the last regions in Neolithic SW Asia to incorporate cattle management into local animal economies. This long delay in the spread of domestic cattle was likely due to a combination of factors including the semi-arid climate and rough terrain that characterize much of the region as well as long-lived local traditions focused on hunting gazelle and wild caprines and herding domestic goat and sheep. Unlike the situation in the Euphrates valley, the Tigris valley appears not to have been a conduit for the movement of early domestic cattle southwards from Çayönü, despite the fact that domestic sheep and likely domestic pigs did diffuse from the northern Levant at different times. These patterns emphasize the complex and heterogeneous nature of Neolithic animal economies in the EFC with the appearance domestic goats, sheep, pigs and cattle all showing different spatial and chronological trajectories. Untangling the myriad local environmental and cultural factors responsible for these regional patterns of change and continuity represents an important challenge for future work reconstructing the processes responsible for the origins and evolution of Neolithic animal economies in this important, yet under-explored, region of the Fertile Crescent.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2016.05.008.

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