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The emergence and evolution of Neolithic cattle farming in southeastern Europe: New zooarchaeological and stable isotope data from Džuljunica-Smărdeš, in northeastern Bulgaria (ca. 6200–5500 cal. BCE)

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ABSTRACT

Cattle were of great importance for the Neolithic farmers of southeastern Europe, in particular as farming expanded towards the well-watered regions of Džuljunica (ca. 6200–5500 cal. BCE), one of the earliest known Neolithic settlements in northeastern Bulgaria. The clear stratigraphy and the substantial *Bos* assemblage from Džuljunica Provided us with a great opportunity to investigate the beginning and evolution of cattle husbandry in the northern Balkans through stable isotope and zooarchaeological analyses. The relative abundance of *Bos* at Džuljunica leaves no doubt about the importance of beef and cattle herding. Mortality profiles suggest a transition in the early phases of the Neolithic from beef-oriented to mixed beef and milk production husbandry, enabled through intensified post-lactation culling. Stable carbon and oxygen isotope analysis of tooth enamel on a limited number of samples provides no evidence for an extended calving season for increasing milk availability or for vertical mobility. Stable carbon and nitrogen isotope values of bone collagen suggest that cattle were kept near the site, where C_3 and C_4 plants were available in summer, and that they were occasionally foddered with forest resources in the winter. Cattle experience a diachronic reduction in size on a regional scale, possibly due to farmers' choices aimed at more manageable herds consisting of smaller individuals. Restricting intermixing with local aurochs and the arrival of a new type of cattle may also have contributed to this change. Local factors or inter-regional influences may have influenced the ways cattle husbandry evolved at Džuljunica in particular and in northeastern Bulgaria more generally. More data from the region are necessary to flesh out the role of the interplay among environmental factors, local developments, and inter-regional contacts that facilitate the transfer of skills and traditions relating to the changing modes of cattle husbandry.

1. Introduction

Cattle (*Bos taurus*) were domesticated in southwestern Asia and emerged subsequently in southeastern Europe via Neolithization (Arbuckle et al., 2014; Conolly et al., 2011; Helmer et al., 2005). Domesticated cattle provided primary and secondary products, probably since the start of its domestication (Vigne and Helmer, 2007), offering an important source of wealth to farming communities (Russell, 1998). While domestic cattle in southeastern Europe seem to share a maternal origin with southwestern Asian cattle (Scheu et al., 2015), there is regional variability in the timing, intensity, and modes of incipient cattle farming across southwestern Asia and Europe. This variability has been interpreted through regional differences in climate, cultural preferences in part related to Neolithization trajectories, and the differences in the role dairy products played in the human diet (Evershed et al., 2008; Conolly et al., 2012; Çakırlar, 2013; Arbuckle et al., 2014; De Groene et al., 2018; Krauß et al., 2018; Ivanova, 2020; Stojanovski et al., 2020). Little is known about early cattle farming in Bulgaria, a key region with

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connections to northwestern Anatolia (via Thrace or the Black Sea coast), the Aegean world (via the Struma and Mesta valleys), and central Europe (via the Danubian corridor) (Krauß et al., 2018). This study looks into how this variability plays out in northeastern Bulgaria through an investigation of the zooarchaeological and faunal stable isotope data from Džuljunica-Smărdeš (hereafter Džuljunica), one of the earliest and most well-stratified Neolithic settlements in the southern Danube catchment, spanning the end of the 7th millennium BCE and the first half of the 6th millennium BCE (Krauß et al., 2014).

To reconstruct cattle management strategies and identify the primary targeted cattle products at Džuljunica, we use biometric and dentition-based age-at-death data. To infer the scale of herding, landscape use, the seasonality of foddering, and the seasonality of calving, we use stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses of bone collagen and stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope analyses of serially sampled tooth bioapatite. The results of this study provide insight into cattle husbandry at the site throughout its Neolithic occupation, allowing inferences about the processes by which cattle husbandry emerged and evolved in southeastern Europe.

2. The site and its environment

The Neolithic settlement of Džuljunica is located north of the Balkan Mountains, on the terrace of the Džuljunica River – a tributary to the Yantra River of the Danube catchment (Fig. 1).

To date, four well-stratified layers (Dž–I, Dž–II, Dž–III, and Dž–IV) have been identified in a total of 22 test trenches, which makes Džuljunica one of the most extensively excavated Neolithic sites in northern Bulgaria. Twenty radiocarbon measurements date the settlement to ca. 6200–5500 cal. BCE (Fig. 2), in other words, covering the entire sequence of the Early Neolithic in southeastern Europe (Krauß et al., 2014).

The earliest occupational level at the site, Dž–I, is contemporary with the pre-Karanovo I and Karanovo I cultures, denoting the Early Neolithic in Bulgaria. The Dž–I settlement probably covered an area of more than ca. 4 ha. The material culture of Dž–I displays affinities with that of nearby Neolithic sites, such as Koprivec, as well as those of western Anatolia (Ulucak, Çukuriçi, and Yeşilova) and the Marmara region (Fikirtepe) (Krauß et al., 2014). Dž–II is characterized by rather thick cultural deposits and concentrations of finds, including human and faunal remains, remnants of clay ovens, ashy deposits, and a large quantity of painted pottery, which makes it the most extensive occupational level at the site. Based on ^{14}C dating, we know that there is an overlap between Dž–I and Dž–II, and this is confirmed by the ceramic assemblage. Dž–III has been documented sporadically and served as a levelling layer rather than an occupational phase (Krauß et al., 2014). Dž–IV is characterized by a drastic decrease in the settlement size, to 0.3 ha, and a significant change in ceramic typology. The new ceramics are more akin to those from Ovčarovo-Gorata and Karanovo II, type sites representing the early 6th millennium BCE in Bulgaria (Krauß et al., 2014).

Wood charcoal analysis indicates a rather open, mosaic landscape dominated by oak woodland, small deciduous trees, and shrubs, along with riparian forests surrounding the site (Marinova and Krauß, 2014). Other macrobotanical remains suggest that local cultivation was focused on hulled barley (*Hordeum vulgare*). Einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*), typical crops of the Early Neolithic Thessaly and Anatolia, were also cultivated. Legumes and flax also contributed to the plant-related diet (Marinova and Krauß, 2014). Previous zooarchaeological studies have shown that domestic sheep (*Ovis aries*), goat (*Capra hircus*), and cattle, as well as aurochs (*Bos primigenius*), were already present in Dž–I (Krauß et al., 2014). The low relative abundance, relatively large size, and herbivorous diet of suids (*Sus scrofa*), inferred from stable carbon and nitrogen isotope analyses of bone collagen, suggest that suids were not (fully) domesticated (de Groene et al., 2018).

3. Material and methods

Faunal remains are hand collected at Džuljunica. The zooarchaeological remains were recorded at the National Archaeological Museum of Sofia, the New Bulgarian University, and the Regional Historical Museum of Veliko Tărnovo, using reference collections and anatomical manuals (e.g., Schmid, 1972). All post-cranial specimens with "diagnostic zones" (DZ) (Watson, 1979) and all dental specimens were identified to the lowest possible taxonomic level. Whenever possible, fusion state (Reitz and Wing, 2008, p. 72), tooth eruption and wear stages (Payne, 1973; Grant, 1982), sex (Ruscillo, 2014), butchery marks (Binford, 1981, pp. 136–142), and biometry (von den Driesch, 1976) were recorded on 3893 zooarchaeological specimens. Dž–II generated the largest dataset ($n = 2484$), whereas Dž–III yielded the smallest ($n =$

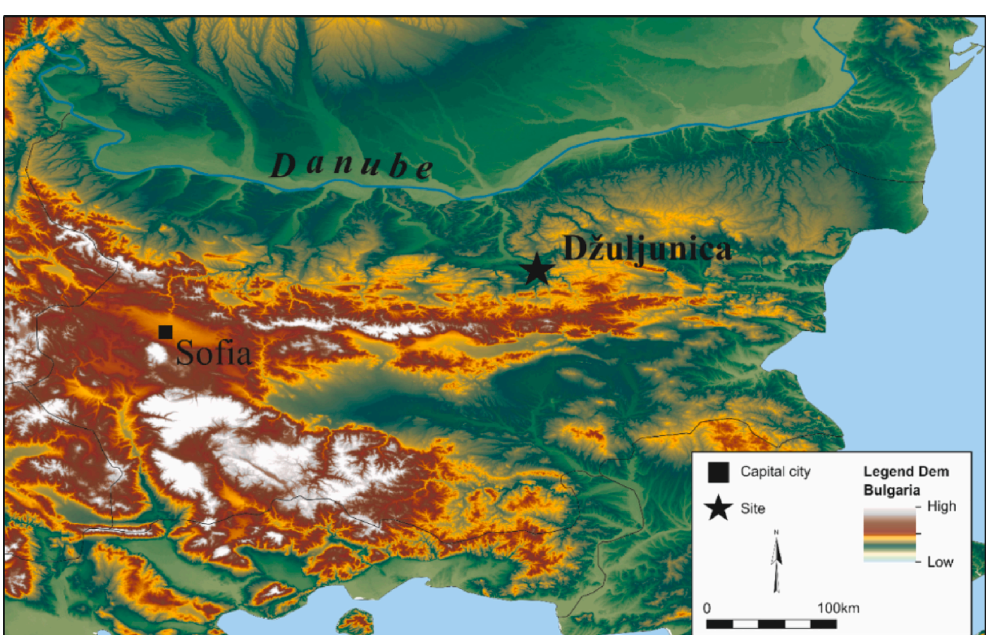

Fig. 1. Location of Džuljunica in northeastern Bulgaria. Map by Erwin Bolhuis, Groningen Institute of Archaeology.

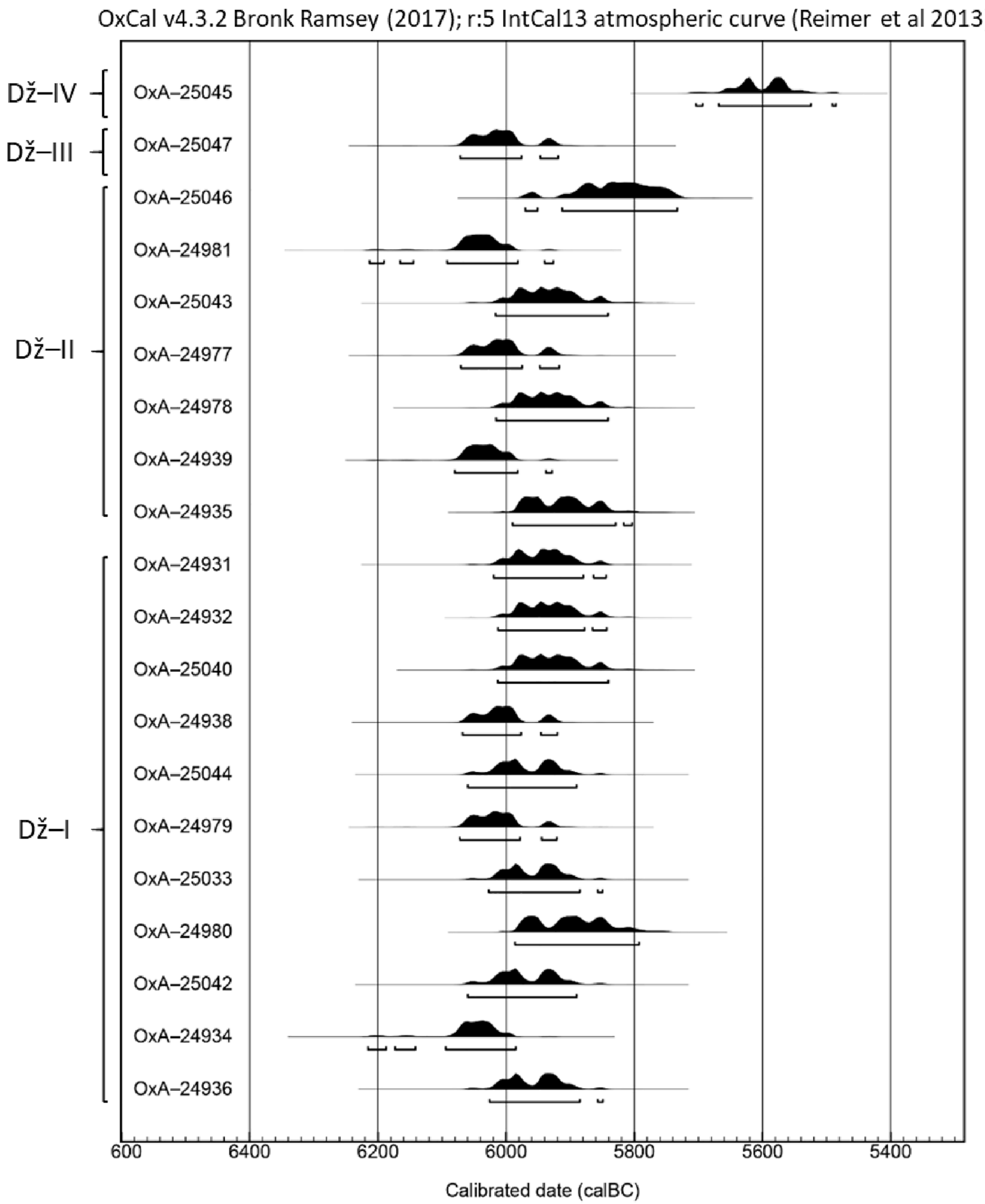

Fig. 2. Radiocarbon dates from Džuljunica. Data from Krauß et al. (2014).

63). An additional 559 cattle specimens from 148 randomly selected contexts were also included in the detailed zooarchaeological and biogeochemical analysis explained here.

From this primary data, we generated information on taxonomic relative abundance, body size, and mortality patterns. We use the taxonomic relative abundance as a rough proxy for the relative palaeoeconomic importance of different taxa and as an indication for their husbandry (Davis, 1987). Researchers working on the Neolithic of the region usually discuss the relative contribution of taxa to the economy based on proportions of the number of identified specimens (%NISP) (Arbuckle et al., 2014). The pitfalls of this method are well known (Grayson, 1984). We calculate taxonomic relative abundance based on diagnostic zone counts following Watson (1979). This method controls the biases resulting from differential butchery and recovery methods, reducing the risk of large taxa, such as cattle being over-represented by over-counting fragments. The additional cattle specimens chosen for further analysis are excluded from the calculations of taxonomic relative abundance. We also calculated the proportions of major ungulate taxa using the "sheep-equivalent factor", as proposed by Clason (1973) based on DZ, as applied by Russell and Martin (2005, p. 45), to infer the potential relative meat contribution of these taxa to the human diet.

Assessing cattle size enables us to investigate the domestication status and diachronic size development of archaeological animal populations, which is related to anthropogenic and environmental factors (von den Driesch, 1976). Size reduction is a phenotypic trait linked to the domestication of artiodactyls, and it can be observed through the biometric analysis of bones and teeth, and it is most visible at the end of the domestication process (Uerpmann, 1978; Meadow, 1989; Zeder, 2006). Size distributions also reflect the sex ratio of the adult cohort, because artiodactyls are sexually dimorphic (Zeder, 2008). Information on sex ratios allows insights into culling preferences and hence management practices (Ruscillo, 2014). In addition, reduction in sexual dimorphism demonstrated by biometric analysis could indicate *in situ* domestication (Helmer et al., 2005). To check the diachronic trend in cattle size and possible allometric discrepancies at a site scale, we use biometric data of the fused elements represented by >25 specimens to produce the logarithmic size index (LSI) following Meadow (1999). These include the humerus, the metacarpus, and the first and second phalanges. We use the Mesolithic female aurochs from Denmark described by Degerbøl and Fredskild (1970) as the standard animal.

Reconstructing mortality profiles is a standard method to infer which primary and lifetime products of animal husbandry were targeted, products which are, in turn, bound to social factors and environmental constraints (Vigne and Helmer, 2007). Equifinality can mask the different factors involved in slaughtering decisions. Incentives to maintain large herds as a source of wealth, for example, may result in a high representation of mature animals in faunal assemblages. This, however, would not necessarily be distinguishable from a slight shift in priority between meat and milk production (Orton, 2012). Using 39 mandibles and 94 isolated mandibular teeth, we generated cattle mortality profiles using the R code described in Gerbault et al. (2016), adapted for Legge's age classes (Gillis et al., 2017). We distinguished the first mandibular molars (M1) from the second mandibular molars (M2) by comparing the cervical length (CervL) to the width of anterior (WA) of 25 isolated molars, following Beasley et al. (1993) and Jones and Sadler (2012).

In addition to macroscopic analysis, we conducted stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope analysis. We analysed enamel bioapatite to assess seasonality of birth (Balasse et al., 2012a; Towers et al., 2014), diet (Balasse, 2002; Cerling, Harris and Passey, 2003; Makarewicz and Pederzani, 2017), and mobility (Tornero et al., 2016). Cattle mandibular third molars (M3) start forming between 9 and 10 months and are completed between 23 and 24 months (Brown et al., 1960), recording all the isotopic input from food and water the animal digests (Bryant et al., 1996). We conducted sequential samplings of enamel on the anterior lobe along the tooth growth axis of eight cattle mandibular M3s. We measured the location of each sample in the tooth crown in relation to the enamel root junction (ERJ). $\delta^{18}O$ values in mammalian bioapatite are reflective of $\delta^{18}O_{H2O}$ values of ingested water and consumed food (Bryant and Froelich, 1995; Pederzani and Britton, 2019), correlative with seasonal air temperature fluctuations. $\delta^{18}O_{H2O}$ values of meteoric water increase in summer and decrease in winter (Kohn and Welker, 2005). As the isotopic values of water are archived in the incrementally growing enamel, $\delta^{18}O$ values of enamel can be used to estimate individual seasonality of birth (Balasse et al., 2003; Towers et al., 2014). To investigate cattle birthing seasonality, we use the inter-individual variation in the tooth crown location in relation to the enamel–root junction (ERJ), where the highest and lowest $\delta^{18}O$ values of the cycle are observed (Balasse et al., 2003, 2012a). $\delta^{18}O$ values do not directly correlate with the season of birth, because of individual differences in tooth growth rates and the delay in enamel mineralization (of about 6 months in modern cattle mandibular M2) (Balasse, 2002). The position (distance to ERJ) of the maximum $\delta^{18}O$ values (x_0) needs to be normalized to the periodic cycle (X, crown length formed over a year) using the "four-parameter model" developed by Balasse et al. (2012a) and Balasse et al. (2012b) to render the data from different individuals comparable. The other two parameters are x as the distance of each sample from ERJ, and A as the amplitude of the $\delta^{18}O$ cycle (in ‰) (Balasse et al., 2012b). We use the Pearson's correlation coefficient (PCC) to measure the proximity between the modelled and raw $\delta^{18}O$ data.

$\delta^{18}O$ and $\delta^{13}C$ and values derived from incrementally sampled dental enamel provide a record of seasonal variability in the grazing environment and seasonal foddering practices (Balasse et al., 2012b; Makarewicz and Pederzani, 2017). An inverse relationship between $\delta^{13}C$ and $\delta^{18}O$ values may indicate animal vertical mobility (Tornero et al., 2016). To infer animal diet, we consider a +14.1‰ $\delta^{13}C$ enrichment observed between enamel and the plants consumed (Cerling and Harris, 1999). Enamel sampling and preparation were conducted at the Groningen Institute of Archaeology following the method proposed by Balasse et al. (2012a) and Balasse et al. (2012b) (Supplementary Text 1). Stable oxygen and carbon isotope analyses of the carbonate fraction of tooth enamel were conducted at the Saskatchewan Isotope Laboratory, University of Saskatchewan. Isotope ratios have been corrected for acid fractionation and ^{17}O contribution using the Craig correction (Craig, 1957) and are reported in per mil notation relative to the Vienna Pee Dee Belemnite (VPDB) scale.

We also conducted stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of bone collagen to infer pasturing environments and foddering strategies (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). We assume $\delta^{13}C$ values between −27.5‰ and −23.5‰ (−25.5‰ on average) for pre-industrial C_3 plants (Kohn, 2010), which includes a correction of +1.5‰ for the fossil fuel effect (known as Suess effect correction; Keeling, 1979; Körtzinger, Quay and Sonnerup, 2003), and a 5‰ ^{13}C-enrichment between the protein fractionation of diet and collagen (Ambrose and Norr, 1993). C_4 plants, characteristic of regions with semi-arid climates, display high $\delta^{13}C$ values, of between −17.3‰ and −4.3‰ (Cerling, Harris and Passey, 2003). Heat/drought stress is known to lead to $\delta^{13}C$ values as high as −24‰ in plants growing in dry environments (Kohn, 2010). Consumption of plants growing in water-rich environments (Lynch, Hamilton and Hedges, 2008) or in dense forests (known as canopy effect), however, leads to $\delta^{13}C$ values as low as −22.5‰ in bone collagen (Van der Merwe and Medina, 1991; Drucker et al., 2008). $\delta^{15}N$ values provide insight into animal diet management strategies, including weaning (Balasse and Tresset, 2002; Gillis et al., 2013) and winter foddering (Makarewicz, 2014). The standard trophic increase in $\delta^{15}N$ values of bone collagen along the food chain is ~3‰ between herbivores to carnivores in both terrestrial and marine ecosystems (DeNiro and Epstein, 1981). Environmental and anthropogenic factors, such as aridity (Ambrose, 1991) and manuring (Bogaard et al., 2007), are known to result in raised nitrogen isotope values.

Here, we present the results from $\delta^{13}C$ and $\delta^{15}N$ analyses of 38 animal bone collagen samples, representing domestic cattle ($n = 21$), sheep ($n = 5$), red deer (*Cervus elaphus*, $n = 6$), roe deer (*Capreolus capreolus*, $n = 5$), and one unidentified caprine, all of which are from three main cultural layers at Džuljunica (Dž–I, Dž–II, and Dž–IV). Each bone belongs to a different adult individual. We also incorporated the valid (i.e., having an acceptable C:N ratio) isotopic data from four previously analysed suids from Dž–IV (de Groene et al., 2018) as baselines to interpret cattle isotopic values (e.g., Thomas and Miller, 2018). Stable carbon and nitrogen isotope analyses of collagen were conducted at the Centre for Isotope Research (CIO), University of Groningen (Supplementary Text 2). The carbon and nitrogen isotope ratios were calibrated relative to VPDB and Air, respectively.

4. Results

4.1. Taxonomic relative abundance

The assemblage revealed a wide range of taxa, including *Bos,* caprines, suids, and cervids (Supplementary Table 1). Dog (*Canis familiaris*), fox (*Vulpes vulpes*), beech marten (*Martes foina*), hare (*Lepus europaeus*), beaver (*Castor fiber*), badger (*Meles meles*), tortoise (Testudinidae), birds, fish (primarily Cyprinidae), and freshwater molluscs are present in all phases. One brown bear (*Ursus arctos*) humerus was identified in Dž–IV.

Bos is present from the beginning of the occupation. *Bos* is the most frequently identified taxon in the assemblage after caprines, comprising ~30% of NISP in Dž–I and Dž–II. Its frequency increases in Dž–IV, to about 46% of NISP, at the expense of caprines, but the increase in %NISP seems to be caused by differential fragmentation and preservation. Using DZ, *Bos* remains the second most abundant taxon in Dž–I and Dž–II (35% and 31%, respectively) (Table 1), and it shows an insignificant increase (*t*-test, $p < .2$) in Dž–IV (to 36%).

Considering their larger size, cattle would have provided more meat than the other mammals. Calculations based on the sheep-equivalent method (Clason, 1973) suggests that beef formed ~90% of the meat provided by the most frequently identified mammals at the site throughout time (Fig. 3).

4.2. Evolution of body size and sexual dimorphism

We measured 447 specimens (Supplementary Table 2). Different skeletal elements in each level display similar LSI distributions, indicating that allometric bias between the standard (the Mesolithic Danish aurochs; Degerbøl and Fredskild, 1970) and the Džuljunica population is negligible (Fig. 4).

In Dž–I and Dž–II, 51 out of 323 specimens are larger than the standard. Dž–I contains the largest specimens in the dataset. In Dž–II, the LSIs largely overlap with those of Dž–I. However, there is a higher frequency of specimens that are clearly smaller than those of Dž–I. This size difference is not statistically significant (*t-test* $p < .21$).

Dž–IV yielded the smallest measurements. In Dž–IV, out of 124 specimens, only one first phalanx is larger than the standard aurochs. The mean LSI of Dž–IV is statistically significantly smaller than the mean in previous phases (*t-test*, $p < .0001$). For example, the metacarpus mean LSI value has reduced from −0.02 in Dž–I to −0.10 in Dž–IV.

Cattle size distribution in Koprivec (Manhart, 1997), located in northern Bulgaria, mirrors the observed diachronic size reduction of cattle at Džuljunica (Fig. 5). At Ovčarovo-Grota, also located in northern Bulgaria but dating mostly the first half of the 6th millennium BCE (Marinova and Krauß, 2014), the size range of cattle is very similar to Dž–IV, with few large individuals (Nobis, 1986).

Table 1
Relative frequency of the principal taxa using DZ, following Watson (1979), during the three main occupational phases at Džuljunica.

TAXA		DZ			DZ%		
		Dž–I	Dž–II	Dž–IV	Dž–I	Dž–II	Dž–IV
Cattle (with some probable aurochs)	*Bos taurus* (with some probable *Bos primigenius*)	70	318	92	35	31	36
Sheep or goat	*Ovis aries/ Capra hircus*	100	645	131	51	63	51
Wild boar/ pig	*Sus* sp.	2	15	6	1	1	2
Roe deer	*Capreolus capreolus*	17	20	7	9	2	3
Red deer	*Cervus elaphus*	9	28	20	5	3	8
Total		198	1026	256	100	100	100

4.3. Mortality profiles

Using tooth length, we established that 16 of the loose molars are M1 and the remaining 9 are M2 (Supplementary Table 3). Dental ageing data from Dž–I are limited (NISP = 13) (Fig. 6a–c and Supplementary Table 4). The profile shows that the early slaughtering of juveniles is focused on individuals aged 3–6 months. Culling generally targets young adults aged 15–36 months, while a limited number of cattle survive up to 3–6 years, which indicates meat production. No individuals older than 6 years are present at this level.

The dental ageing data for Dž–II are more abundant (NISP = 85) compared with Dž–I, allowing us to discuss the mortality profile with greater certainty. No individuals younger than 1 month old are observed. Juveniles between 1 and 3 and 3–6 months appear in high frequencies. Culling individuals between 6 and 15 months, which also occurred frequently, can be explained as "post-lactation" slaughtering. Young adults between 15 and 36 months make the highest contribution to the slaughtering pattern for this level. Cattle slaughtered between 3 and 6 and 6–8 years are also abundant and may have been targeted for meat exploitation. Older individuals (>8 years) are present in the assemblage, which can be attributed to slaughtering cows when their milk production and fertility had decreased.

In Dž–IV (NISP = 35), neonate mortality (0–1 month) is high, which may represent natural mortality at or after birth, mainly during winter, due to exposure (Gillis et al., 2016). Early slaughtering of individuals of 1–6 months is frequent. The post-lactation slaughtering of individuals of 6–15 months has a peak in this level. This is followed by a high number of individuals culled at 15–36 months. Older individuals (3–8 years) are also present in Dž–IV.

4.4. Stable oxygen and carbon isotope values in tooth enamel

$\delta^{18}O$ and $\delta^{13}C$ values of the enamel bioapatite are reported in Fig. 7 and Supplementary Table 5. In all eight specimens, $\delta^{18}O$ values vary between −9.6‰ and −3.5‰. In Dž–I, $\delta^{18}O$ values are between −8.5‰ and −4.8‰ (−6.6‰ on average) in the only specimen analysed (Bos3760). In Dž–II, $\delta^{18}O$ values vary between −9.6‰ and −5.1‰ in three specimens (−7.2‰ on average). In Dž–IV, four specimens analysed have $\delta^{18}O$ values between −9.3‰ and −3.5‰ (−6.2‰ on average). All the specimens display sinusoidal variations (amplitude between 1.2‰ to 2.9‰) in time along with the tooth crown, likely reflecting seasonal variation in meteoric precipitation $\delta^{18}O$ values that are forced by the seasonal temperature cycle.

In Bos3369, Bos4156, and Bos3921, the crowns were worn and the $\delta^{18}O$ sequences do not complete a sinusoidal cycle, which is crucial for a secure assessment of the length of the cycle. In the remaining individuals, the length of tooth crown formation over a year (*X*) varies between 36.5 and 49.5 mm, indicating inter-individual variations in annual tooth growth rate (Supplementary Table 6). The highest $\delta^{18}O$ values are located at 10–18.9 mm from the ERJ. To remove the influence of these variabilities, we normalised the locations in ERJ where the highest $\delta^{18}O$ value is measured (x_0) to the period (*X*, crown length formed over a year), or x_0/X (Balasse et al., 2012a). This corresponds to values between 0.24 and 0.47 in five specimens (Supplementary Table 6). When individuals are born in different seasons, the positions from ERJ where the highest $\delta^{18}O$ value are observed (summertime) would be different as well (Bryant et al., 1996). In our dataset, the normalised locations where the highest $\delta^{18}O$ values are recorded occur at the points that represent the completion of 24% to 47% of an annual cycle. The inter-individual variability in the seasonality of birth of these five cattle is therefore 23% of an annual cycle, corresponding to a 3-month period (Fig. 8). This conclusion is tentative due to the small sample size; however, the Pearson's *r*-values (between 0.89 and 0.98) confirm the similarity between the $\delta^{18}O$ values and the modelled data (Supplementary Table 6).

$\delta^{13}C$ values of enamel carbonate vary between −14.0‰ and −9.4‰

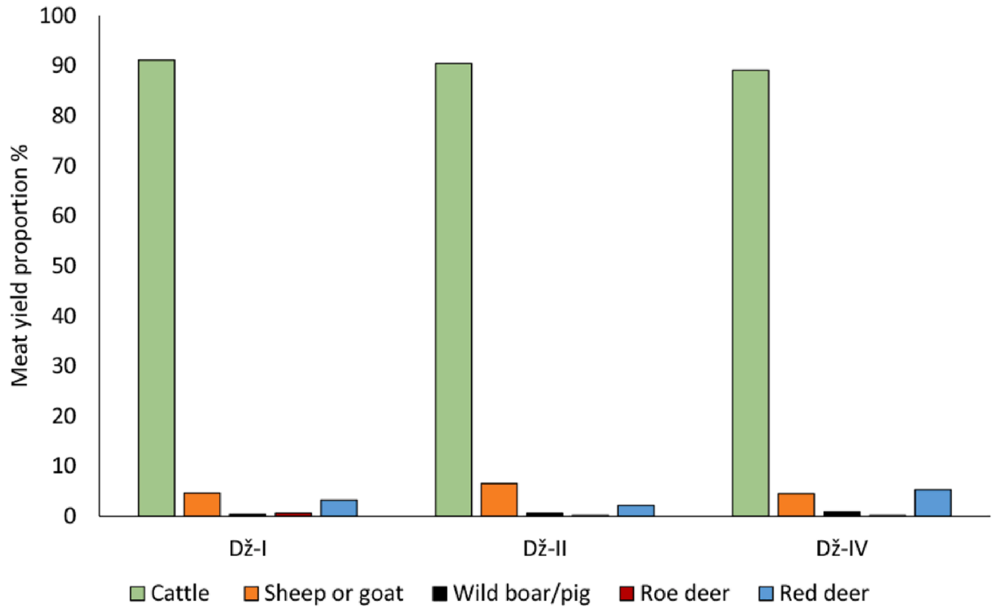

Fig. 3. Proportions of estimated meat yields from major ungulate taxa in the three main occupational phases at Džuljunica using the sheep-equivalent factor (Clason, 1973; Russell et al., 2013).

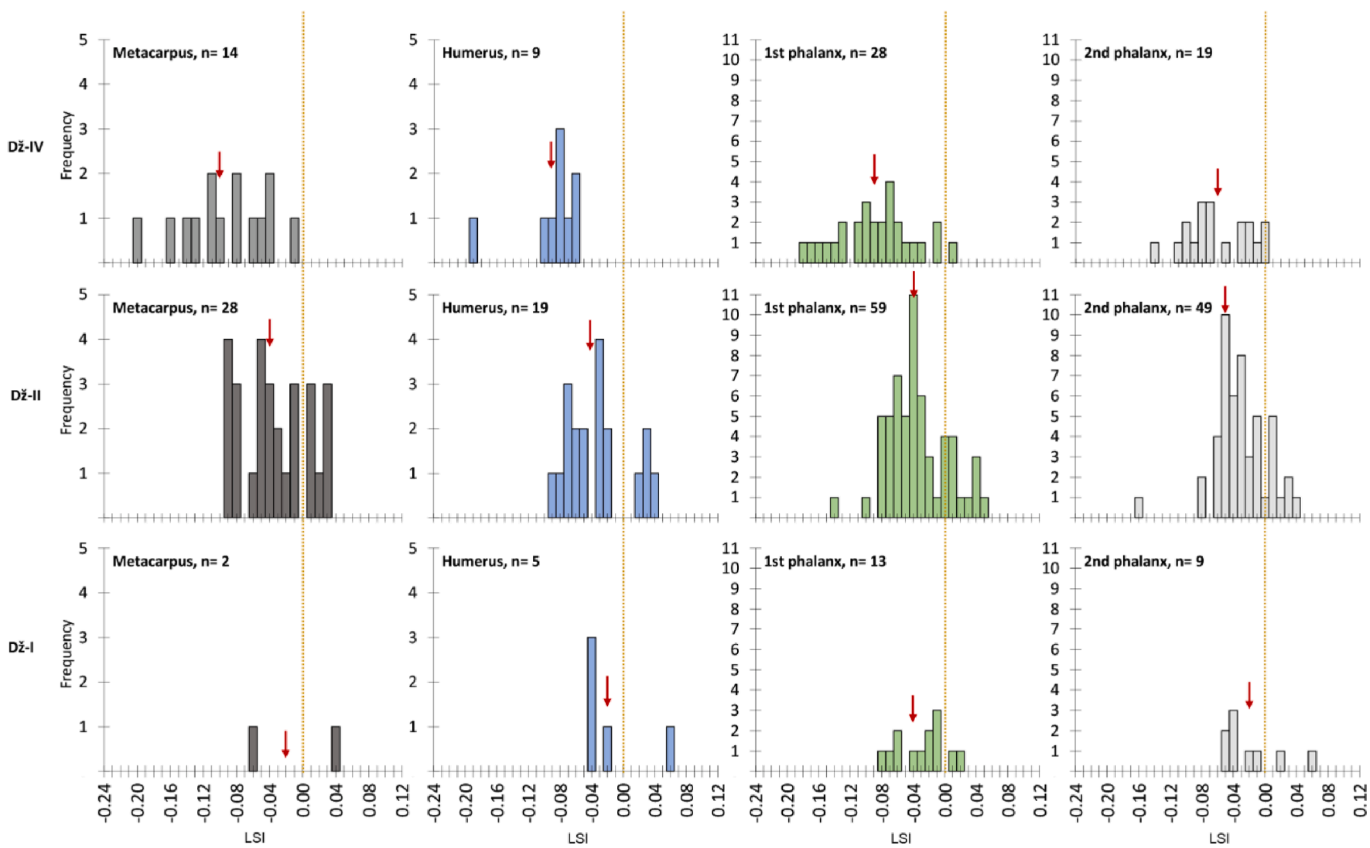

Fig. 4. The diachronic logarithmic size distribution of cattle postcranial elements at Džuljunica in comparison to a Mesolithic female aurochs from Denmark (Degerbøl and Fredskild, 1970) as the standard animal (LSI = 0). Arrow represents the mean.

(mean = −11.3‰ ± 0.9). The amplitude of intra-tooth variation is between 0.5‰ and 1.9‰, mirroring seasonal changes in the isotope values of the animal's diet (Fig. 7). In Dž–I, the average of $\delta^{13}C$ values measured in one bovid (Bos3760) is −10.9‰ ± 0.5. Assuming an enrichment factor of +14.1‰ between diet and enamel (Cerling and Harris, 1999), this animal had a dietary $\delta^{13}C$ value of −25.0‰.

In Dž–II, $\delta^{13}C$ values as high as −9.4‰ were observed in Bos3369 when the $\delta^{18}O$ value is high (−5.6‰), reflecting a contribution of plants with $\delta^{13}C$ value of −23.5‰ in summer. In contrast, Bos3620 exhibits a low $\delta^{13}C$ value (−13‰), which would correspond to a dietary $\delta^{13}C$ value of −27.1‰ in winter. Bos4156, an interesting animal because it has the highest amplitude of $\delta^{13}C$ (1.9‰), reflects the seasonal contribution of

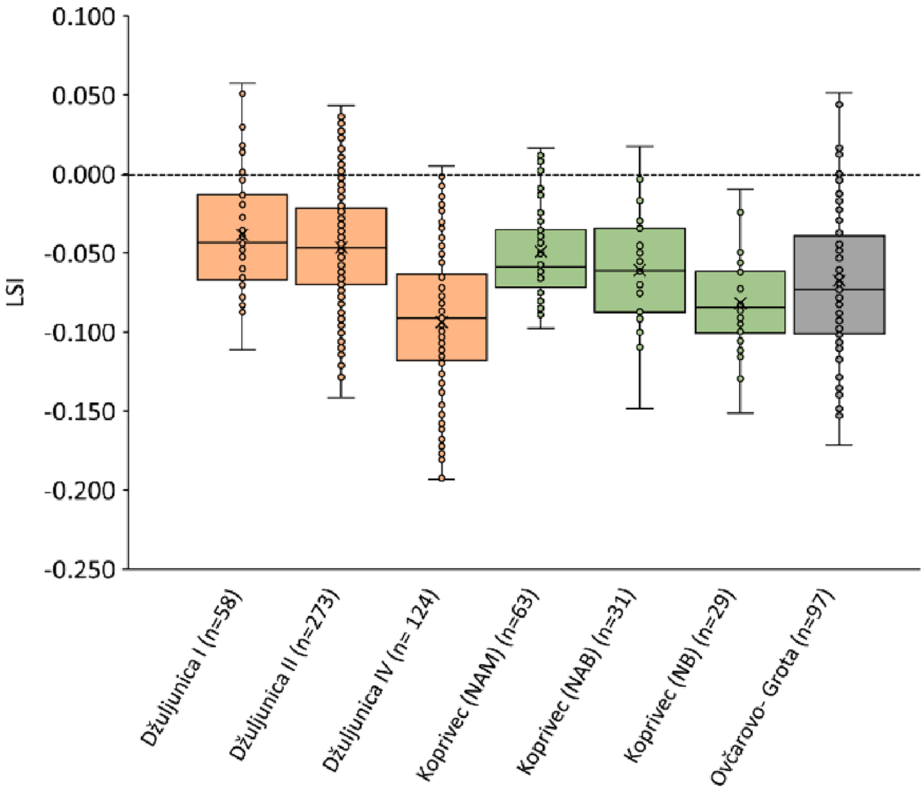

Fig. 5. Diachronic comparison of postcranial LSIs of *Bos* remains in northern Bulgaria. The standard animal (LSI = 0) is the Mesolithic female aurochs from Denmark (Degerbøl and Fredskild, 1970). Data for Džuljunica from this study, Supplementary Table 2; for Koprivec (6200–5800 BCE) from Manhart (1997, pp. 263–265), and for Ovčarovo-Grota (6th millennium BCE) from Nobis (1986).

plants with $\delta^{13}C$ values as high as −24.2‰ in summer and as low as −28.1‰ in winter.

In Dž–IV, Bos3820 and Bos4030 exhibit $\delta^{13}C$ values as high as −9.8‰ in bioapatite. Bos4033 and Bos3921 have $\delta^{13}C$ values between −12.7‰ and −10.6‰. For Bos4033 (Dž–IV) and Bos3760 (Dž–I), the highest $\delta^{13}C$ values are registered during winter, when plants comprise low $\delta^{13}C$ values in nature. For the rest of the specimens, the lowest $\delta^{13}C$ values coincide with the lowest $\delta^{18}O$ values, precluding seasonal vertical mobility.

4.5. Bone collagen stable carbon and nitrogen isotope values

Collagen extraction yields varied from 0.5 to 9.8 mg/g (Supplementary Table 7). The carbon content (%C) of the bone collagen varies between 11.3 and 54.3% (mean 40.7 ± 7.4%), and the nitrogen content (%N) varies between 4.3 and 19% (mean 14.6 ± 2.6%). Atomic C:N ratios vary between 3.1 and 3.3, which means that all samples satisfy the criteria defined for valid stable carbon and nitrogen isotope ratios (%C < 30, %N < 11; Van Klinken, 1999) except for Bos3786 and Ovis4071, in which %C and %N were below the accepted range. Isotopic values of these two specimens will not be discussed further.

$\delta^{13}C$ values of cattle bone collagen vary from −21.5‰ to −18‰, with a mean of −20.1‰ (Fig. 9). In Dž–I, $\delta^{13}C$ values range between −21.5‰ and −19.3‰ (mean −20.4 ± 0.7‰). This would correspond to $\delta^{13}C$ values of −26.5‰ to −24.3‰ for diet. In Dž–II, $\delta^{13}C$ values range between −21.5‰ and −18.8‰ (mean −20.3 ± 0.9‰). A $\delta^{13}C$ value as high as −18.8‰ (Bos3623) would correspond to a dietary $\delta^{13}C$ value of −23.8‰. The cattle in Dž–IV, show relatively higher $\delta^{13}C$ values than those from preceding levels, but the difference is not statistically significant (*t*-test, $p < .06$). They vary between −20.2‰ and −18‰ (mean −19.5 ± 09‰). Bos4047 and Bos1103 (Dž–IV) consumed plants with $\delta^{13}C$ values as high as −23‰ and −24.1‰.

Caprines in all levels exhibit homogeneous $\delta^{13}C$ values, ranging between −20‰ and −21.2‰, being on average 0.3‰ lower than those of cattle, which reflects a lack of contribution of plants with high $\delta^{13}C$ values. $\delta^{13}C$ values of wild fauna (red deer and roe deer) bone collagen vary from −23‰ to −19.9‰ (−20.9‰ ± 0.9 on average). They do not differ significantly over time. Roe deer exhibit the greatest range of variation for the $\delta^{13}C$ values in the dataset, namely, −23‰ to −19.9‰ (mean −20.9 ± 0.9‰). One roe deer (Capr4112) has the lowest $\delta^{13}C$ value (−23‰) in the dataset. Suids have $\delta^{13}C$ values between −21.3‰ and −19.5‰ (−20.4‰ ± 0.8‰ on average). All $\delta^{13}C$ values higher than −19‰ were measured in cattle.

$\delta^{15}N$ values of cattle bone collagen vary from +5‰ to +7.1‰ (+5.9‰ on average). Cattle bone collagen exhibits a $\delta^{15}N$ mean value of +6.0‰ ± 0.5 in Dž–I and of +6.1‰ ± 0.6 in Dž–II. In Dž–IV, the mean of $\delta^{15}N$ values shows a small reduction (+5.5‰ ± 0.3), and the values are less widely distributed compared with the preceding levels. However, the reduction in $\delta^{15}N$ values is not statistically significant (*t*-test, $p >$ .11).

In general, caprines exhibit similar $\delta^{15}N$ values to cattle, except for Ovis71456 (Dž–II), which is slightly enriched in $\delta^{15}N$ (+7.3‰). Red deer in most cases cluster with domesticates, whereas roe deer exhibit slightly higher $\delta^{15}N$ values than red deer (+4.9‰ to +6.8‰, +6.0 ± 0.6‰ on average) and are within the range of two of the suids (Sus 63-1157, Sus 69-1254) in Dž–II.

5. Discussion

5.1. Cattle and cattle husbandry at Džuljunica

Diagnostic zone counts suggest that both caprine and cattle herding were important activities at Džuljunica throughout the Neolithic, especially if large *Bos* remains represent domestic male cattle rather than aurochs. Regardless, estimated relative meat yields suggest that cattle and/or aurochs were by far the main meat provider at the settlement

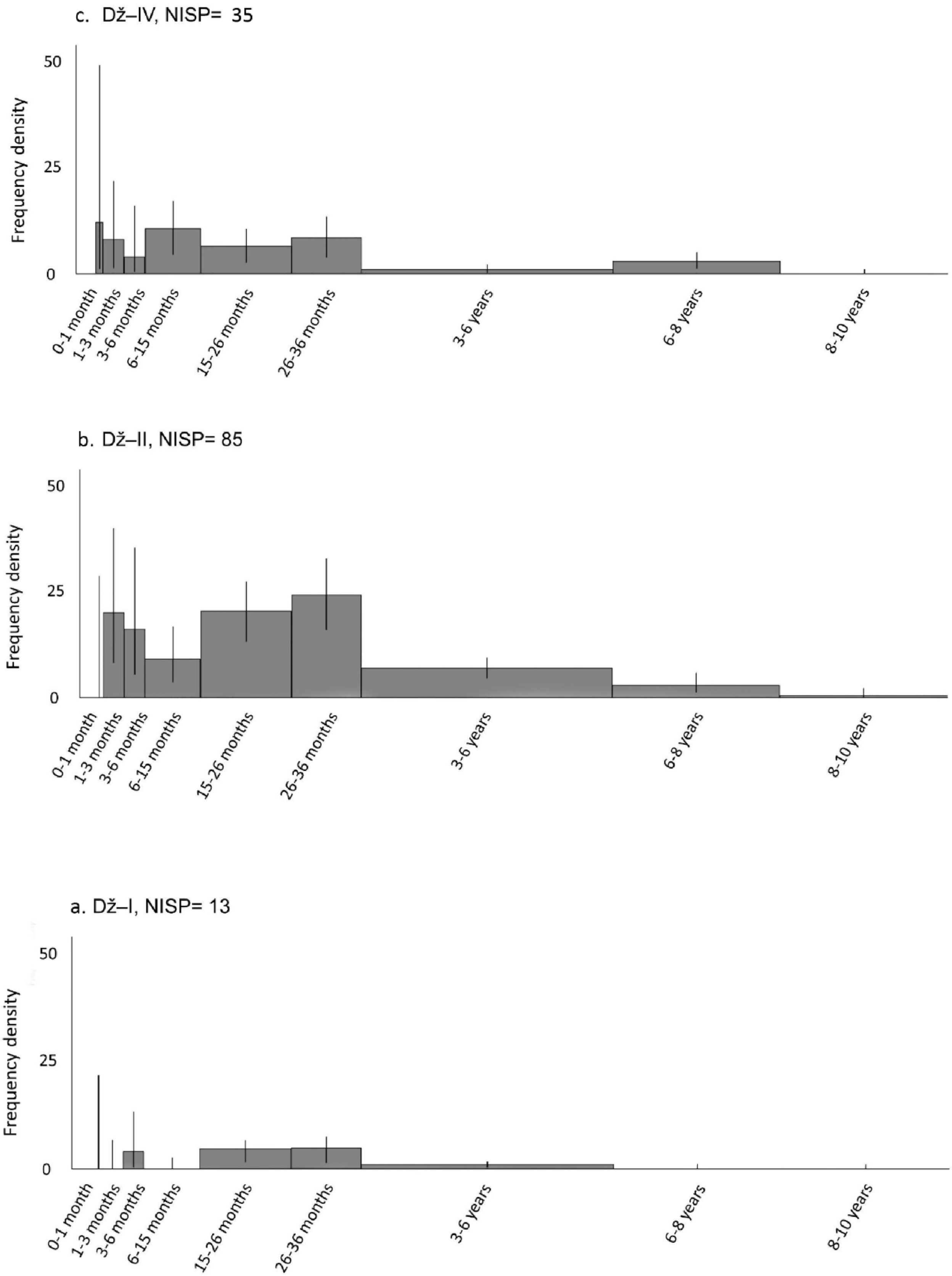

Fig. 6. (a–c) Cattle mortality profiles in the three main occupational phases at Džuljunica, based on tooth eruption and wear stages following Grant (1982) and Legge (1992). Statistics based on the equation in (Gerbault et al., 2016), adapted for cattle (Gillis et al., 2017).

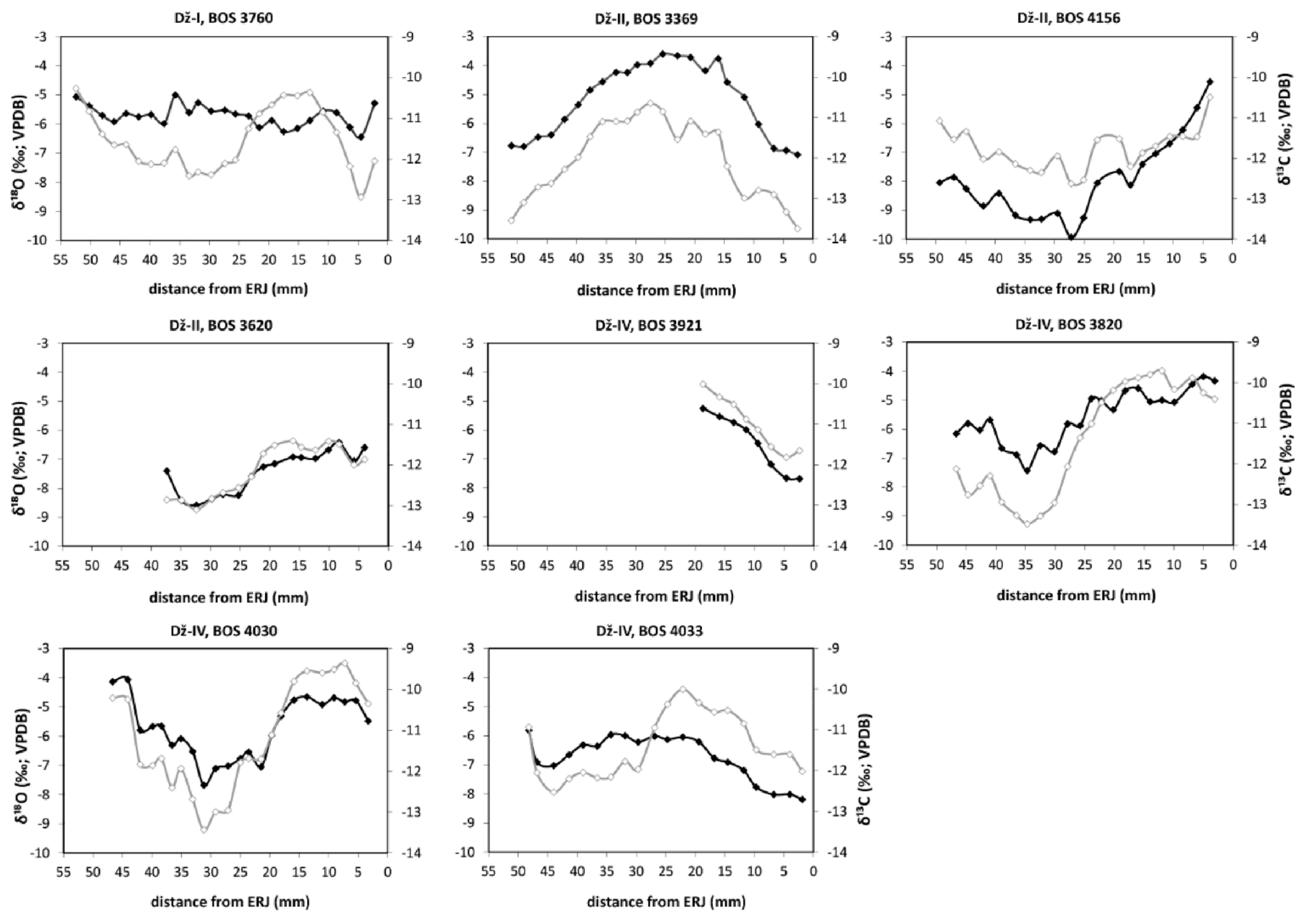

Fig. 7. Results of sequential stable carbon (δ^{13}C, in black) and oxygen (δ^{18}O, in grey) isotope analysis of carbonate fraction of the enamel in eight M3 of *Bos*. Each sample is plotted relative to its distance from the enamel–root junction (ERJ).

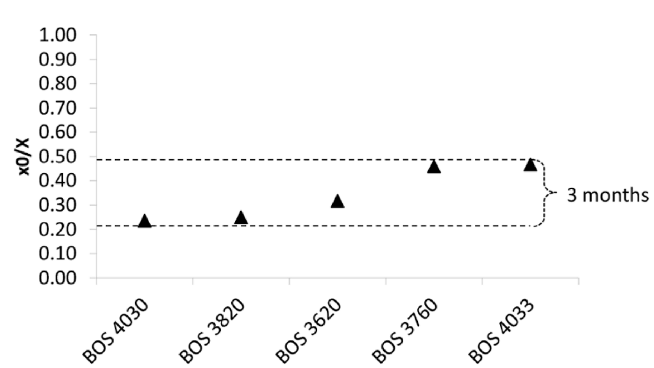

Fig. 8. Cattle birth distribution at Džuljunica indicated by indices calculated from the ERJ distance, where the highest δ^{18}O values are normalized to the period (x_0/X) using the four-parameter model following Balasse et al. (2012a).

throughout its Neolithic occupation.

Osteometric data show the presence of a group of large bovines in Dž–I and Dž–II. Although we found no obvious remains of European bison (*Bisonus bonasus*), such as the distinctive horncores, we cannot completely rule out that some of these large specimens actually represent bison (Benecke, 2005), which survived in the Balkans well into the Holocene and are nearly impossible to distinguish from *Bos* based on skeletal morphology. These large individuals may also represent large male domestic cattle or hybrids between aurochs and cattle. Palaeogenetic research (Schibler, Elsner and Schlumbaum, 2014; Verdugo et al., 2019) has shown that such hybridization occurred in other locations. In Britain and Ireland, cattle and aurochs introgression is proposed to have occurred under human control to varying degrees, with a positive selection towards more immune, more productive, and stronger breeds (Orlando, 2015).

Large *Bos* individuals become extremely rare in Dž–IV. Cattle experiences a clear diachronic size reduction in Dž–IV, and rather small individuals appear for the first time. Size reduction at Džuljunica does not seem to relate to a change in the composition of the female:male ratio among individuals who survived into adulthood, because there is no notable change in the skewness of the LSI datasets (Fig. 4). The same pattern is observed at the nearby contemporary site of Koprivec, suggesting that the trend was regional. Size reduction possibly also occurred at the nearby contemporary site of Ovčarovo-Grota. The observed size reduction may have resulted from an intentional breeding strategy to decrease mature body weight. One of the main advantages of this breeding strategy is that calves with low weight at birth are less likely to cause birthing complications (Johanson and Berger, 2003; Ring et al., 2018). Small calves become small adult individuals, and therefore this strategy would buffer the risks involved in feeding large-bodied animals during times of food shortage (poor pasture caused by dry seasons or insufficient fodder caused by crop failure) while enabling humans to maintain a large herd size. Restricting domestic cattle to interbreed with aurochs may have been part of these herd improvement strategies, but the removal of the aurochs from the equation alone would not be sufficient to explain the appearance of small individuals in the area in the early 6th millennium BCE. It should be noted that palaeogenetic research on the mtDNA of cattle from nearby contemporary sites in Bulgaria suggests that a genetic change took place in cattle during the early 6th millennium BCE, through intermixing with new haplotypes from the Balkan aurochs (Hristov et al., 2017, 2018). Further studies

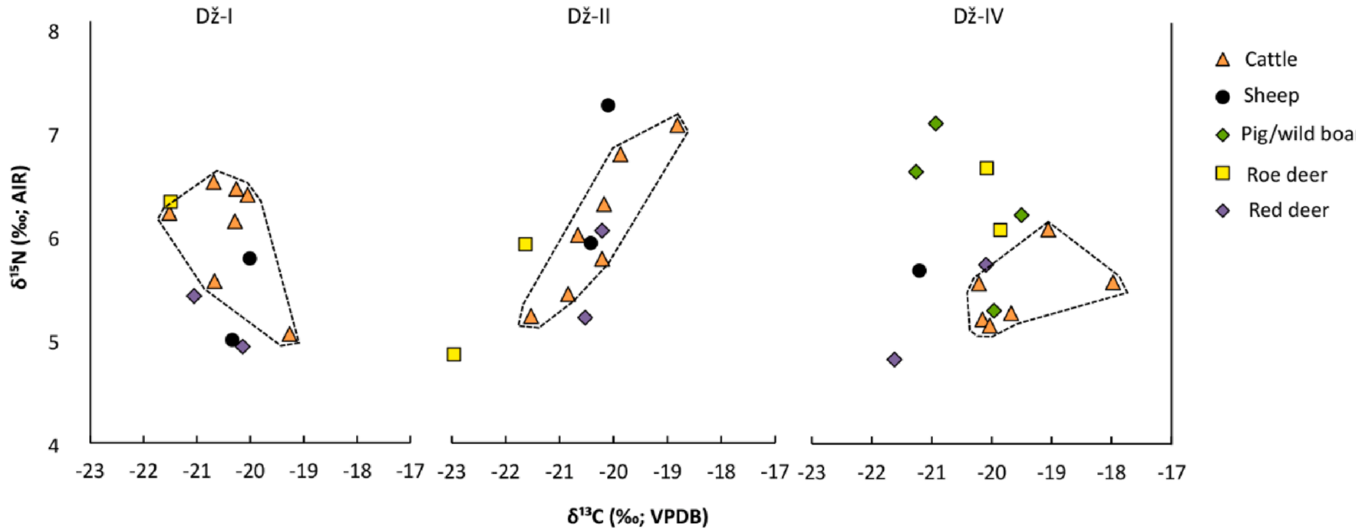

Fig. 9. δ^{13}C and δ^{15}N values of animal bone collagen during the three occupational phases of Džuljunica. Data for suids from de Groene et al. (2018).

correlating body size and genomic markers can be expected to shed light on the role of intermixing with new cattle breeds that could be associated with the new elements in material culture observed in Dž–IV (Krauß et al., 2014).

Along with changes in cattle body size, the goals of the herding of cattle seem to have shifted through time. The culling emphasis on individuals at their optimal weight in Dž–I, based on an admittedly small sample, suggests that cattle husbandry was meat-oriented. Although we cannot rule out milk production in Dž–I, the notable presence of older cattle, possibly retired lactating cows, in Dž–II and Dž–IV, indicates that in addition to meat, milk production had become important. Milking may have been facilitated by post-lactation slaughtering of calves because of cows' sensitivity to being milked without them (Peske, 1994). Post-lactation slaughtering is most visible in Dž–IV, with the most popular culling age now being 6–15 months, down from 15 to 36 months in Dž–II.

In addition to keeping females into adulthood and culling a portion of the young animals once they are weaned, manipulating the timing of cattle birthing to extend the birthing season allows milk to be available longer for human consumption throughout the year (Balasse et al., 2012b). At Džuljunica, although the cattle mortality profiles suggest increased dairy production and a size decrease suggests more intensive husbandry, δ^{18}O values of tooth enamel, albeit for a limited number of specimens, indicate a restricted calving season of about 3 months. This is similar to the short calving period (March to April) observed among the extensively raised, primitive Grey cattle breed in the Thrace region of Turkey (Soysal and Kök, 2008). Considering a 7 month lactation period in primitive cattle breeds (Peske, 1994; Soysal and Kök, 2008), the short, 3 month birthing season at Džuljunica would have led to milk availability for humans for a maximum of 10 months per year. This period would have been reduced because calves need to drink colostrum to boost their immunity.

Environmental and climatic factors, namely food, water availability, and temperature, are known to influence cattle reproductive activities (Reinhardt, Reinhardt and Reinhardt, 1986; Balasse and Tresset, 2007). Cold and heat stress negatively affect animal welfare and increase infant mortality. Calves born in cold seasons (~−4°C) have lower daily weight gain, have higher water and food intake needs, and require 32% more energy to stay warm, compared with calves born in warmer seasons (Roland et al., 2016). Northern Bulgaria has a temperate–continental climate, with hot summers and cold and long winters. Abundant snowfall occurs throughout the winter. Assuming a similar climate during the Neolithic, the short calving season observed at Džuljunica could be explained by the animal's biological adaptation to these environmental conditions.

Herders can prolong the birthing season to conform to the economic focus of farming (meat, milk, or both) through providing shelter, provisioning with winter fodder, and seasonally moving the herds towards better pastures and milder environments. There is no evidence for vertical or seasonal mobility in the Džuljunica cattle. From the earliest occupational levels at Džuljunica, both wild and domestic animals were mainly grazing in C_3-plant-dominated areas. In Dž–I, the low amplitude of δ^{13}C value variation in tooth enamel suggests little animal mobility. Cattle occasionally consumed plants with high δ^{13}C values in wintertime. This indicates winter foddering, facilitated by the consumption of leaves and twigs collected by humans from forests during summer to support the herd in winter. In Dž–II, open C_3 environments remained the main pasture for the majority of domestic and wild species, indicated by shared carbon isotope ratios across species. Additionally, cattle seem to have grazed seasonally in forests or water-rich environments (Lynch, Hamilton and Hedges, 2008) or were foddered (Van der Merwe and Medina, 1991; Drucker et al., 2008), which led to low δ^{13}C values in two cases. Although Džuljunica is located close to water sources, we cannot exclude a forest component in the cattle diet because the diet of one of the roe deer (Capr4112) confirms the presence of forested areas near the site. The spectrum of hunted mammals and the plant species gathered by the community reflect the major role of natural vegetation resources near the site for the community. Plants with high δ^{13}C values made a moderate dietary contribution (about 20–26% following Kohn, 2010) to the cattle diet in summer. None of the sampled wild fauna represent arid conditions, and we should not expect much aridity in this environment. Therefore, these high δ^{13}C values may indicate a contribution of C_4 plants to the cattle diet. C_4 plants make up<1% of the native flora in Bulgaria (Collins and Jones, 1985). Weedy C_4 species, such as white goosefoot (*Chenopodium album*) and sedges (*Carex* sp.), which typically thrive in areas disturbed by human activity, were identified, although not in large proportions, suggesting their availability near the site (Marinova and Krauß, 2014). An increase in human agro-pastoral activities over time, as proposed by archaeobotanical studies (Marinova and Krauß, 2014), may have increased the availability of C_4 weedy species, as these trampling-resistant plants would have favoured disturbed areas near the site. Consumption of these plants may explain the high δ^{13}C and δ^{15}N values in some cattle, assuming they were held near the site. Altogether, the observed seasonal diversity in the cattle diet indicates local-scale cattle husbandry for Dž–II. In this herding system, cattle may have been herded near the site, where C_3 and C_4 plants were available in summer, and stalled in winter, during which time they were foddered. In Dž–IV, the seasonal contribution of C_4

plants to animal diet continues, while C_3 plants remain dominant. The canopy effect, or consumption of plants from forested areas, is detected only in one sheep (Ovis4071). The low amplitude and enrichment of $\delta^{13}C$ values in cattle bone collagen and enamel in Dž–IV may suggest a more intensive cattle husbandry at the site, compared with the previous levels. The lack of significant contribution of C_4 plants in the sheep diet suggests that they were herded in a different environment, while cattle were held near the site.

High $\delta^{15}N$ values in domesticates in Dž–I and Dž–II may relate either to the long-term use of the same pasture, a practice that increases the nitrogen level in soil (Makarewicz, 2014) or to the use of manured crops to feed livestock (Bogaard et al., 2007). Low $\delta^{15}N$ values in bone collagen of wild fauna preclude aridity as a reason for the increase in the nitrogen level in the soil (Ambrose, 1991). The trend towards lower $\delta^{15}N$ and higher $\delta^{13}C$ values in domesticates in Dž–IV indicates grazing in open environments. Further stable isotope analysis of the soil and the cereals are necessary to establish the degree to which environmental and anthropogenic factors affected the soil nitrogen level in the past.

Overall, we suggest non-extensive cattle husbandry at Džuljunica, in which domesticates were kept near the site. Farmers practiced control over animal diet and mobility through fodder provision since the early phases of the settlement. This control may have intensified in Dž–IV. This may have been a strategy to support the herd during winter drought and to eliminate the environmental and geographical constraints on animal physiology, especially when transitioning towards higher latitudes. The limited number of teeth available for sequential sampling and the lack of human palaeodietary analysis and lipid residue analysis of ceramic vessels pose some limitations for the interpretation of these results.

5.2. *Cattle husbandry at Džuljunica in a regional context*

Stable isotopic and zooarchaeological results from Dž–I to Dž–IV provide important information about the beginning, intensity, and modes of cattle husbandry at the settlement of Džuljunica between ca. 6200 and 5500 BCE. The %DZ counts (and %NISP) highlight the importance of cattle herding, and especially beef production, but also point at the importance of caprine herding. The difference between DZ counts, which provide greater control to avoid overestimation of relative taxonomic abundance, on the one hand, and NISP counts, on the other hand, calls for caution when interpreting small changes in %NISP of taxa. Previous studies that tackled late 7th–early 6th millennium BCE cattle husbandry in Bulgaria and adjacent regions, such as northern Greece, the Adriatic, and western Anatolia, based their inferences on % NISP and osteometric data (Orton, 2010; Arbuckle et al., 2014; Orton, Gaastra and Linden, 2016; Ivanova et al., 2018). A high %NISP of morphologically domestic cattle has already been shown for the Early Neolithic in northwestern Anatolia and Bulgaria, while caprines are dominant in coastal Mediterranean environments (Orton, 2010; Çakırlar, 2013; Orton, Gaastra and Linden, 2016; Ivanova et al., 2018), confirming the hypothesis about the link between temperate climate and cattle rearing in early Neolithic Europe (Conolly et al., 2012). As argued especially by Ivanova et al. (2018), while the high rate of cattle rearing in northern Bulgaria, as exemplified not only by Džuljunica, but also by the nearby settlements of Koprivec and Ovčarovo-Grota (Nobis, 1986; Manhart, 1997), may have been an opportunistic adaptation to water availability, caprine herding, which was not at all a negligible practice in the region, may have buffered the risks involved in mono-species animal husbandry.

Transfer of traditions and skills through inter-regional contacts, which is well known through pottery and material culture, may also have played a role in the mixed cattle and caprine husbandry and the near absence of boar hunting/pig rearing in northern Bulgaria (shown previously in de Groene et al., 2018; Manhart, 1997). Present scholarship on the Neolithization for the Balkans focuses on material culture parallels and places the emphasis on the Aegean route, but little is known about the Early Neolithic of northwestern Anatolia, Thrace, and the submerged coastline of the Black Sea (Krauß et al., 2018; de Groot, 2019; Özdoğan, 2019). The preference for cattle (as well as the abundance of barley and the rarity of suids) at Džuljunica and other Neolithic sites in northern Bulgaria aligns better with the patterns in northwestern Anatolia, where zooarchaeological and biomolecular studies highlight the importance of cattle and dairy products, accompanied by caprine husbandry, and indicate a lack of suids (Evershed et al., 2008; Thissen et al., 2010; Çakırlar, 2013).

Osteometric results from Džuljunica indicate that cattle husbandry does not remain static after its emergence in northeastern Bulgaria at the end of the 7th millennium BCE. *Bos* goes through a clear size reduction that affects the entire population; this is clear in the Dž–IV dataset and the contemporary datasets from the region. A pronounced reduction in body size, mainly in males, which results in a reduced sexual dimorphism, is widely recognized as a consequence of ungulate domestication (Helmer et al., 2005; Meadow, 1989; Uerpmann, 1978). The main factors in domestic animal size reduction are still subject to discussion (Zohary, Tchernov and Horwitz, 1998; Zeder, 2008; Wright, 2013). At Džuljunica, the shift in body size occurred in the entire population, which rules out domestication syndrome as the cause. The previously proposed correlations between body size and local temperature (resulting in larger individuals in higher temperatures) have been shown to be spurious; these correlations are argued to be a function of the availability of nutrients and energy during periods of growth (Geist, 1987). Among the anthropogenic factors proposed to explain diminishing cattle size in Neolithic Europe are the intensification in herding strategies through early weaning, accelerated maturation, and sub-adult breeding (Manning et al., 2015). The early weaning of calves (at 4–6 weeks) to reserve the milk supply for humans is reported to decrease calf bodyweight gain and cause food deficiency among modern dairy cattle herds (Eckert et al., 2015). Changes in feeding strategies, population density, pasture usage, mobility patterns, or gene flow between different cattle populations have also been proposed to result in cattle size reduction (Wright, 2013; Hristov et al., 2017). Due to the paucity of stable isotope analyses of faunal remains from Bulgaria, we cannot assess the extent to which animal dietary and mobility changes may have affected animal size, but we can show that at Džuljunica, osteometric changes are accompanied by a shift in culling intensity towards recently weaned individuals (post-lactation slaughtering), suggesting increased dairy production and intensification of cattle husbandry. Due to data incompatibility, it is not possible to compare the cattle mortality data from Džuljunica with that from other sites where a size reduction in cattle was observed. Previously, a substantial reduction in body mass has been observed in cattle farther west in Europe from the 5th millennium BCE onwards, but the main reasons for this reduction are still a matter of debate (Manning et al., 2015). The osteometric data from Džuljunica (and from elsewhere in the Yantra basin) show that cattle size reduction took place earlier in Bulgaria, following quite rapidly after the initial dispersal of cattle husbandry in southeastern Europe.

Although the dataset is still limited, $\delta^{13}C$ and $\delta^{15}N$ values from cattle bone collagen from Džuljunica corroborate the idea of increased control on cattle herding, suggesting that herds were kept in the vicinity of the site, with some degree of access to forest resources, but in increasingly open, anthropogenic environments. The occasional use of forest resources for cattle herding has been previously observed in Linearbandkeramik (LBK) farming practices of central Europe in the 6th and 5th millennia BCE, while open landscapes and cultivated fields remained the optimal pasture (Oelze et al., 2011; Marciniak et al., 2017; Berthon et al., 2018). This strategy supports a subsistence based on crop cultivation and animal husbandry using open environments, cultivated lands, and forest resources as a successful mixed farming subsistence (Gillis et al., 2020).

It is interesting that although the cattle mortality profiles suggest a shift to post-lactation culling in Dž–IV, the $\delta^{18}O$ and $\delta^{13}C$ values in the incremental structure of tooth enamel show no evidence for seasonal vertical mobility of the herds to seek better pastures or an extension of the calving season to increase dairy production at Džuljunica. Studies at Măgura (6000–5800 BCE, Romania), Cheia (5000–4700 BCE, Romania) (Balasse et al., 2013, 2014; Balasse and Tresset, 2007), and the LBK site of Chotěbudice (5400–5100 BCE, Bohemia, Czech Republic) (Berthon et al., 2018), too, have suggested that a short calving season restrained the milk availability. Seasonal fodder scarcity has been put forward for the restricted calving at the latter site (Berthon et al., 2018). In contrast, at Bercy (4th millennium BCE, Paris basin), seasonal food supplementation to expand the calving season (to about 6 months) (Balasse et al., 2012b) and post-lactation slaughtering of weaned calves (Balasse and Tresset, 2002) has been argued to have led to year-round availability of milk for human consumption. At Schipluiden (4th millennium BCE, Rhine–Meuse delta, the Netherlands), calving spread over 5.5 months, which would have led to a longer availability of milk (Kamjan et al., 2020). A short birthing season would not preclude the possibility of using milk as a rich source of nutrition for infants in order to enhance their chance of surviving into adulthood (McClure et al., 2018). Moreover, fermentation for longer availability of dairy products, particularly during periods of drought and food scarcity, would remain a possibility. The variability in the emerging spatio-temporal patterns of human interference with cattle birthing seasonality suggests that diverse husbandry strategies were employed across Neolithic Europe to produce dairy, which is omnipresent in lipid residues in the remains of ceramic pots from northwestern Anatolia to northwestern Europe (Evershed et al., 2008; McClure et al., 2018).

6. Conclusions

The zooarchaeological and stable isotopic analyses of cattle remains from Džuljunica provide us with important information regarding the beginning and the evolution of early cattle husbandry in northern Bulgaria between ca. 6200 and 5500 cal. BCE.

At Džuljunica, herding of both cattle and caprines was important, but beef was far more important than pork, lamb, or venison in the subsistence throughout this period. There was a reduction in cattle size from the early phases of settlement to the later phases. This was a regional phenomenon, perhaps forced by farmers' cattle breeding strategies. Aurochs hunting and cattle intermixing with local aurochs may also explain the large individuals in early Džuljunica, but this hypothesis requires further research. Data from the earliest settlement at Džuljunica are too limited to make any firm suggestions about the main targeted products, but dentition-based mortality profiles indicate that intensive post-lactation slaughter enabled more milk production for human consumption in Dž–IV. Although the stable oxygen and carbon isotope data from enamel are limited, together, they indicate a limited calving season, implying that the calving season was not manipulated to increase milk availability. This may have been a risk-reduction strategy to minimize winter calf mortality. Stable carbon and nitrogen isotope analyses of animal bone collagen suggest local herding near the site, where C_3 and C_4 plants were abundant in the summer. Cattle were occasionally foddered with forest resources in winter. Although these conclusions are tentative because of limited stable isotope analyses available from Early Neolithic contexts in Bulgaria and a lack of palaeogenetic research on cattle, intensification of cattle husbandry at Džuljunica in the first half of the 6th millennium BCE as a local adaptation to the newly settled temperate climate of southeastern Europe remains the most plausible explanation for the observed patterns in the zooarchaeological and stable isotopic data. The preference for beef and the avoidance of suids from the beginning of the settlement may hint at the influence of traditions and skills transferred via central Anatolia, via northwestern Anatolia, through Thrace, or along the Black Sea coast, rather than the influence of Neolithic traditions coming from the northern Aegean.

Generating more detailed and inter-operable zooarchaeological, stable isotopic, and palaeogenetic data from the region will be critical to place the implications of this study in their regional and supra-regional context. Understanding the ways in which cattle husbandry emerged and evolved in southeastern Europe and adjacent regions will certainly inform the discussions on the interplay among cultural preferences, subsistence modes, and environmental adaptation throughout the process of Neolithization.

CRediT authorship contribution statement

Safoora Kamjan: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition. **Donna de Groene:** Formal analysis, Writing - review & editing. **Youri van den Hurk:** Formal analysis, Writing - review & editing. **Petar Zidarov:** Data curation, Writing - review & editing, Resources. **Nedko Elenski:** Data curation, Resources. **William P. Patterson:** Formal analysis, Writing - review & editing. **Canan Çakırlar:** Conceptualization, Validation, Formal analysis, Formal analysis, Writing - original draft, Writing - review & editing, Supervision, Project administration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2021.102789.

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