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Animal keeping in Chalcolithic north-central Anatolia: what can stable isotope analysis add?

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Abstract Stable isotope analysis is an essential investigative technique, complementary to more traditional zooarchaeological approaches to elucidating animal keeping practices. Carbon (δ^{13}C) and nitrogen (δ^{15}N) stable isotope values of 132 domesticates (cattle, caprines and pigs) were evaluated to investigate one aspect of animal keeping, animal forage, at the Late Chalcolithic (mid-fourth millennium BC) site of Çamlıbel Tarlası, which is located in north-central Anatolia. The analyses indicated that all of the domesticates had diets based predominantly on C_3 plants. Pig and caprine δ^{13}C and δ^{15}N values were found to be statistically indistinguishable. However, cattle exhibited distinctive stable isotope values and, therefore, differences in diet from both pigs and caprines at Çamlıbel Tarlası. This difference may relate to the distinct patterns of foraging behaviour exhibited by the domesticates. Alternatively, this diversity may result from the use of different grazing areas or from the foddering practices of the Çamlıbel Tarlası inhabitants.

Introduction

Archaeological research in north-central Anatolia has focused predominantly on Late Bronze Age and Iron Age urban sites. By comparison, prehistoric settlement in the region has received relatively little attention (e.g. Parzinger 1993; Steadman 1995; Özdoğan 1996; Schoop 2005; Düring 2008). As a result, the animal keeping practices and human use of meat and secondary products of this region and time period are poorly understood.

Dietary stable isotope studies of animal bones offer a direct means of reconstructing at least one aspect of animal production: the type of forage domesticates had access to or were given. While such information will not be a panacea in understanding herding practices per se, it elucidates a new dimension directly relevant to animal keeping in the Anatolian region. Here carbon (δ^{13}C) and nitrogen (δ^{15}N) stable isotope analyses of remains from domesticated animals and humans (Pickard et al. 2016) from the Late Chalcolithic settlement site of Çamlıbel Tarlası are used to investigate animal diets. The implications of the results for stock-keeping and the consumption of meat and secondary products by a rural farming community in north-central Anatolia are explored.

Çamlıbel Tarlası—archaeological background

Çamlıbel Tarlası is one of only a very small number of prehistoric sites to have been investigated in north-central Anatolia. Located 2.5 km east of the modern village of

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Boğazkale (the location of the Late Bronze Age Hittite capital Ḫattuša), the site was excavated, as a cooperative project between the German Archaeological Institute and Edinburgh University, over three seasons from 2007 to 2009 (Schoop 2010, 2011, 2015 for summary reports). A small, short-lived settlement and mortuary site, Çamlıbel Tarlası was occupied in the mid-fourth millennium BC (Schoop et al. 2009). The site is located on a small plateau (c. 1040 m asl) in a mountainous and previously wooded region (Dörfler et al. 2000; Marsh 2010), a short distance from the main Budaközü Plain (Fig. 1).

Seven phases of activity (summarised in Table 1) have been identified at Çamlıbel Tarlası, all of which date to the Late Chalcolithic between 3650 and 3375 cal BC. Extractive metallurgy and small-scale agriculture are the principal activities evident at the site. The site's occupants may have been attracted to this location because, in addition to the close proximity of an outcrop of copper ore ~2 km to the east of the site, the surrounding plateaus would have been ideally suited to small-scale agriculture (Marsh 2010).

Çamlıbel Tarlası—the animal remains

An assemblage of 2752 identifiable animal bones (67.7 kg) was recovered at Çamlıbel Tarlası (Bartosiewicz and Gillis 2011; Bartosiewicz et al. 2013). Wild species constituted less than 1 % of the assemblage by NISP (Fig. 2). The remains were predominantly waste from food consumption. Cattle dominated the domesticate remains with pig and caprines also common. Tooth wear and epiphyseal fusion data indicate that the vast majority of the cattle were mature animals. Longevity is attributable to several factors in cattle including the slow reproduction rate and intrinsically high value of individuals as well as secondary product exploitation. Single purpose pigs were slaughtered at or before adulthood for meat. The proportion of bones from young to mature caprines was low. In addition to cattle potentially having been used for traction and sheep for wool, all bovids (including goats) were likely exploited for dairy produce. Distinction between the bones of young lambs and kids, however, tends to be unreliable, further distorting
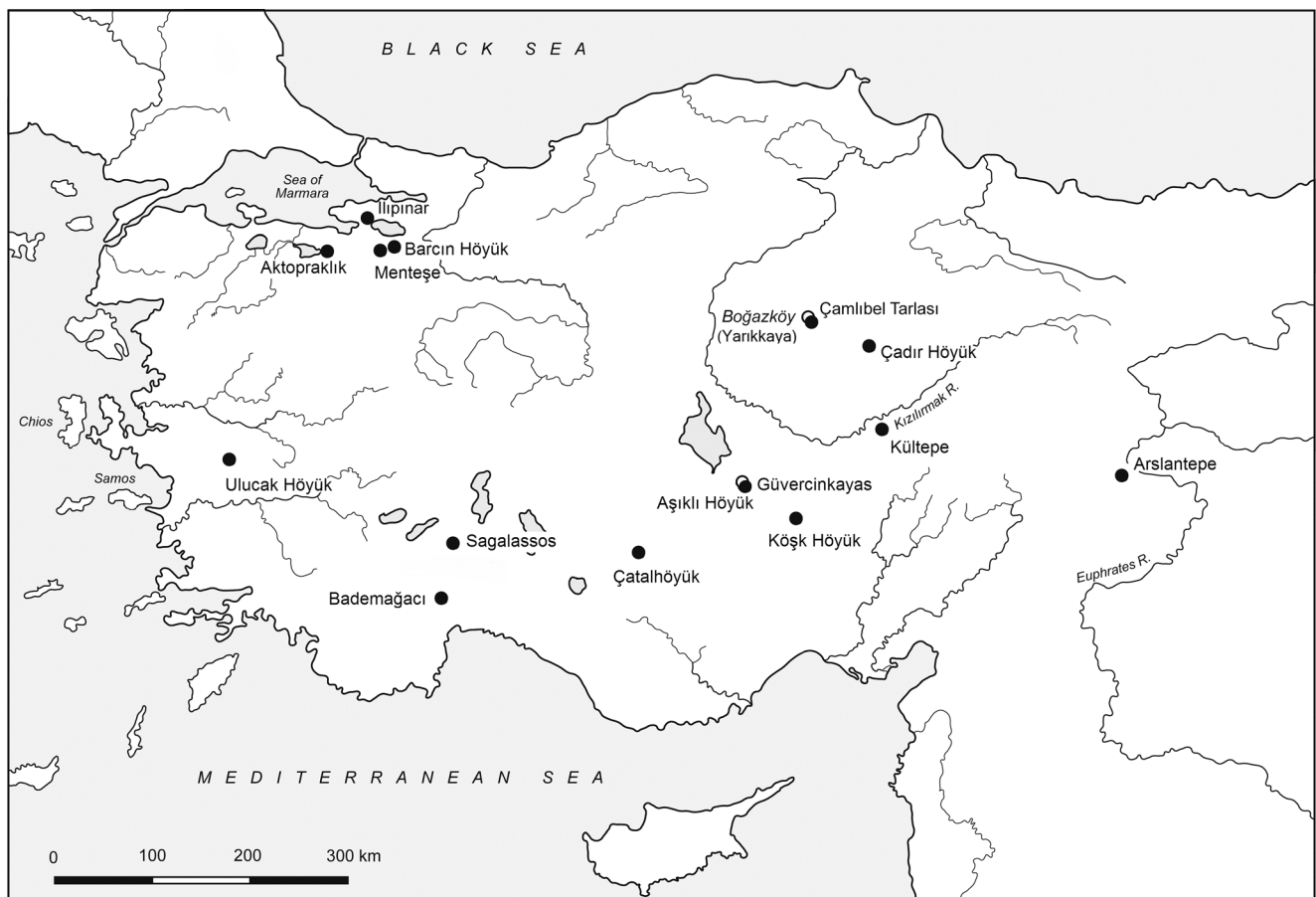

Fig. 1 Map of Anatolia indicating the location of Çamlıbel Tarlası and other major Neolithic and Chalcolithic settlements

Table 1 Phases of activity at Çamlıbel Tarlası

Phase	Characteristic features
TPEU	Fragmentary burials in plough zone
ÇBT IV	Habitations, large courtyard with evidence of slag processing, slag, crucibles
SPEU	Second phase of ephemeral use: seasonal presence, bowl furnaces, ore
ÇBT III	Large, free-standing buildings, crucibles, copper slag
FPEU	First phase of ephemeral use: seasonal presence, bowl furnaces, ore
ÇBT II	Dense architecture, room clusters, bowl furnaces, copper ore, many infant graves
ÇBT I	No habitation structures, water course, seasonal use?, bowl furnaces, copper ore
Virgin soil/bedrock	

speculations concerning the 'management' of caprine herds (Bartosiewicz et al. 2013).

It has been inferred from remains of churns found at Çamlıbel Tarlası (Fig. 3) and nearby sites such as Yarıkkaya (Boğazköy) that dairy produce was important at least in the local economy (Sauter et al. 2003, Figs. 1, 2 and 3). This is congruent with the identification of animal fats, in one case likely milk fat or a derivative, on two pottery sherds from Yarıkkaya (Sauter et al. 2003).

Problems with proxies

Animal remains recovered at settlements such as Çamlıbel Tarlası typically represent food refuse or manufacturing waste unless interpreted as 'ritual' deposits of intact or articulated skeletons. However, there is a tendency to contextualize them in broader terms, inseparably mixing evidence of consumption with far less tangible aspects of exploitation, especially for secondary products. Evidence for the latter is related to animal longevity as secondary products are renewable resources from live animals (e.g. Gerritsen et al. 2010). However, interpretations regarding the bones of calves or lambs/kids alternate between showing emphasis on milk or

meat 'production' (cf. Gourichon and Helmer 2008 and Gerritsen et al. 2010). Moreover, age profiles treated as key evidence are often based on small or unknown numbers of ageable elements encountered among the food remains.

Stable isotope analysis

Stable carbon and nitrogen isotope analysis of bone collagen has been widely demonstrated to be a useful tool in the investigation of animal diets (e.g. Pearson et al. 2007; Towers et al. 2011; Fuller et al. 2012; Gillis et al. 2013).

The technique involves the measurement of carbon ($\delta^{13}C={}^{12}C/{}^{13}C$) and nitrogen ($\delta^{15}N$ ${}^{14}N/{}^{15}N$) isotope ratios in samples of bone collagen (Sealy et al. 1995). ${}^{12}C/{}^{13}C$ isotopes are incorporated into plant tissues during photosynthesis. Carbon
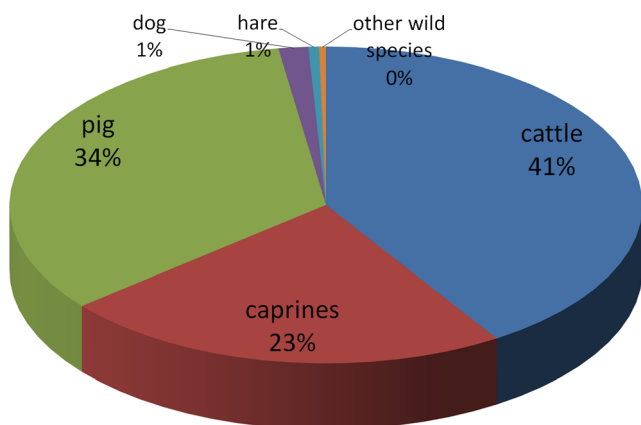

Fig. 2 Animal taxa representation at Çamlıbel Tarlası by NISP

Fig. 3 Example of a reconstructed pottery 'churn' from Çamlıbel Tarlası II

isotope ratios ($\delta^{13}C$) vary between plants depending on the mechanism used to fix atmospheric carbon. Most plants fix carbon through one of two routes, either the C_3 or C_4 pathways (Edwards and Walker 1983). C_3 plants comprise cereals such as wheat and barley, and most fruits and vegetables, while C_4 plants include some tropical grasses and cereals such as millet and sorghum. Variation in plant $\delta^{13}C$ is passed on to the tissues of animal and human consumers. Plant $\delta^{13}C$ values may also exhibit inter-species variation within a C_3 plant environment (e.g. Feranec 2007). The $\delta^{13}C$ value of animal bone collagen can therefore be used to determine not only the relative importance of C_3 vs C_4 plants to diet but may also distinguish between different patterns of foraging behaviour in regions with an exclusively C_3 biome (DeNiro and Epstein 1978; Feranec 2007).

Nitrogen isotope ratios ($\delta^{15}N$) exhibit a 'trophic level' effect, becoming more 'enriched' with each step in the food chain, i.e. they indicate an organism's position in the food chain. The increase in $\delta^{15}N$ values of animals over that of their diets has been observed to be in the order of 3–5 ‰ (e.g. Bocherens and Drucker 2003)—although the diet-consumer offset may vary between species and has been demonstrated to be higher than 5 ‰ in humans (Hedges and Reynard 2007; O'Connell et al. 2012). $^{14}N/^{15}N$ isotopes may be incorporated into plants from soils and/or drawn from atmospheric N_2. Plants that fix nitrogen from the atmosphere (e.g. legumes) generally have lower $\delta^{15}N$ values than those plants that fix nitrogen from soil nitrate or ammonium (DeNiro and Epstein 1981). Plant $\delta^{15}N$ values can also vary significantly depending on water stress (e.g. Ambrose 1991), salinity (e.g. Britton et al. 2008) and increased nitrogen cycling in forested environments (e.g. van der Merwe and Medina 1991). The variability in $\delta^{15}N$ values is passed on to the consumers of plants and may therefore indicate distinctive foraging behaviours among domesticates.

Although the fundamental principles of stable isotope analysis were established in the 1970s and have remained largely unchallenged, it is important to bear in mind that there are a number of additional issues (both dietary and non-dietary) that have implications for the reconstruction of animal forage from stable isotope values, for example the potential effects of physiological stresses, such as gestation and lactation on intra- and inter-individual isotope signatures, as well as the impact of practices such as manuring on isotopic signatures in plants and their animal consumers (e.g. Jenkins et al. 2001; Fuller et al. 2005; Bogaard et al. 2007; Nitsch et al. 2010; Olsen et al. 2014).

Materials and method

A total of 163 domesticated animal (cattle, caprine and pig) bone specimens from Çamlıbel Tarlası were measured for $\delta^{13}C$ and $\delta^{15}N$ to investigate animal forage and human diets

(see Pickard et al. 2016) in Late Chalcolithic north-central Anatolia—see Table 2 for animal data.

A sample of approximately 1 g of bone was taken from each specimen. Pre-treatment included cleaning to remove 1–2 mm of the outer surface of the bone. Collagen was extracted using a modified version of the Longin (1971) method (Brown et al. 1988). Each sample was demineralized in 1 N HCl at 20 °C for a minimum of 24 h, rinsed three times in Milli-Q™ purified water and gelatinized in 0.03 N HCl at 80 °C for approximately 16 h. The resulting solution was then lyophilised. Samples with well-preserved collagen, i.e. collagen wt% yield of >1.00 % (Brock et al. 2010; van Klinken 1999), were measured for $\delta^{13}C$ and $\delta^{15}N$ by the SUERC Radiocarbon Laboratory in East Kilbride, UK, using a Thermo Scientific Delta V Advantage continuous-flow isotope ratio mass spectrometer (CF-IRMS) coupled via a Thermo Scientific ConfloIV to a Costech ECS 4010 elemental analyser (EA) fitted with a pneumatic autosampler. In-house gelatine standards, which are calibrated to the International Atomic Energy Agency (IAEA) reference materials USGS40 (L-glutamic acid, $\delta^{13}C_{V-PDB}$ = −26.39 ‰), USGS41 (L-glutamic acid, $\delta^{13}C_{V-PDB}$ = + 37.63 ‰), IAEA-CH-6 (sucrose, $\delta^{13}C_{V-PDB}$ = −10.45 ‰), USGS25 (ammonium sulphate, $\delta^{15}N_{AIR}$ = −30.41 ‰), IAEA-N-1 (ammonium sulphate, $\delta^{15}N_{AIR}$ = +0.43 ‰) and IAEA-N-2 (ammonium sulphate, $\delta^{15}N_{AIR}$ = +20.41 ‰), are run in duplicate for every ten unknown samples. Results are corrected for linearity and instrumental drift and are reported as per mil (‰) relative to the internationally accepted standards V-PDB and AIR, with 1σ precisions of ±0.2 and ±0.3 ‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. Collagen integrity was assessed according to the following criteria: (i) C/N ratio in the range 2.9 to 3.6 (DeNiro 1985) and (ii) minimum %C and %N as outlined by Ambrose (1990).

Less than 1 % collagen yield was obtained from 22 samples (seven caprines, 11 cattle and four pig). A further nine samples (one cattle, seven pig and one sheep) had a collagen yield of wt% >1.0 % but when measured failed to meet the criteria cited for well-preserved collagen. These samples were excluded from the discussion below.

Results

The average carbon isotope values of the domesticates (cattle, caprines and pigs) are typical of animals foraging predominantly on C_3 resources.

The domestic caprine $\delta^{13}C$ and $\delta^{15}N$ values were found to be relatively homogeneous, with average $\delta^{13}C = -19.2 \pm 0.5$ ‰ and $\delta^{15}N = 6.4 \pm 0.7$ ‰ ($n = 38$), and are typical of herbivores consuming exclusively C_3 resources (cf. Pearson et al. 2007). Little difference in the average isotope values of goat and sheep is evident (sheep average $\delta^{13}C = -19.1 \pm 0.5$ ‰ and

	Sample ID (GUsi)	Species	Phase	$\delta^{13}C$	$\delta^{15}N$	C/N	%N	%C
Table 2 Stable isotope data and collagen preservation indicators of Çamlıbel Tarlası domesticate remains (previously published in Pickard et al. 2016)	2202	Cattle (*Bos*)	ÇBT III	−19.4	5.9	3.1	13.8	37.1
	2205	Cattle (*Bos*)	FPEU	−19.6	6.0	3.2	14.6	39.9
	2207	Cattle (*Bos*)	ÇBT III	−19.4	8.0	3.2	13.3	35.9
	2270	Cattle (*Bos*)	ÇBT III	−18.1	6.2	3.2	13.6	37.7
	2271	Cattle (*Bos*)	ÇBT IV	−18.9	7.7	3.2	14.8	40.7
	2272	Cattle (*Bos*)	ÇBT III	−17.6	9.8	3.2	14.2	39.1
	2273	Cattle (*Bos*)	ÇBT IV	−19.0	8.1	3.2	14.3	39.8
	2274	Cattle (*Bos*)	ÇBT II	−19.4	9.7	3.2	13.3	36.7
	2275	Cattle (*Bos*)	ÇBT I	−16.8	7.0	3.2	12.1	33.6
	2276	Cattle (*Bos*)	ÇBT I	−18.3	6.1	3.2	13.7	37.5
	2326	Cattle (*Bos*)	ÇBT II	−19.4	6.7	3.2	13.3	36.9
	2327	Cattle (*Bos*)	ÇBT I	−18.2	6.8	3.3	15.6	43.9
	2328	Cattle (*Bos*)	ÇBT III	−20.1	7.0	3.2	13.6	37.4
	2329	Cattle (*Bos*)	ÇBT I	−19.9	6.1	3.2	15.8	43.9
	2330	Cattle (*Bos*)	ÇBT II	−19.5	8.6	3.3	14.1	39.5
	2331	Cattle (*Bos*)	ÇBT I	−18.7	6.5	3.3	15.6	43.4
	2332	Cattle (*Bos*)	ÇBT I	−18.3	6.7	3.3	15.4	43.4
	2333	Cattle (*Bos*)	ÇBT IV	−18.8	6.3	3.2	12.4	34.1
	2334	Cattle (*Bos*)	ÇBT II	−17.4	8.9	3.3	14.9	41.6
	2335	Cattle (*Bos*)	ÇBT IV	−18.2	9.1	3.2	14.7	40.8
	3096	Cattle (*Bos*)	SPEU	−19.6	6.4	3.3	11.4	31.8
	3114	Cattle (*Bos*)	FPEU	−18.5	5.5	3.2	11.3	31.4
	3115	Cattle (*Bos*)	ÇBT I	−17.0	7.5	3.2	11.8	32.6
	3116	Cattle (*Bos*)	ÇBT IV	−17.5	7.4	3.3	10.7	30.1
	3117	Cattle (*Bos*)	ÇBT III/IV	−20.1	7.4	3.3	13.0	36.7
	3118	Cattle (*Bos*)	ÇBT III	−17.6	7.4	3.2	14.2	39.4
	3119	Cattle (*Bos*)	ÇBT I	−17.6	6.5	3.3	13.8	38.9
	3120	Cattle (*Bos*)	ÇBT II	−19.7	7.3	3.3	13.7	38.6
	3135	Cattle (*Bos*)	ÇBT I	−18.8	6.8	3.3	12.7	36.3
	3136	Cattle (*Bos*)	ÇBT III	−19.3	6.2	3.3	13.1	37.0
	3137	Cattle (*Bos*)	ÇBT III	−18.4	6.5	3.3	10.3	29.2
	3143	Cattle (*Bos*)	ÇBT I	−18.2	6.9	3.2	13.6	37.5
	3144	Cattle (*Bos*)	ÇBT IV	−18.3	6.3	3.2	12.4	34.3
	3145	Cattle (*Bos*)	SPEU	−19.2	7.5	3.2	14.3	39.7
	3147	Cattle (*Bos*)	FPEU	−17.7	6.8	3.2	12.3	34.2
	3149	Cattle (*Bos*)	SPEU	−18.1	8.2	3.3	10.6	29.8
	3154	Cattle (*Bos*)	SPEU	−19.2	5.9	3.2	13.1	36.2
	3155	Cattle (*Bos*)	SPEU	−19.5	6.0	3.3	11.6	32.4
	3156	Cattle (*Bos*)	FPEU	−19.8	7.1	3.2	11.7	32.4
	3157	Cattle (*Bos*)	ÇBT I	−20.0	6.1	3.2	12.4	34.3
	2325	Caprine	ÇBT III	−19.2	6.5	3.2	14.8	41.3
	3017	Caprine	ÇBT IV	−18.6	7.9	3.2	12.7	35.2
	3022	Caprine	ÇBT I	−19.6	7.3	3.3	14.5	40.3
	3023	Caprine	ÇBT II	−19.4	6.6	3.3	12.4	34.6
	3092	Caprine	ÇBT III	−19.5	7.2	3.2	13.2	36.7
	3254	Caprine	ÇBT I	−19.4	6.1	3.2	13.2	36.8
	3255	Caprine	ÇBT II	−19.9	5.5	3.3	5.0	14.2
	3256	Caprine	ÇBT I	−19.3	6.1	3.2	13.2	36.4
	3257	Caprine	ÇBT II/III	−19.4	7.2	3.2	13.1	36.2

Table 2 (continued)

Sample ID (GUsi)	Species	Phase	δ^{13}C	δ^{15}N	C/N	%N	%C
3258	Caprine	ÇBT III/IV	−19.6	7.2	3.3	7.2	24.1
3259	Caprine	ÇBT III	−18.8	6.2	3.2	14.3	39.6
3090	Goat (*Capra hircus*)	SPEU	−20.2	4.9	3.3	15.3	43.1
3161	Goat (*Capra hircus*)	ÇBT IV	−18.0	6.0	3.2	13.4	37.2
3164	Goat (*Capra hircus*)	ÇBT III	−19.3	5.1	3.2	10.6	29.1
3168	Goat (*Capra hircus*)	SPEU	−19.6	6.5	3.2	8.9	24.8
2204	Sheep (*Ovis aries*)	ÇBT I	−18.8	5.7	3.2	12.0	32.5
2268	Sheep (*Ovis aries*)	ÇBT III	−19.4	7.8	3.3	13.7	38.2
3018	Sheep (*Ovis aries*)	ÇBT IV	−19.7	5.4	3.3	12.1	34.0
3019	Sheep (*Ovis aries*)	ÇBT I	−19.0	6.2	3.3	15.5	43.4
3020	Sheep (*Ovis aries*)	FPEU	−19.2	7.1	3.2	13.9	38.4
3021	Sheep (*Ovis aries*)	ÇBT III	−19.6	6.4	3.3	7.6	21.8
3024	Sheep (*Ovis aries*)	ÇBT I	−18.1	6.7	3.2	13.7	38.0
3025	Sheep (*Ovis aries*)	ÇBT III	−19.2	7.0	3.3	13.5	37.6
3026	Sheep (*Ovis aries*)	ÇBT I	−19.0	6.1	3.2	14.7	40.6
3027	Sheep (*Ovis aries*)	ÇBT II	−19.3	6.1	3.2	13.4	36.9
3089	Sheep (*Ovis aries*)	ÇBT III	−19.2	6.4	3.2	15.6	43.2
3091	Sheep (*Ovis aries*)	SPEU	−18.7	6.6	3.3	11.0	30.7
3093	Sheep (*Ovis aries*)	ÇBT III	−19.6	7.1	3.2	14.6	40.4
3094	Sheep (*Ovis aries*)	ÇBT IV	−19.0	6.2	3.2	13.1	36.3
3095	Sheep (*Ovis aries*)	ÇBT IV	−19.1	6.0	3.2	13.6	37.7
3097	Sheep (*Ovis aries*)	SPEU	−20.2	5.6	3.2	14.6	40.6
3098	Sheep (*Ovis aries*)	FPEU	−19.3	6.5	3.3	7.7	21.9
3158	Sheep (*Ovis aries*)	ÇBT II	−19.5	5.9	3.3	13.9	38.8
3163	Sheep (*Ovis aries*)	FPEU	−18.2	5.9	3.2	13.5	36.9
3250	Sheep (*Ovis aries*)	ÇBT I	−18.8	7.1	3.3	14.6	40.9
3252	Sheep (*Ovis aries*)	ÇBT III	−19.3	6.5	3.2	14.2	39.6
3251	Sheep (*Ovis aries*)	ÇBT II	−18.5	5.7	3.2	13.0	35.8
3253	Sheep (*Ovis aries*)	FPEU	−19.6	6.0	3.2	13.9	38.5
2203	Pig (*Sus*)	ÇBT III	−19.0	7.3	3.2	13.1	35.8
2651	Pig (*Sus*)	SPEU	−20.1	5.5	3.2	9.8	27.4
2652	Pig (*Sus*)	ÇBT III	−19.5	7.1	3.2	13.7	37.8
2653	Pig (*Sus*)	ÇBT I	−19.9	5.6	3.4	4.5	12.9
2655	Pig (*Sus*)	ÇBT II	−18.7	4.7	3.3	8.5	24.0
2657	Pig (*Sus*)	ÇBT II	−19.2	7.3	3.2	11.8	32.9
2658	Pig (*Sus*)	ÇBT IV	−18.9	5.9	3.3	10.2	29.0
2659	Pig (*Sus*)	ÇBT II	−19.4	6.6	3.3	9.7	27.1
2661	Pig (*Sus*)	FPEU	−19.8	8.0	3.2	9.7	26.9
2662	Pig (*Sus*)	ÇBT IV	−19.8	6.7	3.3	10.9	30.9
2663	Pig (*Sus*)	ÇBT III	−20.2	5.7	3.4	7.3	21.2
2664	Pig (*Sus*)	SPEU	−20.0	6.5	3.3	8.9	25.3
2666	Pig (*Sus*)	ÇBT IV	−18.7	6.0	3.3	8.7	24.8
2667	Pig (*Sus*)	ÇBT II	−19.4	6.4	3.3	12.6	35.5
2668	Pig (*Sus*)	FPEU	−19.7	7.6	3.5	4.0	12.0
2669	Pig (*Sus*)	ÇBT IV	−20.3	6.7	3.3	10.4	29.2
2926	Pig (*Sus*)	ÇBT I	−19.1	6.0	3.2	13.2	36.2
2927	Pig (*Sus*)	ÇBT IV	−19.6	7.2	3.2	15.4	42.1
2928	Pig (*Sus*)	ÇBT I	−19.4	6.3	3.2	13.5	37.1
3015	Pig (*Sus*)	ÇBT I	−19.0	6.7	3.2	14.1	39.1

Table 2 (continued)

Sample ID (GUsi)	Species	Phase	$\delta^{13}C$	$\delta^{15}N$	C/N	%N	%C
3016	Pig (*Sus*)	SPEU	−19.4	7.1	3.2	13.4	37.1
3088	Pig (*Sus*)	ÇBT IV	−19.5	6.9	3.2	9.4	26.1
3122	Pig (*Sus*)	ÇBT I	−19.6	6.6	3.3	9.0	25.3
3123	Pig (*Sus*)	ÇBT III	−19.4	6.9	3.3	9.6	27.4
3124	Pig (*Sus*)	ÇBT III	−19.3	7.0	3.3	9.8	27.5
3125	Pig (*Sus*)	ÇBT III	−20.3	6.7	3.3	13.5	38.0
3126	Pig (*Sus*)	ÇBT II	−19.8	6.2	3.3	9.6	27.0
3127	Pig (*Sus*)	ÇBT I	−19.6	7.7	3.2	12.9	35.6
3128	Pig (*Sus*)	ÇBT III	−19.5	7.6	3.3	14.0	39.2
3129	Pig (*Sus*)	ÇBT II	−19.4	6.5	3.2	12.1	33.7
3130	Pig (*Sus*)	SPEU	−19.0	8.2	3.3	12.4	34.7
3131	Pig (*Sus*)	ÇBT I	−19.3	6.1	3.3	9.8	27.4
3132	Pig (*Sus*)	FPEU	−19.0	6.8	3.3	12.5	35.2
3133	Pig (*Sus*)	ÇBT III	−19.2	7.8	3.4	5.6	16.4
3134	Pig (*Sus*)	ÇBT II	−19.3	7.0	3.2	11.6	32.2
3139	Pig (*Sus*)	ÇBT III	−20.3	6.4	3.3	10.5	29.6
3148	Pig (*Sus*)	SPEU	−19.1	7.3	3.2	8.7	24.3
3150	Pig (*Sus*)	ÇBT III	−19.0	6.0	3.2	11.8	32.8
3151	Pig (*Sus*)	ÇBT III	−19.0	6.6	3.2	12.6	35.1
3152	Pig (*Sus*)	ÇBT III	−19.0	7.1	3.2	13.0	36.1
3153	Pig (*Sus*)	ÇBT I	−19.5	6.0	3.2	13.4	36.9
3159	Pig (*Sus*)	FPEU	−18.3	5.4	3.2	8.8	24.4
3160	Pig (*Sus*)	FPEU	−19.5	7.6	3.2	12.0	32.8
3162	Pig (*Sus*)	ÇBT III	−19.3	6.6	3.2	12.6	35.0
3165	Pig (*Sus*)	ÇBT III	−19.0	7.3	3.3	10.0	28.0
3166	Pig (*Sus*)	ÇBT I	−18.6	6.0	3.2	18.3	50.7
3167	Pig (*Sus*)	ÇBT I	−18.8	6.4	3.2	13.0	35.9
3242	Pig (*Sus*)	ÇBT II	−19.2	6.7	3.2	13.5	37.4
3243	Pig (*Sus*)	ÇBT II/III	−19.4	7.3	3.3	13.8	38.6
3245	Pig (*Sus*)	FPEU	−19.1	7.8	3.2	11.3	31.1
3249	Pig (*Sus*)	ÇBT III	−19.4	7.1	3.2	10.0	27.8
3246	Pig (*Sus*)	ÇBT II	−19.9	6.6	3.3	13.2	36.8
3247	Pig (*Sus*)	ÇBT III	−19.9	7.0	3.2	12.0	33.3
3248	Pig (*Sus*)	FPEU	−19.4	6.0	3.3	12.3	34.5
2206	Dog (*Canis familiaris*)	ÇBT I	−19.4	6.2	3.1	12.6	34.0
3109	Dog (*Canis familiaris*)	ÇBT III	−19.0	7.7	3.2	12.7	35.1
3110	Dog (*Canis familiaris*)	ÇBT I	−18.9	8.3	3.2	12.4	34.2
3111	Dog (*Canis familiaris*)	ÇBT I	−19.3	6.1	3.3	11.0	30.9
3112	Dog (*Canis familiaris*)	ÇBT II	−18.9	6.9	3.2	13.5	37.4
3113	Dog (*Canis familiaris*)	FPEU	−18.6	9.8	3.3	11.3	32.2
3121	Dog (*Canis familiaris*)	ÇBT II	−18.9	7.2	3.2	10.9	30.4
3146	Dog (*Canis familiaris*)	ÇBT III	−19.4	6.5	3.3	8.3	23.3

$\delta^{15}N = 6.4 \pm 0.6 ‰ (n = 23)$; goat average $\delta^{13}C = −19.3 \pm 0.8 ‰$ and $\delta^{15}N = 5.8 \pm 0.8 ‰ (n = 4)$).

The pigs sampled were identified as domestic based on their small phenotypic size in comparison to the wild progenitor and on the fact that other hunted animals were a very small component of the faunal assemblage (Bartosiewicz and Gillis 2011; Bartosiewicz et al. 2013, 111, Figs. 7 and 8). One of the pigs sampled, GUsi-2663, is a sub-adult specimen. However, the $\delta^{13}C$ and $\delta^{15}N$ values of this specimen overlap those obtained for the adults, i.e. no suckling enrichment effect is

evident by this age. This specimen is therefore considered along with the adults. Pig mean $\delta^{13}C$ and $\delta^{15}N$ values suggest a relatively uniform diet, with average $\delta^{13}C$ and $\delta^{15}N$ of -19.3 ± 0.4 and 6.8 ± 0.6 ‰ ($n = 54$), respectively.

By comparison, cattle $\delta^{13}C$ and $\delta^{15}N$ values are more variable, with a relatively large range in both isotope values evident (see Table 2 and Fig. 4). The average values with standard deviation are $\delta^{13}C = -18.7 \pm 0.9$ ‰ and $\delta^{15}N = 7.1 \pm 1.1$ ‰ ($n = 40$). The range of cattle $\delta^{15}N$ values is wide, spanning 4.3 ‰ with a minimum value of 5.5 ‰ and a maximum value of 9.8 ‰. The range of cattle $\delta^{13}C$ values is also broad, from -20.1 to -17.0 ‰. The variation in cattle stable isotope values does not correspond to diachronic change (there are no statistically significant differences in the $\delta^{13}C$ and $\delta^{15}N$ values between bones associated with various phases of activity at Çamlıbel Tarlası).

Statistical evaluation of domesticate herbivore stable isotope values

Bartlett's test was used to assess the null hypothesis that the variance of the $\delta^{13}C$ values of the domesticates (cattle, caprine and pig) is homogenous. The variance of the domesticate $\delta^{13}C$ values was found to be significantly different (Bartlett $\chi^2 = 25.582$ with probability 0.000003, χ^2 value for significance at 5 % and $d.f.$ 2 is >5.991). Figure 5 shows the distribution of $\delta^{13}C$ values by taxon. The non-parametric Kruskal–Wallis test

was used to assess the null hypothesis that the $\delta^{13}C$ values of the domesticates were uniform. The $\delta^{13}C$ values were found to be statistically different ($K = 12.466179$, $p = 0.001963$). The same statistical tests were undertaken for the domesticates with the exclusion of goats (owing to small sample size) and the caprines that could not be identified to species level. Bartlett's test indicated that the variance of the domesticate $\delta^{13}C$ values (i.e. cattle, pig and sheep) remained significantly different (Bartlett $\chi^2 = 24.763$ with probability 0.000004, χ^2 value for significance at 5 % and $d.f.$ 2 is >5.991). The Kruskal–Wallis test also indicated that there is a statistically significant difference in the $\delta^{13}C$ values of the different domesticates ($K = 12.938133$, $p = 0.001551$, for cattle, caprine and pig; $K = 12.466179$, $p = 0.0001963$, for cattle, sheep and pig).

The same sets of statistical analyses were repeated to compare the $\delta^{15}N$ values of the domestic herbivores. The variances of the $\delta^{15}N$ values were found to be unequal (Bartlett $\chi^2 = 9.957$ with probability 0.002069, χ^2 value for significance at 5 % and $d.f.$ 2 is >5.991, for cattle, caprines and pig; Bartlett $\chi^2 = 12.362$ with probability 0.006885, for cattle, sheep and pig)—see Fig. 6 for distribution of $\delta^{15}N$ values. The $\delta^{15}N$ values of the domesticates are significantly different (Kruskal–Wallis test—$K = 10.135896$, $p = 0.006295$, for cattle, caprines and pig; $K = 9.423774$, $p = 0.008988$, for cattle, sheep and pig).

A post hoc Mann-Whitney U test was used to examine pairwise differences in stable isotope values. Increased

Fig. 4 Scatterplot of average $\delta^{13}C$ and $\delta^{15}N$ values of Çamlıbel Tarlası domesticate samples by species with standard deviation indicated by error bars. The average $\delta^{13}C$ and $\delta^{15}N$ values of the adult humans from Çamlıbel Tarlası have been included for comparison
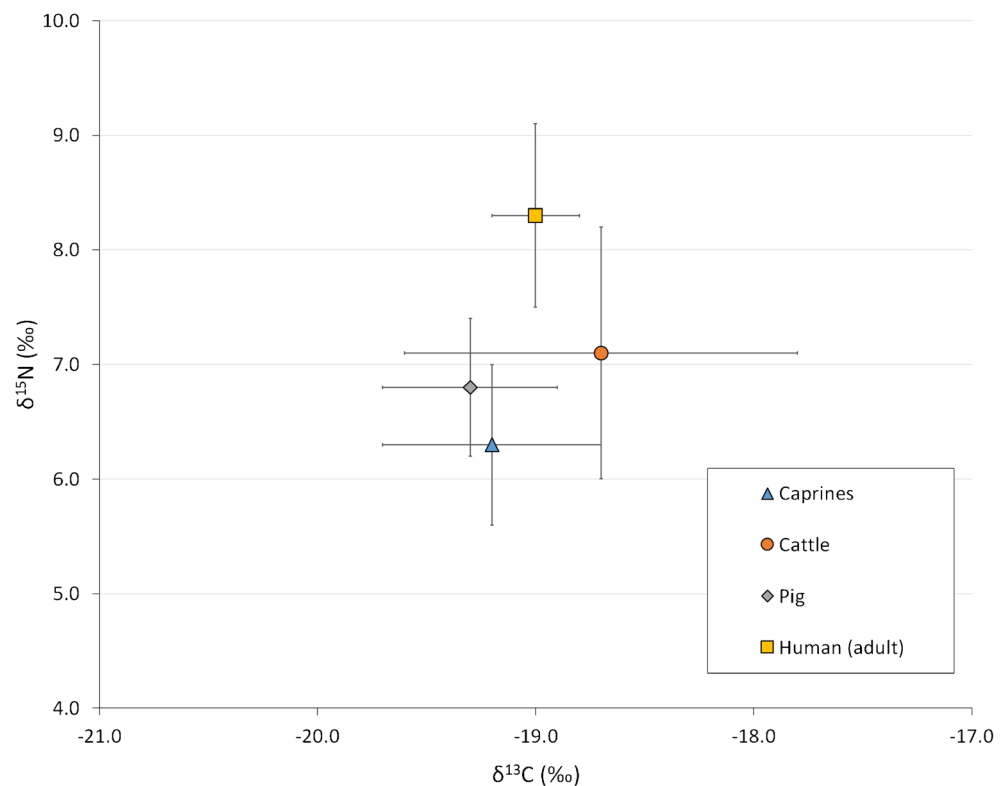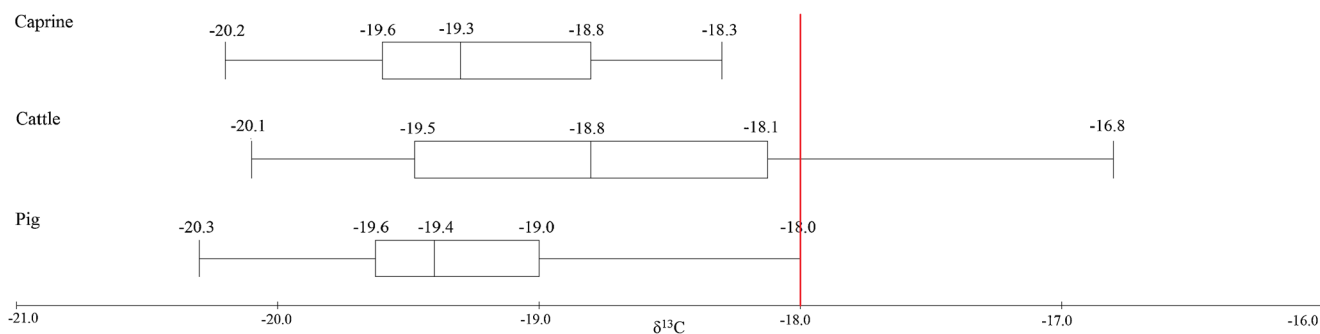
Fig. 5 Boxplot showing the distribution of δ^{13}C values of the domesticates from Çamlıbel Tarlası by taxon. The *red line* highlights the δ^{13}C value −18.0 ‰, which has been used as a 'threshold' value for the consumption of C4 resources (e.g. Pearson et al. 2007)

stringency was employed to compensate for multiple testing (p has significance at ≤0.05/3, i.e. 0.0167). The p values of the Mann-Whitney U test and a summary of statistical significance are presented in Tables 3, 4 and 5. Figure 7 provides a graphical representation of the isotopic relationships of the cattle, caprines and pigs for both carbon and nitrogen values based on the Mann-Whitney results.

Discussion

Domesticate forage and animal keeping at Çamlıbel Tarlası

Statistical analysis of the carbon and nitrogen stable isotope values of the domesticates has demonstrated that the cattle have distinctive stable isotope values from both the pigs and the caprines at Çamlıbel Tarlası. There are several possible diet-related explanations that may account for these differences including (i) differences in foddering practices, (ii) differences in foraging behaviour and (iii) differences in areas grazed.

Domesticate animals often have multiple uses and may be fed distinctive diets depending on function (Bayer et al. 2003). For example, in traditional small-scale farming economies, cattle kept principally for milk may be non-grazed, fed exclusively on fodder crops to ensure high quality diet to maximise productivity (van Shaik et al. 1996). At Late Neolithic/Early

Chalcolithic Ilıpınar, barley kernels and chaff were recovered in the dung of stalled cattle, interpreted by Cappers (2008, p. 120) as a diet specific to 'beasts that are used for ploughing' (Cappers 2008, p. 120). Although the energy requirements of non-female draught cattle have been demonstrated to be similar to that of non-draught bulls (Goe and McDowell 1980), cows used for traction show reduced fertility and milk production partially mitigated if nutritionally high quality feed is provided (Jabbar 1993). The majority of the identified cattle remains were those of mature animals, a mortality profile consistent with use for traction or dairy (Bartosiewicz and Gillis 2011). There is no archaeological evidence to support confined stalling or selective foddering of cattle at Çamlıbel Tarlası. However, the most recent settlement at Çamlıbel Tarlası was surrounded by a boundary wall, a relatively weak construction which was clearly not defensive in character. Such a wall would have been extremely useful for the protection of livestock in an environment which was potentially home to a range of large predators such as leopards, lions, bears and wolves—the latter still present today.

Domesticates have distinct ingestive and digestive capabilities (Prache et al. 1998) resulting in different behaviours in free-foraging animals. Pigs, as facultative omnivores, might be anticipated to have a distinctive diet from the domesticated ruminants. The diets of domestic pigs vary depending on husbandry practices. Pig farmers traditionally practice one of three feeding strategies, (i) free roaming and foraging; (ii) grazing in fields often with other livestock; and (iii) penning,
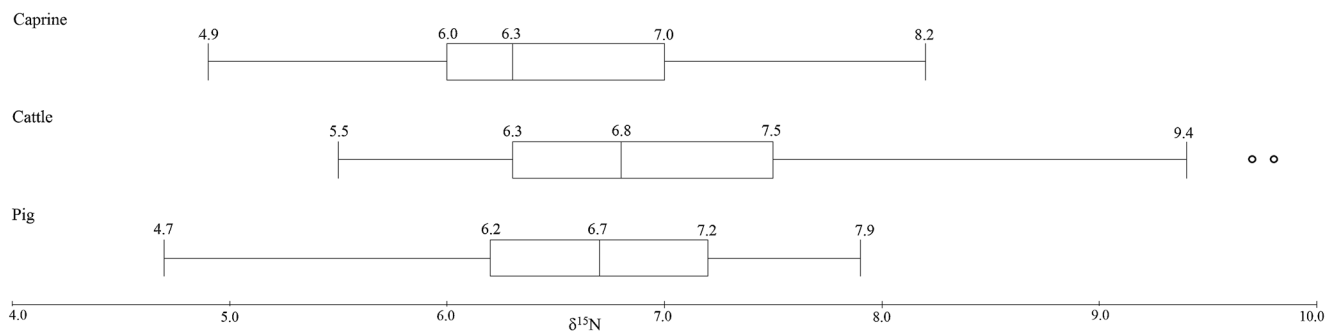

Fig. 6 Boxplot showing the distribution of δ^{15}N values of the domesticates from Çamlıbel Tarlası by taxon. Two cattle have statistically outlying δ^{15}N values

Table 3 Mann-Whitney U test p values of pairwise comparison of domesticate $\delta^{13}C$ values

$\delta^{13}C$	Cattle	Caprines	Pig
Cattle			
Caprines	$p = 0.032544$		
Pig	$p = 0.000630$	$p = 0.138028$	
Sheep	$p = 0.139705$	$p = 0.466061$	$p = 0.039171$

i.e. confined to spaces such as pig sties. Free roaming pigs tend to forage over large areas and while they consume a wide range of animal foods including insects, eggs, small mammals and carrion, they are predominantly herbivorous (Studnitz et al. 2007). Penned pigs will generally be fed on plants and on domestic/household waste. If the waste products include animal proteins (e.g. milk and meat or even faeces) resulting pig $\delta^{15}N$ values will be higher than those of free roaming or field grazed animals. However, as indicated above, the $\delta^{13}C$ and $\delta^{15}N$ values of the pigs at Çamlıbel Tarlası are statistically equivalent to those of the sheep as well as the extended group that includes all caprines (i.e. obligate herbivores), suggesting that the pigs were unlikely to have been fed on domestic refuse often rich in animal proteins.

Cattle and sheep, despite both being grazing ruminants, may also have distinctive foraging behaviours. Sheep tend to target higher quality forage owing to reduced gut size and shorter digestion times as well as being able to be more selective in forage owing to the shape and reduced size of the ovine dental arcade (Prache et al. 1998). Cattle tolerate lower quality and rougher forage more readily than sheep (Prache et al. 1998).

Local vegetation heterogeneity accompanied by different foraging behaviours could potentially account for the differences evident in the isotope values of cattle and sheep at Çamlıbel Tarlası. Given the range of the cattle $\delta^{13}C$ values at Çamlıbel Tarlası, from −20.1 up to −17.0 ‰, it could be argued (cf. Pearson et al. 2007; Budd et al. 2013) that the source of this heterogeneity is the inclusion (or greater inclusion) of C_4 plants in cattle diet. However, all of the crop and wild grass species identified at Çamlıbel Tarlası use the C_3 photosynthetic pathway (Papadopoulou and Bogaard 2012, Table 4). Two plants recovered were not identifiable to species

**Table 4** Mann-Whitney U test p values of pairwise comparison of domesticate $\delta^{15}N$ values

$\delta^{15}N$	Cattle	Caprines	Pig
Cattle			
Caprines	$p = 0.003240$		
Pig	$p = 0.232884$	$p = 0.025863$	
Sheep	$p = 0.004600$	$p = 0.743375$	$p = 0.022187$

Table 5 Summary of statistical significance of differences in $\delta^{13}C$ and $\delta^{15}N$ values of domesticates

	$\delta^{13}C$			$\delta^{15}N$		
	Cattle	Caprines	Pig	Cattle	Caprines	Pig
Cattle						
Caprines	No			Yes		
Pig	Yes	No		No	No	
Sheep	No	No	No	Yes	No	

level, one from the borage (Boraginacaea) or sedge (Cyperaceae) families and the other from the saltbush genus (*Atriplex* sp.). These families include both C_3 and C_4 species (Edwards and Walker 1983). However, the presence of these broad taxa does not convincingly indicate the presence of C_4 plant species in the Çamlıbel Tarlası locale. Furthermore, it is unlikely that C_4 cereal crops such as millet (*Panicum miliaceum*) were available to the inhabitants of Çamlıbel Tarlası. Millet was not cultivated in central Anatolia in large quantities before at least the Bronze Age and possibly later (e.g. Nesbitt and Summers 1988; Riehl and Nesbitt 2003).

An alternative scenario to heterogeneity in local plant forage is the movement of domestic livestock between different pastures, potentially some distance from settlements and possibly with access to isotopically distinct plants (cf. Peters et al. 2013). Although C_3 plants have dominated Anatolian vegetation throughout the Holocene (Rao et al. 2012), C_4 plants were certainly present at least regionally. Consumption of C_4 plants is clearly indicated by the range of $\delta^{13}C$ values of wild cattle (*Bos* spp.) and the plant remains at the Aceramic Neolithic site of Aşıklı Höyük in the Cappadocian region of Turkey (Pearson et al. 2007). C_4 plants have also been recovered from a number of sites in Anatolia and in some cases were evidently
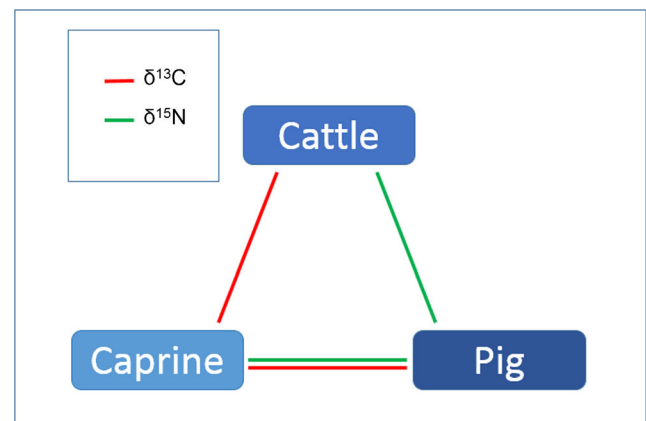
Fig. 7 Graphical representation of statistical significance based on Mann-Whitney U test with increase stringency. *Lines* between the groups represent statistically indistinguishable isotope values. Statistical equivalence of $\delta^{15}N$ values is indicated by the *green line*, while that of $\delta^{13}C$ is indicated by the *red line*

consumed by livestock. For example, at Çatalhöyük, located in south-central Anatolia, C_4 grasses *Aeluropus*, *Crypsis* and *Sporobolus*, as well as *Eleocharis* (generally a C_4 plant although Bruhl and Wilson (2007) describe C_3/C_4 intermediate and variant species), were recovered from animal dung (Richards et al. 2003; Bogaard et al. 2013a). The C_4 ruderal, sun spurge (*Euphorbia helioscopia*), is present at Late Neolithic/Early Chalcolithic Ilıpınar, in North West Anatolia, but is not abundant (Cappers 2008).

A further possibility cannot be ruled out, that is the external, and possibly long-distance, provisioning of smaller settlements such as Çamlıbel Tarlası with at least some of their livestock or meat. Arbuckle (2012) noted increasing complexity in the management of sheep herds throughout the Chalcolithic in central Anatolia, which were at least in part distributed to settlements by specialist mobile pastoralists. Concrete evidence for far-reaching trade contacts at Çamlıbel Tarlası include finds of cockle shells (Cardiidae), which must have originated from either the Black Sea or the Mediterranean, obsidian from Cappadocia, flint blades from unknown exotic sources and a casting mould for ring-shaped figurines indicating an ideological link to the Southern Balkans (Schoop 2011; Schoop and Lehner 2013). Livestock may thus have been imported in the form of exchange or at social occasions when groups living in the broader area congregated. Meanwhile, locals may have kept small stocks. That cattle meat may have been consumed only occasionally, possibly during social gatherings or 'feasts', is supported indirectly by the average nitrogen stable isotope value of the inhabitants of Çamlıbel Tarlası (Pickard et al. 2016), which is similar to that of the cattle, suggesting that cattle meat was unlikely to be a significant or consistent source of dietary protein.

Domesticate forage and animal keeping across prehistoric Anatolia

The results from Çamlıbel Tarlası add to a small but growing body of isotope data from domesticates at Neolithic and Chalcolithic sites across prehistoric Anatolia.

At Çamlıbel Tarlası, the relatively low $\delta^{15}N$ values of the pigs in comparison to ruminants suggest that they were likely free roaming and foraging. Pearson et al. (2015) also noted that the relatively low average $\delta^{15}N$ value of pig in comparison to the human inhabitants and domesticates of Neolithic Çatalhöyük suggested that these animals were not fed on domestic waste (although three outliers with comparatively high $\delta^{15}N$ values may be an exception). By contrast, at the PPNB site of Nevalı Çori in southeast Turkey, domestic pig and humans have similar $\delta^{15}N$ mean values (5.5 ± 1.9 and 6.1 ± 1.0 ‰, respectively) and ranges (3.9 to 8.2 ‰ and 4.4 to 8.8 ‰, respectively) implying similar diets, i.e. at Nevalı Çori, the pigs were likely fed on household waste and thus

possibly penned (Lösch et al. 2006). However, only four pig specimens were analysed at this site.

The wide ranges of $\delta^{13}C$ and $\delta^{15}N$ values of sheep and cattle from Çatalhöyük were attributed by Pearson et al. (2007, 2015) to the grazing of herds in different areas—in pastures with only C_3 species, as well as those with both C_3 and C_4 plants. Extra-local grazing of at least some cattle is paralleled at Çamlıbel Tarlası. By contrast, the sheep from Çamlıbel Tarlası have relatively homogeneous $\delta^{13}C$ and $\delta^{15}N$ values. The differences in sheep forage and by implication stock-keeping practices between Çatalhöyük and Çamlıbel Tarlası may reflect the distinctive nature of the two sites. The scale of Çatalhöyük, a large agglomerated village or proto-urban site spanning c. 130,000 m^2 (Hodder and Cessford 2004), likely necessitated extra-household herding strategies and grazing in various pastures potentially at some distance from the site (Pearson et al. 2015). In contrast, Çamlıbel Tarlası was a small-scale rural settlement covering an area of no more than 250 m^2—small herds of sheep were likely managed locally.

A trend of ^{15}N enrichment is evident in the sheep from later levels at Çatalhöyük. Budd et al. (2013) also noted an increase in $\delta^{13}C$ and $\delta^{15}N$ values of animal remains ($n = 9$) from Neolithic to Early Chalcolithic contexts at Aktopraklık, Northwest Anatolia. As both Pearson et al. (2015) and Budd et al. (2013) indicated, one possible explanation for ^{15}N enrichment is the grazing of animals on manured fields (e.g. Fraser et al. 2011; Bogaard et al. 2013b; Styring et al. 2014). Crop manuring has been demonstrated at early Neolithic sites in southeastern Europe from c. 5900 BC (Bogaard et al. 2013b). At Çamlıbel Tarlası, the average $\delta^{15}N$ value of all the domesticates is 6.7 ‰. Assuming a diet-herbivore offset of 4 ‰, the average $\delta^{15}N$ value of the domesticate forage at Çamlıbel Tarlası was 2.7 ‰; this relatively low forage $\delta^{15}N$ value suggests that these animals were not fed on manured crops/stubble (cf. Bogaard et al. 2013b). However, identifying manuring practices and/or animal penning from the stable isotope values of domesticates is non-trivial. In part, this is a consequence of the temporal and spatial variability in soil $\delta^{15}N$ values (e.g. Ambrose 1991). Also problematic is the inclusion of ^{15}N-depleted pulse crops in domesticate diet, which may mask the effects of consuming manured cereals or stubble. Moreover, ^{15}N enrichment of pulse crops is evident only with intensive and protracted manuring (Fraser et al. 2011; Bogaard et al. 2013b). Pulses including bitter vetch and lentil were identified at Çamlıbel Tarlası and may have comprised a significant part of human (see Pickard et al. 2016) and/or domesticate diet.

The comparative analysis of the domesticate stable isotope datasets presented above is offered cautiously because of (i) spatial and temporal variations in environmental $\delta^{13}C$ and $\delta^{15}N$ values (e.g. Schwarcz et al. 1999; van Klinken et al. 1994; van Klinken et al. 2000) and the broad geographical

range and chronological span of sites with stable isotope datasets in prehistoric Anatolia, (ii) the difficulty of distinguishing early domesticates from wild progenitors from morphological characteristics at Early Neolithic sites (see Zeder et al. (2006) for summary), (iii) the small datasets available from some sites and (iv) the complexities of identifying the consumption of pulses.

Conclusion

Carbon and nitrogen stable isotope analyses indicate that the domesticates from Çamlıbel Tarlası had diets based mainly on C_3 resources. Of all the domesticates at Çamlıbel Tarlası, cattle exhibit the widest range of $\delta^{13}C$ and $\delta^{15}N$ values. Moreover, cattle have statistically distinct isotope values from both the sheep/caprines, and the pigs recovered from the site. This indicates that the cattle had distinctive foraging behaviour not only from that of the pigs (which is perhaps not surprising) but also from that of the sheep. The $\delta^{13}C$ values of the cattle hint at the inclusion of C_4 plants in diet. However, no C_4 plants were identified in the plant macro assemblage recovered at the site and this suggests (if indeed C_4 plants were included in the diet of cattle) that they were grazing in non-local pastures. The inter-species variability in isotope values points to distinctive and potentially complex foraging and/or feeding behaviours at Late Chalcolithic Çamlıbel Tarlası.

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