

Reduced intensity of bone fat exploitation correlates with increased potential access to dairy fats in early Neolithic Europe.

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Keywords

Bone fats; bone fracture analysis; LBK; European Neolithic; subsistence stress; nutrition, bone marrow; bone grease; dairying.

Abstract

Important nutritional resources can be acquired by breaking bone shafts to access marrow, whereas heavy comminution and boiling of cancellous bone is required to extract bone grease. Since labour and fuel costs of these processes differ considerably, the relative intensities of these activities provide a possible proxy for nutritional stress or elevated fat requirements in the context of an overall subsistence strategy. We investigated faunal material from eleven early Neolithic sites in central Europe for bone fracture and fragmentation patterns to ascertain the intensity of bone marrow and grease exploitation. These data indicate that bone grease processing was practised rarely if at all during the early Neolithic, likely made unnecessary by ample access to crop carbohydrates. Bone marrow was exploited at all sites, but with varying intensity that exhibited a significant negative correlation with the proportion of milk-producing domestic ruminants. This observation is consistent with the hypothesis that fats obtained from dairy products reduced requirements for intensive marrow exploitation.

1 Introduction

The exploitation of the fat reserves within animal bones by early farmers in central Europe is poorly understood. Intensive utilisation is traditionally associated with hunter-gatherer societies in harsh environments (e.g. Binford 1978; Speth 1989; Leechman 1951), rather than farming societies living in relatively warm and wet temperate climates (Rück 2009). Nevertheless, bone fats could have been a crucial resource for early Neolithic farmers, especially at times of nutritional stress.

1.1 Sites studied

Eleven sites were studied, attributed to three early Neolithic linear pottery cultures. In Hungary, three Alföld (ALP; 5600-4700 calBC, Domboróczy 2009) and one Transdanubian (TLP; 5600/5500 – 5000/4900 calBC, Oross and Bánffy 2009) sites were analysed, in addition to seven sites from the central European Linearbandkeramik culture (LBK 5500-5000 calBC, Bickle and Whittle 2013). The TLP culture is closely associated with the wider LBK

phenomenon (Whittle et al. 2013: 49), but the ALP on the Great Hungarian Plain is often distinguished by its different settlement and material culture style, Neolithisation process and connections with the Vinča cultural complex to the south (Bánffy 2004; 2008; Oross and Bánffy 2009). Both Hungarian variations also followed earlier farming societies in their locales, unlike the LBK, which was the first farming society of central Europe (Bickle and Whittle 2013; Whittle et al. 2013; Raczky and Anders 2012: 273; Kalicz and Makkay 1977: 38-56; Whittle 2007).

The subsistence of these cultures was based largely on domesticated crops and animals, and supplemented with wild flora and fauna (*ibid.*; Glass 1991; Lüning 2000; Kreuz et al. 2005; Jacomet 2007; Kohler-Schneider and Caneppele 2008; Bogaard et al. 2011). Animal carcasses would have provided meat and fat, and domestic ruminants may have been partially managed for milk production (Bogucki 1984; 1988; Salque et al. 2012; Salque et al. 2013; Gillis et al. 2017). Fat reserves within animal bones were utilised, although the exploitation of this resource is poorly characterised in these cultures despite its potentially crucial contribution to diet (Marciniak 2005; 2011; Boulestin et al. 2009; Johnson et al. 2016; Johnson 2017).

1.2 Importance of fat

Fats are a particularly important dietary component. By weight they provide more than double the calories of carbohydrate and protein and can be a source of essential fatty acids and lipid-soluble vitamins such as A, D, E and K (Outram 2001; 2004; Mead et al. 1986; Erasmus 1986). In periods of nutritional stress, particularly when access to carbohydrates is limited, fat consumption can commute the adverse and potentially fatal effects of a protein-rich diet (Speth and Spielmann 1983: 13; Speth 1989; Outram 2004). However, great effort is typically required to extract all fats from a carcass, particularly those within bones. Bone fat resources increase in importance as nutritionally stressed animals utilise their subcutaneous fat reserves leaving only lean meat high in protein, while bone fat may remain (Cheatum 1949; Brooks 1977; Peterson et al. 1982; Davis et al. 1987; Outram 2004; Speth and Spielmann 1983: 12; Speth 1990). Intensive extraction of bone fats may therefore indicate that other dietary sources are not meeting requirements, and that the society may be experiencing subsistence stress (Outram 2004).

The most rudimentary form of bone fat processing is extracting marrow fat, where marrow-bearing bones are fractured using percussive force and the marrow extracted (Binford 1978). Marrow is used extensively by both hunter-gatherer and mixed farming societies (see for example Binford 1978, Abe 2005, Gifford-Gonzalez 1993; Speth 1989: 185; Lee 1979). Before or after marrow extraction, bones may also be boiled in stews to liquefy soluble nutrients and enrich the resultant broth (Binford 1978; Gifford-Gonzalez 1993; Richards 1951).

Epiphyses and other cancellous elements may be split in this case to increase the surface area and thus the rate of nutrient extraction (Church and Lyman 2003; Janzen *et al.* 2014), but also to 'pot-size' them for the vessels they are to be boiled in (Oliver 1993; Gifford-Gonzalez 1993). Bone grease processing, the most intensive form of bone fat extraction, involves heavy comminution and boiling of cancellous axial and articular bone, resulting in liquefied bone grease that floats to the surface and can be scooped off (Leechman 1951; Binford 1978; Outram 2002: 51; 2005: 33; Abe 2005: 116). Use of grease is particularly prevalent in ethnographic accounts of hunter-gatherers living in highly seasonal or harsh climates (e.g. Leechman 1951; Saint-Germain 1997; Binford 1978; Abe 2005; Speth 1990), and was practised in farming communities at times of subsistence stress (e.g. Outram 2003). Grease extraction requires a great deal of time, energy and fuel (Church and Lyman 2003, Janzen *et al.* 2014), whereas bone marrow extraction and bone-enriched stews require comparatively little effort. However, bone grease has several advantages over bone marrow and bone-fat enriched stews; particularly that grease is a more storable fat source (Leechman 1951) that is less likely to spoil as a result of rendering.

The demand for bone fat would potentially be reduced by access to cattle and caprine milk, an excellent alternative source of dietary fat. Cattle milk has a fat content of between 3.5% and 5.5%, goats approximately 3.5% and sheep approximately 5% (Ryan 2005; Outram and Mulville 2005). Whilst our data do not permit us to directly estimate the amount of milk exploitation at each site, we assume a monotonic relationship between the proportion of milk bearing animals and the amount of milk exploitation. Therefore, we hypothesise that the intensity of bone fat extraction, particularly marrow fat, would negatively correlate with the proportion of milk producing animals.

2 Methodology

2.1 Archaeological signatures of bone fat exploitation

The processes involved in bone marrow and grease exploitation have different archaeological signatures, which revolve around the identification of human-induced fracture and fragmentation of bones. Dynamic loading on the diaphysis of fresh (peri-mortem) long bones causes a helical fracture with a smooth fracture surface texture and acute or obtuse angles of that surface to the cortical surface, and may cause percussion marks or impact and rebound scars around the point of loading (Morlan 1984; Johnson 1985; Outram 1998; 2001; 2002; Blumenschine and Selvaggio 1988). These "fresh" fractures can be a signature of bone fat extraction. Over time bone loses moisture and has a greater tendency to fracture in straight lines or steps, following drying-induced micro-cracks along the bone's structure (Johnson 1985: 160). These "dry" fracture surfaces tend to be perpendicular to the cortical surface and

the texture of the fracture is more granular than fresh bone (Johnson 1985: 177; Outram 2001; 2002). All these features are often present in their full extent in mineralised bones that have lost their energy-absorbing and elastic capabilities through extensive moisture loss, protein degradation and altered microstructure (Johnson 1985: 178; Outram 2001: 403). Dry and mineralised breaks are more likely to be caused by deposition practices, taphonomic processes, and later context disturbance. These three bone fracture types – fresh, dry and mineralised – occur in a sequence, as bones fractured when fresh can also be later fractured when dry and/or mineralised, but not vice versa (Johnson *et al.* 2016).

Bone marrow processing can be inferred from high levels of fresh fracture on marrow-bearing bones – i.e. the humerus, femur, radius, tibia, mandible and metapodia (Outram 1998; 2002; 2004). Where exploitation of marrow is intensive, unbroken marrow-bearing bones are rare, diaphysis fragments are common, and high-yield marrow-bearing bones may be preferentially targeted (Outram 2004: 75). Some further minor fragmentation of articular ends may be associated with pot-sizing and boiling in stews (Gifford-Gonzalez 1993). In addition to freshly-fractured long bones, high levels of fragmentation of cancellous bone is the primary signature of intensive bone grease rendering. The greatest amount of bone, in terms of mass, should be found in the smallest size classes; fragmented cancellous bone should be common and whole grease-bearing bones and long bones with complete epiphyses should be rare (Outram 2001; 2005). On sites where bone grease processing was an established practice it is possible that archaeological features related to this activity will be discovered (for example Karr *et al.* 2015). If the assemblage fragmentation is indeed a result of human agency and not inadvertent modification such as bioturbation, trampling or compaction, it is likely that bones rarely targeted for marrow or grease, such as ribs, will be preserved in a less fragmented state. If non-deliberate taphonomic factors were the principal cause of fragmentation then such elements would be equally affected (see Outram 2001: 409).

2.2 Bone fat recording methodologies

The methodology employed to study the different types of bone fat processing involved characterising fracture types, fragmentation levels, and the type of bones fragmented. Observed fracture types (fresh, dry and/or mineralised) visible on marrow-bearing bone were recorded based on characteristics described above. Canid bones showed different carcass processing traditions from 'food' animals and were removed from the analysis in this paper. Where more than one fracture affected a single specimen, these fractures were listed in order of the first fracture that must have occurred based on moisture loss (Parmenter 2015), and then grouped by subsequent sequences of fracture (Johnson *et al.* 2016). These different fracture sequences, rather than the number of overall fractures, are presented using a fracture

history profile (Johnson *et al.* 2016). On sites with large amounts of subsequent taphonomic fracture, presenting fracture types as a proportion of the total number of fractures can underrepresent those fractures caused by marrow processing. By grouping specimens by the fracture sequence that affected the bone, the intensity of marrow processing is accurately presented, whilst still giving an indication of taphonomic fracture (*ibid.*; figure 3). Fragmentation was analysed by weighing all bones – both identifiable and indeterminate - and assigning them a specimen type, such as cancellous, diaphysis, rib, and a size class based on maximum dimensions (Outram 1999; Gron 2015). Mass (g) was used as a measure of fragmentation as a whole bone broken into many pieces still represents the same mass. Mass therefore shows the distribution of bone in all size classes, whereas small bone fragments are overrepresented by frequency. The analysis also involved a basic identification of the bone to species, element and zones represented (Dobney and Rielly 1988) where possible. Bones with evidence of tool use were removed from analysis. Extensive analysis of butchery, heat exposure, animal gnawing and taphonomic agents was also undertaken to ensure distinction of a human fragmentation signature from one caused by taphonomy.

2.3 Graphical and statistical methodology

We employed correspondence analysis to visualize differences in species abundance and fracture type frequencies between sites. To accommodate uncertainties in frequency estimates due to finite sample sizes, we generated 30,000 random deviates of the percentages in each class of the species and fracture profile, given the observed sample and a uniform prior, using the Dirichlet distribution, and added these deviates to the correspondence analyses (Gerbault *et al.* 2016: 35).

All statistical analyses, and generation of correspondence analysis plots, were performed using the statistical analysis scripting language R, version 3.3.1 (R Development Core Team, 2012). Correspondence analysis plots were generated using the “ca” library (Nenadic and Greenacre 2016), and the ‘rdirichlet’ function in “MCMCpack” (Martin *et al.* 2011).

2.4 Sites

Analysis of the eleven sites was undertaken as part of the larger NeoMilk research programme that is investigating the use of dairying in the Neolithic of Central Europe using multiple proxies (ERC Advanced Grant ERC324202; NeoMilk Website). Sites were selected for study to cover a wide geographic and temporal range, based on those targeted for lipid residue analysis, and those where the animal bone assemblage had a substantial sample size and exhibited good preservation (table 1; figure 1). Given these constraints, and the poor bone preservation that Loess soils typically allow (Bogucki 1984: 21; Bickle and Whittle 2013:13)

the choice of sites was limited. Those targeted were typically large-scale excavations of sites that commonly had a number of different occupation phases or feature types. A full discussion of the different archaeological components of each site can be found in Johnson (2017; see also Johnson *et al.* 2016) and the references in table 1. We tested our hypothesis that marrow exploitation negatively correlates with the proportion of dairy taxa using data aggregated at both the site level (n = 11) and the phase level (n = 30).

Table 1: List of sites analysed, grouped roughly chronologically and geographically. A brief description of the site, along with radiocarbon dates, settlement size, and excavation area, is given where available. ALP = Alföld Linear Pottery, TLP = Transdanubian Linear Pottery, LBK = Linearbandkeramik. Sampling strategies included a few contexts (3), 50% or more of the assemblage (2) and all zooarchaeological material from the relevant phases (1). All data can be found in tables 2 and 4.

	Site	References	Culture, phases, description, sample	
F U G	Füzesabony-Gubakút Heves County North Eastern Hungary	Domboróczki 2009	ALP phases I-V (5500-5200 calBC) Two sets of two house rows facing each other built on both banks of a stream 8-10ha settlement, 2.5ha excavation	2
P P D	Polgár-Piócás-dűlő Upper Tisza Region Hungary	Raczky and Anders 2009	ALP phase I (Szatmár II) Two houses, pits, postholes, wells and graves	1
P F H	Polgár-Ferenci-hát Upper Tisza Region Hungary	Raczky and Anders 2012	ALP phase I-IV Enclosed settlement with intensive activity, dispersed exterior settlement. Number of houses unknown. ~12ha settlement, ~4 ha excavated	1
A P C	Apc-Berekalja I Border of Heves/ Nógrád Counties Hungary	Domboróczki <i>et al.</i> unpub.	TLP 'Archaic' (oldest) LBK – Zeliezovce 20-30 houses in 10-15 settlement rows 20-30ha settlement, ~2ha excavation	1
T E S	Těšetice-Kyjovice Sutny Znojmo District Czech Republic	Mateiciucová 2008	LBK early – middle Settlement with houses in rows, 14 houses excavated	2
L D W	Ludwinowo 7 Kujawy-Pomerania District Poland	Pyzel 2012	LBK Kuyavian phase I-III Settlement with 13/14 houses in rows 9.5 ha settlement, 4.3 ha excavation	2
S T E	Stephansposching Deggendorf District Germany	Pechtl 2008	LBK Ältere – Jüngste Settlement with around 100 houses and enclosure ditch Complete excavation of 10ha settlement	1
D S T	Dillingen-Steinheim Wickenpoint Dillingen an der Donau District Germany	Pechtl pers. comm.	LBK Ältere – Mittlere Settlement with enclosure ditch	1
H E R	Herxheim Südliche Weinstraße District Germany	Boulestin <i>et al.</i> 2009; Haack 2016	LBK Ältere – Jüngste (5300-4950BC) Heavily eroded settlement within 5ha double ditch enclosure. Partial excavation.	2
B I S	Bischoffsheim Basse-Alsace France	Lefranc <i>et al.</i> 2004	Rubané Ancien – Récent Settlement with 41 houses 3 ha excavation	3
R O S	Rosheim Sainte-Odile Basse-Alsace France	Jeunesse and Lefranc 1999; Jeunesse 2011; Arbogast 2000	Rubané Récent – Final Settlement with two houses and enclosure ditch	1

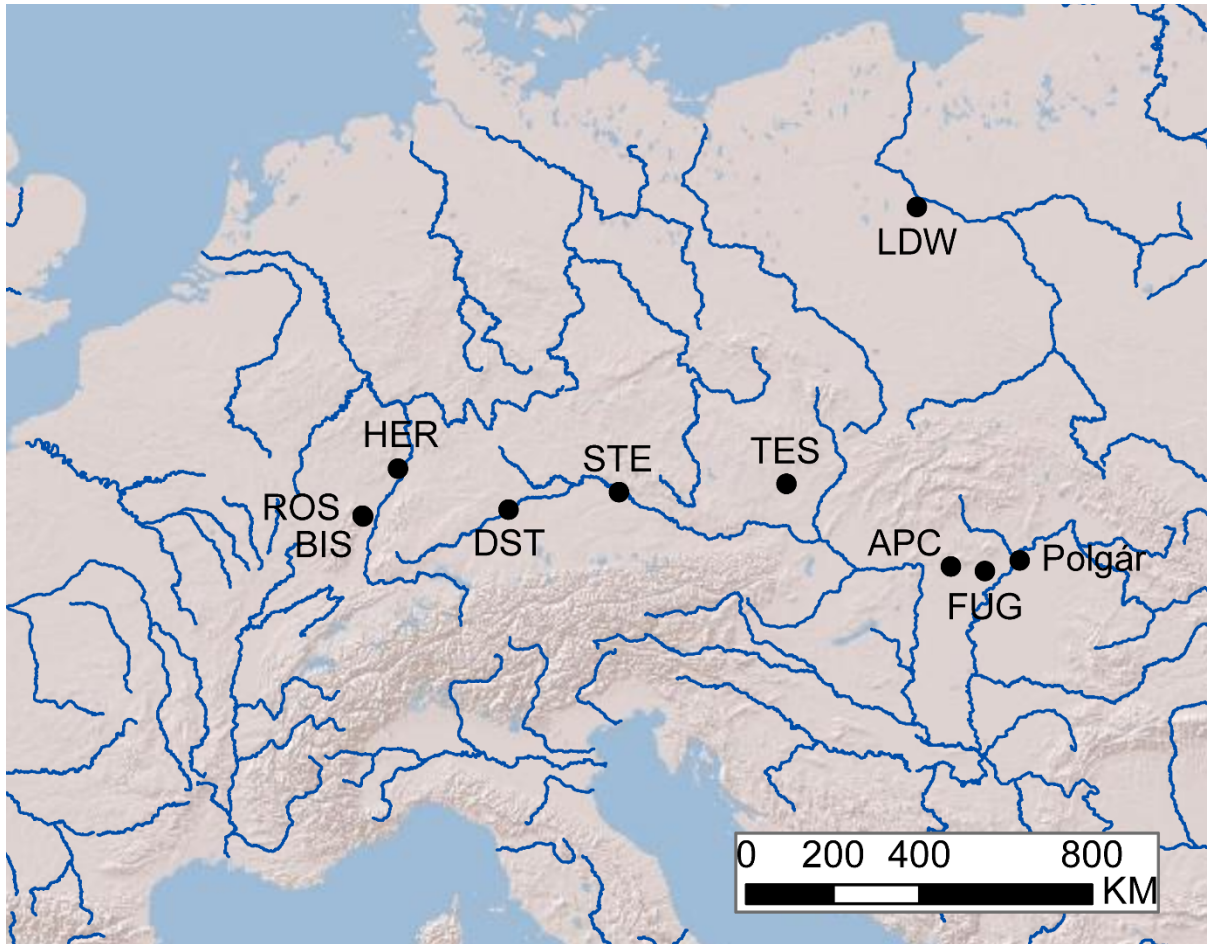


Figure 1: Map of all sites studied. Both Polgár sites (PPD, PFH) are represented by the Polgár place mark. Data supplied by Penny Bickle and Jessica Smyth. Map created using ArcGIS® software by Esri.

Table 2: Overall taxa abundance at each archaeological site by number of identifiable specimens (NISP), overall fracture sequences on fractured marrow-bearing bone, and number of high- and low-yield marrow-bearing bone first fractured when fresh. C= Cattle, P = Pig, SG = Sheep/Goat (caprine), and W=Wild, including aurochs, red deer, roe deer, wild boar, wild horse, small mammals and birds. F=Fresh, D=Dry, M=Mineralised and sequences thereof. N= total. Data pertains to figures 2, 3, 4, 5 and 6.

Site	Species					Fresh				Dry		Mineralised	N fractured bones	High yield		Low yield	
	C	P	SG	W	NISP	F	FD	FDM	FM	D	DM	M		F	N	F	N
FUG	273	65	259	131	728	329	27	0	3	1107	22	49	1537	41	165	17	158
PPD	251	70	112	147	580	290	22	0	2	214	0	23	551	66	104	28	84
PFH	177	68	169	40	454	133	12	0	3	245	1	51	445	42	99	21	74
APC	403	66	142	55	666	101	9	0	1	254	4	10	379	49	151	16	85
TES	243	124	184	61	612	465	38	0	6	417	6	23	955	87	131	39	85
LDW	645	51	75	79	850	667	130	1	23	911	18	77	1827	104	161	61	183
STE	189	64	35	63	351	322	12	0	3	132	3	13	485	79	89	41	60
DST	47	26	16	12	101	64	3	0	0	25	0	6	98	26	29	6	9
HER	375	357	229	152	1113	741	42	0	5	548	5	95	1436	155	254	54	117
BIS	74	80	43	28	225	262	29	0	2	85	2	10	390	58	68	28	48
ROS	156	233	136	49	574	422	221	1	4	354	11	22	1035	164	213	49	118

3 Results

Zooarchaeological analysis of the bone assemblages from the eleven sites indicated varying intensity of bone fat processing. Evidence for grease processing and marrow extraction will be discussed after first characterising the sites in terms of their species representation, which would have likely influenced dietary decisions. It should be noted that the picture represented by this data is an overall, broad-brush determination of each site. It is likely that annual fluctuations in the availability of certain animals, animal products and social requirements such as feasting would have caused variations in the way that animals were treated and consumed now largely invisible in the archaeological record.

3.1 *Species abundance*

At almost all sites cattle were the predominant domesticate in terms of the number of identifiable specimens (NISP), followed by pigs or caprines depending on region (figure 2 and 3; Johnson 2017). Caprines were relatively abundant at Hungarian ALP and TLP sites (FUG, PPD, PFH, APC), and Těšetice (TES), pigs were more common in Northern Alsace and Germany (HER, ROS, BIS), and cattle were particularly well represented at Ludwinowo 7 (LDW). Wild animals generally contributed around 10% to the overall NISP, with higher proportions at some ALP sites (FUG and PPD, but not PFH). These data demonstrate typical regional variation for the linear pottery cultures in these areas (Lüning 2000; Bickle and Whittle 2013). Domestic dog remains were present in small numbers at many sites, but were removed from the analysis as there was no evidence for dog bone processing. Correspondence analysis shows this regional grouping, and illustrates differences between most sites in terms of species representation (figure 3).

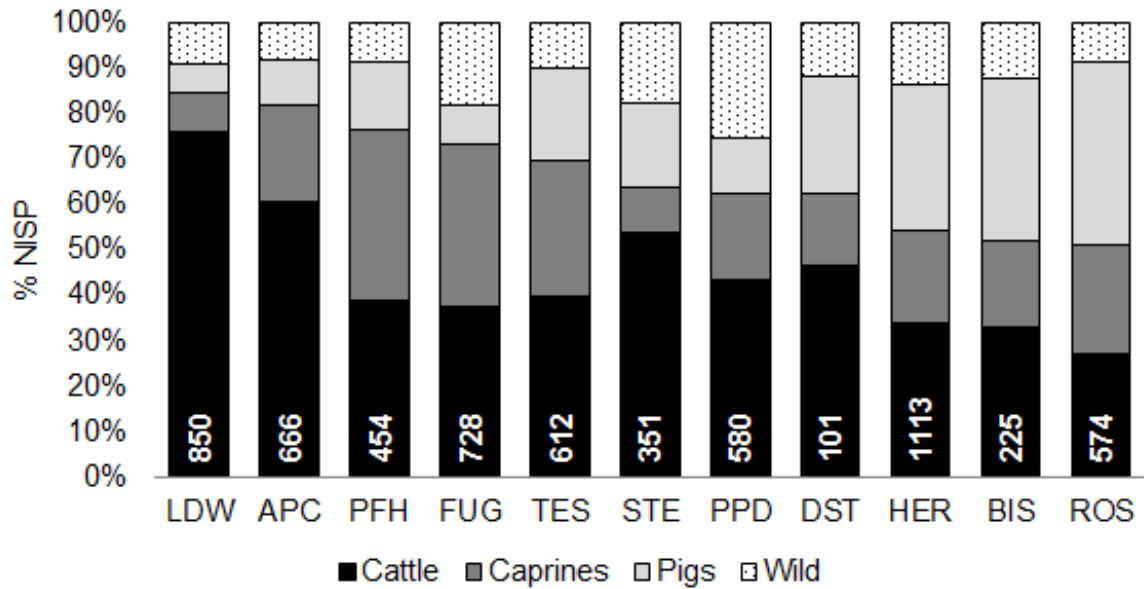


Figure 2: Species representation (% Number of Identifiable Specimens, NISP) from all sampled sites, arranged in order of the domestic ruminant proportion of the NISP, decreasing from left to right. N values are at the base of each bar. See table 1 for site codes and table 2 for data.

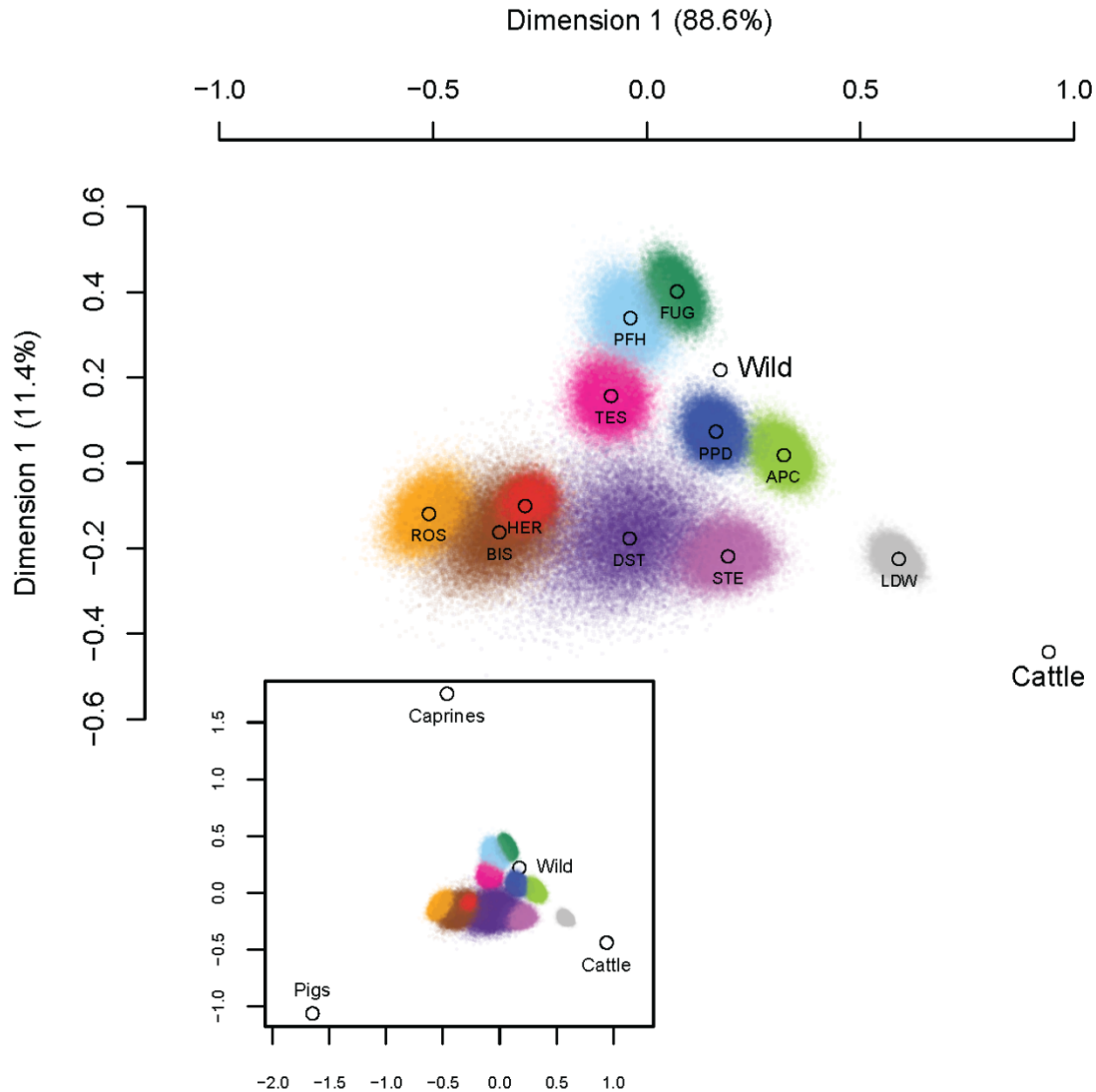


Figure 3: Correspondence analysis of species proportions and Dirichlet deviates of the population frequencies for each site, represented by a different colour. Note that the *Wild* class sits in the third dimension outside the 2D triangle. See table 1 for site codes and table 2 for data.

3.2 Bone grease exploitation

Bone grease does not appear to have been processed on an intensive scale at any site (Johnson 2017). Grease-rich epiphyses were often unfragmented, and overall assemblage fragmentation was low, with a mean of 6.5% of the assemblage mass in smaller size classes (<40mm) across the 11 sites. Taphonomic factors may have contributed to fragmentation as small rib and cranial fragments were common, unlikely to have been purposefully comminuted in carcass processing. However, possible small-scale bone grease extraction could be inferred from assemblages with relatively high levels of fresh fracture (figure 3) and assemblage fragmentation, particularly cancellous and diaphysis material in small size classes. Such sites include Stephansposching (total assemblage mass = 21884.6g, of which 10.4% comprised fragments <40mm in maximum dimensions) and Těšetice (total assemblage mass = 40928.9g, of which 11.7% comprised fragments <40mm). Small-scale, non-intensive bone grease extraction was also suggested from a single context at Herxheim (Johnson forthcoming; Boulestin *et al.* 2009). Cancellous fragmentation at these sites may better represent low-intensity pot-sizing and bone boiling in stews, supported by lipid residue analysis providing evidence for the cooking of animal products in early Neolithic pots (Salque *et al.* 2013). Systematic comminution of grease-rich bone as seen at sites like the Initial Middle Missouri site of Mitchell, South Dakota (Karr *et al.* 2010; 2015) was not identified.

It is likely that the early Neolithic diet and climate negated the need for intensive bone fat processing as a food resource. Domesticated plants and animals, supplemented by wild resources, could have supplied people with a food base sufficient in fats and carbohydrates to make relatively inefficient bone grease processing unnecessary. Intensive bone fat processing for nutritional needs is usually identified in particularly harsh climates (such as Binford 1978; Abe 2005), unlike the warm and wet climate of the LBK (Rück 2009). However, grease may still have been used on a small scale during subsistence stress, or alternatively to provide heat and light through burning, and for waterproofing (Binford 1978: 24). This possibly ad-hoc use of grease may be less archaeologically detectable than systematic processing for nutritional requirements.

3.3 Bone marrow exploitation

Bone marrow was a far more commonly exploited resource than grease, likely due to the lower labour costs involved in marrow acquisition. The proportion of bones that were fractured when fresh is a proxy for the intensity of marrow exploitation, as marrow spoils over time and would likely be undesirable from a dry-fractured bone (Johnson 1985: 187). Figure 4 shows the overall proportions of different fracture sequences on marrow-bearing bones from all analysed sites, with plain, blue-coloured series indicating the proportion of marrow-bearing

bone fragments fractured when fresh, suggestive of marrow processing. All sites had evidence of fresh fracture affecting marrow-bearing bones, and on all sites bones yielding high quantities of marrow had a significantly greater proportion of fresh fracture (871/1464) than low-yield marrow-bearing bones (360/1021, $X^2=140.36$, $df=1$, $p<0.001$, figure 5). This indicates that high-yield bones were preferentially targeted for marrow extraction and that fresh fracture was not an indiscriminate feature of taphonomy.

The intensity of marrow extraction varied between sites; at some sites levels of freshly fractured bone were relatively low (such as FUG and APC), compared to the greatest exploitation at Stephansposching, Dillingen-Steinheim Wickenpoint and Bischoffsheim. Some degree of regional grouping is indicated, with Hungarian ALP and TLP sites showing relatively low fresh fracture proportions (APC, PFH and FUG, but not PPD), whereas sites in Germany and Alsace (STE, DST, HER, ROS and BIS) show higher values. This can also be seen in the correspondence analysis plot of the number of bones first fractured when fresh, dry or mineralised (figure 6), yet these regional groupings are not as well-defined as they are in the species correspondence analysis plot (figure 3).

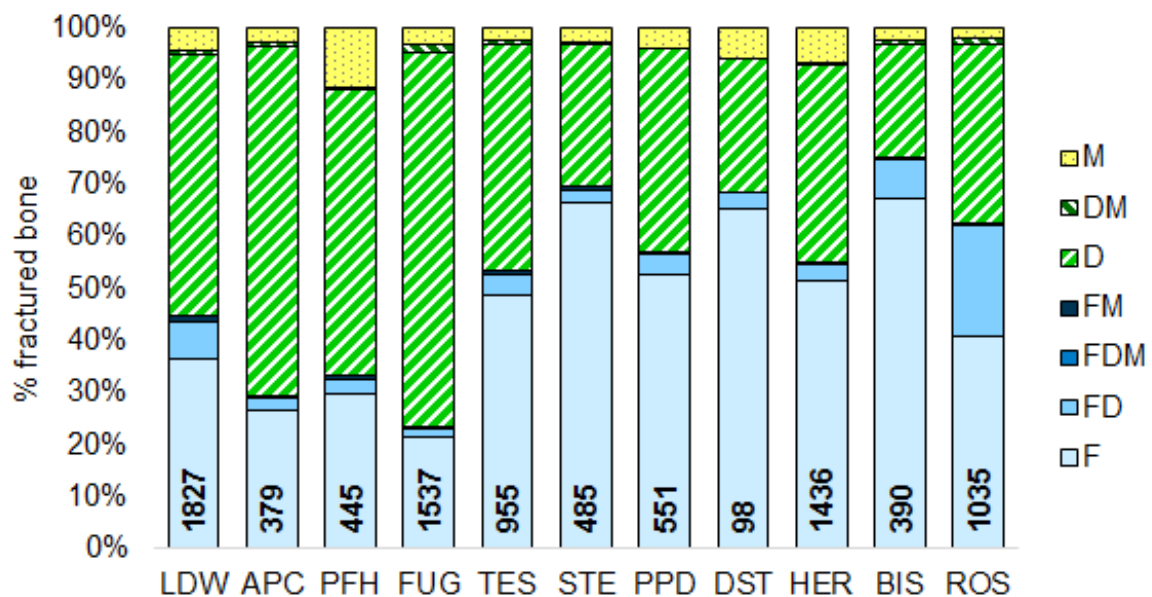


Figure 4: Fracture history profiles showing sequences of fracture freshness affecting all marrow-bearing bones from each site studied. F=Fresh, D=Dry, M=Mineralised and sequences thereof. N values are at the base of each bar. See table 1 for site codes and table 2 for data.

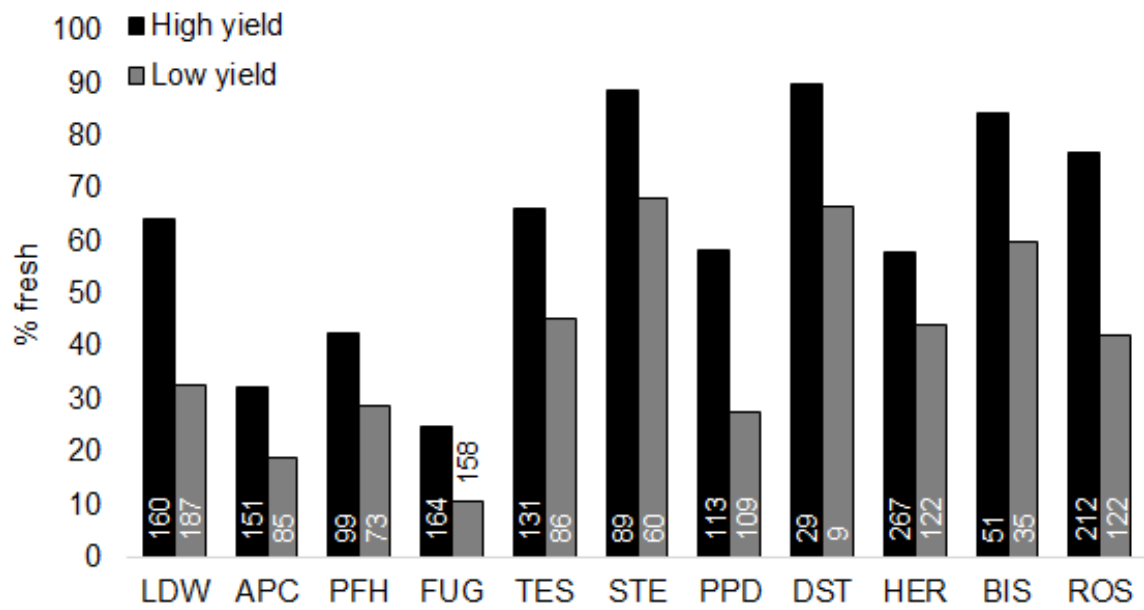


Figure 5: Proportion of fresh fracture on bones yielding high (humerus, femur, radius and tibia) and low quantities of marrow (metapodia and mandible). N values are at the base of each bar. See table 1 for site codes and table 2 for data.

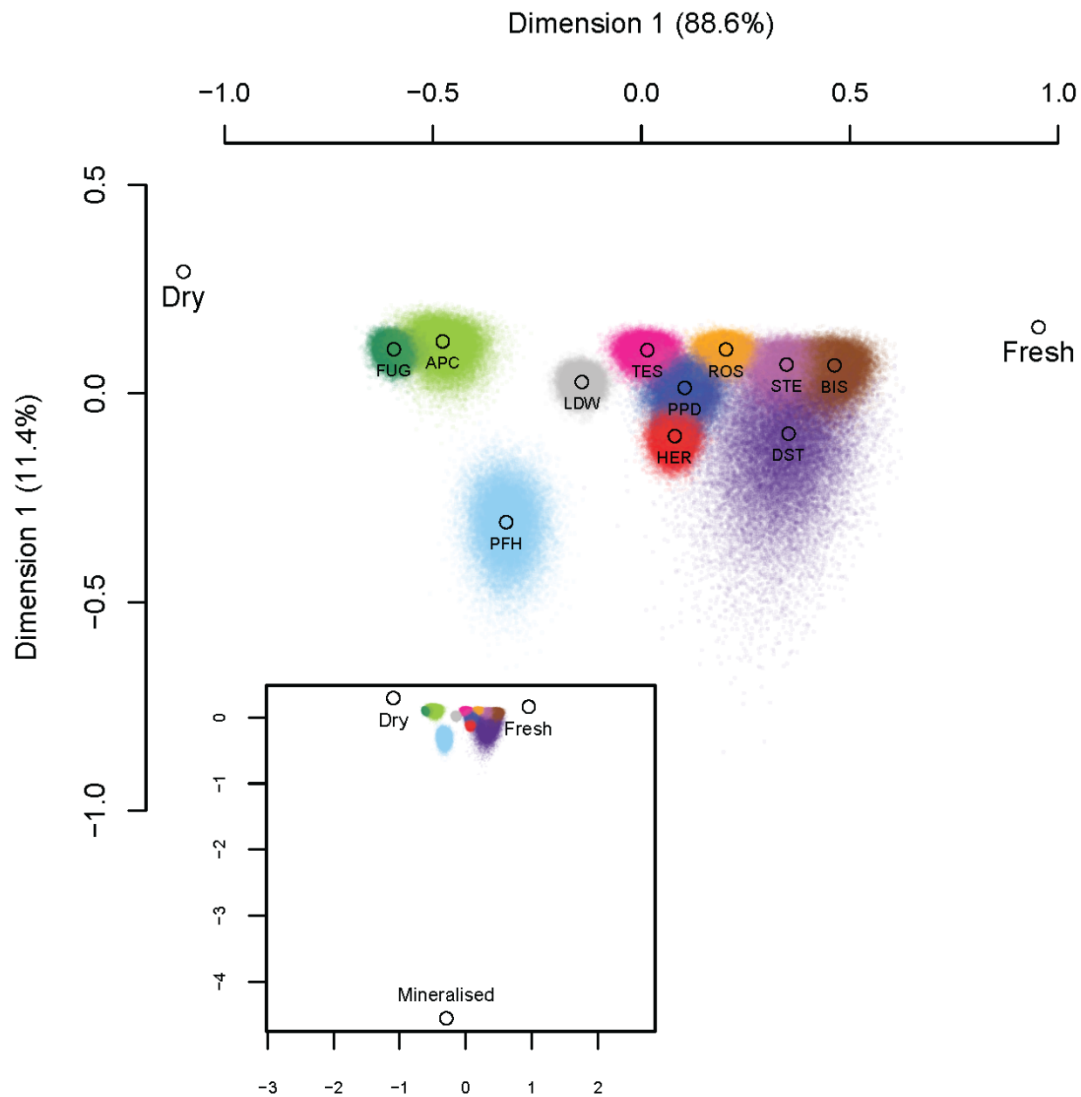


Figure 6: Correspondence analysis of first fracture type proportions and Dirichlet deviates of the population frequencies for each site, represented by a different colour. See table 1 for site codes and table 2 for data.

3.4 Fresh fracture by species

The overall proportion of fresh fractures between sites was not obviously related to any particular species. The proportions of fresh fracture on the bones of cattle, pigs, caprines and wild animals varied between sites, but on sites where marrow was being intensively exploited, *all* species tended to be fresh-fractured in higher proportions than at sites with low levels of overall fresh fracture. Figure 7 shows the proportion of bones attributed to cattle, caprines, pigs and wild taxa that were fractured when fresh alongside the proportion of all marrow-bearing bones fractured when fresh, including those partially identified to large/medium mammal but excluding domestic dogs. The figure shows that as overall fresh fracture proportion increases, the fraction of fresh fracture tends to increase for all species. Wild animals are often the species most exploited for marrow, yet numbers of wild marrow-bearing

bones are often low (table 3), and it is unlikely that their presence determines fracture freshness prevalence on sites.

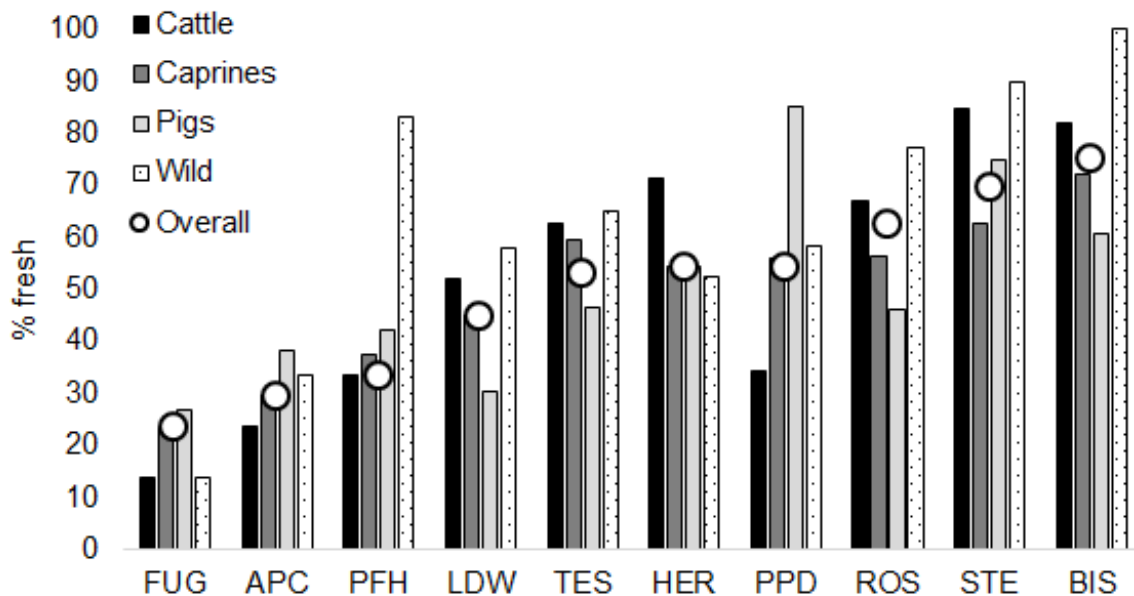


Figure 7: Proportion of fractured bones identified as cattle, caprines, pigs and wild taxa that were fractured when fresh (bars) and the proportion of all fractured marrow-bearing bones fractured when fresh (dots) for each site. Sites are arranged in order of the proportion of all fractured bones first fractured when fresh, increasing from left to right. N values are in table 3, below. DST was not included in this graph due to small sample sizes for species fracture.

Table 3: Total number of fractured marrow-bearing bones for cattle, caprines, pigs and wild animals, and total number of all fractured marrow-bearing bones, from all sites studied.

Site	Cattle	Caprines	Pigs	Wild	Overall
FUG	88	134	15	29	1537
APC	136	61	21	12	379
PFH	60	72	26	6	445
LDW	203	29	33	31	1827
TES	78	62	43	23	955
HER	112	81	94	44	1436
PPD	76	41	20	48	551
ROS	79	87	143	22	1035
DST	20	1	10	5	98
STE	78	16	12	20	485
BIS	39	25	33	5	390

3.5 Abundance of ruminants and marrow exploitation intensity

A priori we hypothesised that sites with less potential for dairy exploitation would show more extensive animal bone marrow extraction, as an alternative nutritional fat source. This relationship predicts a negative correlation between the proportion of cattle/caprine remains,

and the proportion of fresh bone fractures. Therefore, we compared two statistics from each of the 11 archaeological sites: caprine/cattle NISP divided by total NISP; and count of fresh fractures divided by count of all fractured bones (see table 2 and 4). Across the 11 sites there was a negative correlation (Pearson's $R = -0.647$). Statistical significance was evaluated using a permutation test. To ensure only the relationship between the two sets of proportions was fairly tested and all other structure in the data remained the same, both sets of proportions were randomly shuffled 1 million times among sites to build a null distribution of Pearson's R . Finally, since a negative correlation had been hypothesised, a one-tailed p -value of 0.0175 was calculated by counting the proportion of null R values that are smaller or equal to the observed R value. Thus, we can reject the null-hypothesis that the proportion of dairy animals does not predict the fresh fracture rate. Despite the large NISP and fracture sample sizes, the power of this statistical test is based entirely on differences between sites ($n = 11$), so the statistically significant negative correlation from such a small sample size is in itself noteworthy. We also performed the same permutation test after separating the site data into individual phases, giving a dataset of 30 phase groups across the eleven sites (table 4). This provides a more conservative test since the total NISP and fractured bones at each site is reduced by excluding those samples that cannot be securely attributed to any particular phase, and because the individual phases (in some cases a single context) become less representative of a particular human population's animal processing practices. As a consequence, the negative correlation is slightly weaker (Pearson's $R = -0.419$), although the increase in sample size from $n = 11$ to $n = 30$ allows us to reject the null with even greater confidence ($p = 0.0109$).

Table 4: Species and fracture sequence data split into the different archaeological phases, and in some cases comparable context groups (Herxheim), within sites. For an explanation of each site's phasing, please refer to references in table 1. Phasing data was not available for all sites; these sites were included as overall counts.

Site	Phase/ Context	Taxa				First Fracture		
		<i>Cattle</i>	<i>Pigs</i>	<i>Caprines</i>	<i>Wild</i>	<i>F</i>	<i>D</i>	<i>M</i>
LDW	Pyzel 1	3	0	1	2	6	2	0
LDW	Pyzel 2	49	3	2	4	63	97	10
LDW	Pyzel 3	123	3	36	28	195	217	9
LDW	Pyzel 4	7	0	2	1	13	5	1
LDW	Pyzel 5	174	2	3	16	141	175	33
LDW	Pyzel 6	77	35	12	3	98	167	10
APC	Archaic LBK	76	9	37	12	14	60	1
APC	Notenkopf	59	11	13	8	19	36	1
APC	Notenkopf / Zeliezovce	102	14	39	18	36	67	1
APC	Zeliezovce	74	14	16	8	22	39	4
PFH	Middle Neolithic (Szatmár II)	0	2	6	2	4	2	2

PFH	Middle Neolithic (LBK - ALP)	83	15	71	21	44	93	20
PFH	Middle Neolithic (Tiszadob group)	24	13	44	7	22	39	9
PFH	End of the Middle Neolithic	70	38	48	10	78	112	20
FUG	I	37	3	23	12	23	53	3
FUG	II-III	24	16	35	15	51	184	4
FUG	IV	164	39	178	69	261	764	21
FUG	V	37	6	18	27	13	92	21
TES	Site	243	124	184	61	503	423	23
STE	Site	189	64	35	63	337	135	13
PPD	Site	251	70	112	147	314	214	23
DST	Site	47	26	16	12	67	25	6
HER	Ältere	7	4	4	4	28	18	1
HER	Mittlere	7	6	15	12	26	69	6
HER	Jüngere	28	42	43	21	112	53	7
HER	Jüngste Settlement	55	68	37	41	251	174	17
HER	Jüngste Internal Ditch	214	143	86	46	230	147	53
HER	Jüngste External Ditch	50	78	43	25	113	82	18
BIS	Site	74	80	43	28	293	87	10
ROS	Site	156	233	136	49	648	365	22

4 Discussion

Our analyses indicate that the proportion of ruminants (cattle, sheep and goats) is negatively correlated with the intensity of marrow exploitation, supporting our hypothesis that in general, bone fat processing is associated with the capacity to produce milk across early farming sites in the European Neolithic.

Milk and milk products would have been a rich source of nutrients for early farming people, providing good quantities of proteins, fats, carbohydrates and micronutrients without the death of an animal (Walther *et al.* 2008: 393-394). Manufacture of cheese may have eased milk nutrient storage and transportation and reduced lactose content, particularly significant for human populations who may have not yet have evolved lactase persistence at appreciable frequencies (Burger *et al.* 2007; Itan *et al.* 2009; Gerbault *et al.* 2013; Salque *et al.* 2013). We argue that in general, a greater proportion of milk bearing animals provided a greater availability of milk fat, which reduced the demand on bone marrow nutrients. However, our analyses also show that this is not a simple predictive relationship ($R^2 = 0.42$), with more than half the variance explained by unknown factors. These may include 1) economic variation, for example a greater focus on pigs would provide more adipose fat, which may reduce the demand for milk fats; 2) environmental variation, influencing the seasonal supply of milk and

other food resources; 3) variation in the relationship between the proportion of milk bearing animals and the amount of milk actually exploited from them.

Of course, dietary decisions are not always made considering the optimum nutritional efficiency of the resource. Communal feasting may have affected the consumption of marrow. At Ludwinowo 7, for example, there is convincing evidence for a dairying economy in the presence of sieves (Salque *et al.* 2013; Bogucki 1984) and the highest proportion of ruminants (84.7%, n=850). Despite this, marrow exploitation was still evident, with 44.9% (n=1827) of marrow-bearing bones fractured when fresh, and some likely roasted before extraction as a part of communal feasting of cattle and pigs (Marciniak 2005; 2011). Fluctuations in the social calendar of the year may have affected the seasonal requirements for different food products, including bone fats.

Therefore, regardless of a site's ability to produce milk, it is unlikely that bone marrow, as a nutritious and relatively easy-to-access resource, would be completely abandoned, and was still exploited in line with the taste and cultural preferences of the settlement. However, long-term cultural evolutionary processes would favour traditions that make optimal dietary decisions more likely, and our results are consistent with such a process having operated in the LBK and associated cultures.

5 Conclusion

Firstly, we find that the intensity of bone fat processing on linear pottery culture sites was low. This was likely a consequence of new farming practices and a temperate climate, which negated the nutritional need for very intensive bone fat processing, particularly grease rendering. Secondly, we show a strong negative correlation ($R = -0.647$) between the amount of bone marrow processing and the proportion of dairy animals across the 11 sites studied. From this we infer that the exploitation of one fat type negated the requirement for the other fat type. Indeed, almost half the variation in bone fat processing can be explained by the proportion of milk bearing species present, or vice-versa. Ongoing research will monitor lipid residue and osteological herd structure analyses to further assess the importance of milk production in this relationship.

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