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Zooarchaeological evidence for livestock management in (earlier) Neolithic Europe: Outstanding questions and some limitations of current approaches

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A R T I C L E I N F O

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A B S T R A C T

With the increasingly routine recovery of faunal remains from archaeological excavations and zooarchaeological analysis of such assemblages by macroscopic and, more recently, biomolecular methods, we now have an unprecedented wealth of evidence for early European livestock management at local, regional and continental scales. We can identify broad geographical and temporal trends in the relative abundance, size and mortality patterns of different livestock species, and have more piecemeal evidence for their diet, mobility and seasonality of reproduction and for human exploitation of their secondary as well as primary products. Conversely, we have little if any direct zooarchaeological evidence for the scale of livestock management and this, coupled with disagreement regarding the intensity of secondary products usage, hinders consensus on the contribution of livestock to human subsistence in Neolithic Europe. It is proposed here that most domestic ruminants in Neolithic Europe were managed for non-specialised exploitation of a mixture of carcass and secondary products and, drawing on a range of indirect proxies, that livestock were mostly kept in small numbers. It follows that the direct dietary contribution of domestic animals to Neolithic human subsistence will normally have been subordinate to that of grain crops and secondary to their role in supporting cultivation and social dynamics. If these propositions are accepted, some recent attempts to interpret regional (and diachronic) variation in zooarchaeological evidence in terms of latitudinal contrasts in climate and vegetation may be ill-founded. In conclusion, it is argued that sound interpretation of the wealth of zooarchaeological data now available, as evidence for early European animal keeping, requires their integration with other lines of archaeological, bioarchaeological and palaeoecological investigation in the context of broader models of Neolithic subsistence, land use and political economy. The approach advocated, while illustrated with examples from Neolithic Europe, is of wider geographical relevance and, despite its critical tone, this assessment of the state of the field is essentially optimistic.

1. Introduction

To put in perspective what zooarchaeology today tells us of the early history of animal husbandry in Europe, it is instructive to consider how different such an assessment would have been just a few decades ago. In a seminal contribution to the prehistory of animal husbandry, Sherratt (1981) argued that the goals and scale of livestock management changed radically during the 4th and 3rd millennia BC in western Asia and Europe: domestic ruminants, previously reared for consumption of their carcasses, were now exploited also for their secondary products of milk, labour and wool; and these innovations in turn underpinned the colonisation of agriculturally marginal landscapes and the development of pastoralism, urban living and social hierarchy. His model of a 'secondary products revolution' was thus striking for the breadth of its vision of socioeconomic change, but also for the wide range of archaeological evidence to which it appealed, including iconography, ceramic repertoires, waterlogged wooden artefacts, buried land surfaces and settlement patterns. Sherratt also drew extensively on analogical reasoning, for example in discussing impediments to early dairying posed by lactose intolerance in adult humans and reluctance of primitive cows to 'let down' milk for consumers other than their calves. Equally striking, however, given his subject matter, was his sparse use of evidence from animal skeletal remains, that in turn reflected the then patchy availability of zooarchaeological information on kill-off patterns – restricted to a few examples scattered widely in time and space (e.g., Sherratt, 1981, 284-5) – and even on regional and diachronic trends in taxonomic composition.

Today, the macroscopic zooarchaeological record is immeasurably

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richer, enabling geographically large-scale, synthetic surveys of taxonomic composition (e.g., Conolly et al., 2012; Manning et al., 2013a) and kill-off patterns (Vigne and Helmer, 2007; Debono Spiteri et al., 2016; Gillis et al., 2017), while modifications of limb bone articulations, consistent with the use of cattle as draught animals, are reported increasingly widely in time and space (e.g., Armour-Chelu and Clutton-Brock, 1985; Helmer and Gourichon, 2008; Isaakidou, 2006). Biomolecular analyses of skeletal material are also making available ancient DNA (aDNA) evidence for the origins and subsequent development of livestock lineages (e.g., Larson et al., 2007; Scheu et al., 2015; Scheu, 2018) and stable isotope records of their diet (e.g., Balasse et al., 2012; Gron and Rowley-Conwy, 2017; Ivanova, 2020, 23 Fig. 1.3), mobility (e.g., Bogaard et al., 2016, 30–38; Vaiglova et al., 2018; Tornero et al., 2018) and seasonality of reproduction (Balasse et al., 2012, 2020; Gron et al., 2015; Tornero et al., 2020). At the same time, examination of lipid and protein residues from cooking pots is yielding evidence of human use of dairy as well as adipose fats (e.g., Salque et al., 2012; Debono Spiteri et al., 2016; Cubas et al., 2020), while studies of protein and aDNA in *human* skeletal material are shedding light on the consumption of dairy products (Charlton et al., 2019) and exploring the development of adult lactose tolerance in early farmers (Leonardi et al., 2012).

This explosion in the quantity, variety and resolution of relevant bioarchaeological evidence, which *inter alia* demonstrates that human use of secondary products is much older (e.g., Evershed et al., 2008; Vigne and Helmer, 2007; Halstead and Isaakidou, 2011) than Sherratt originally envisaged, has greatly enriched our understanding of the history of animal husbandry. The intention here is not to offer an alternative to Sherratt's model nor to focus particularly on the use of livestock secondary products, but rather to argue that the evidence now available for early animal husbandry in Europe – despite its remarkable wealth – has some significant limitations. For the sake of brevity, discussion focusses chronologically on the (especially earlier) Neolithic and thematically on very practical dimensions of the management of the four principal 'farmyard' animals: cattle, pigs, sheep and goats. The first section of this contribution highlights our currently variable success in answering four basic, *descriptive* questions about early animal husbandry in Europe: which species were kept? in what numbers? for what products or services? and how significant was their contribution to subsistence? The second section then considers the implications of areas of uncertainty for attempts to *interpret* spatial and temporal variation in husbandry practices.

2. Describing early animal husbandry in Europe: some basic questions and partial answers

2.1. Which species of livestock were kept?

The answer to this most basic question is now clear. To a perhaps surprising degree, domestic sheep, cattle and pigs at least seem to be fairly ubiquitous in Europe from the earlier Neolithic onwards, while goats too are a regular component of early livestock across Mediterranean Europe and, perhaps more patchily (e.g., Rowley-Conwy, 2013, 284), further north.

2.2. In what (relative and absolute) numbers were livestock kept?

Some fairly consistent regional trends are also emerging regarding the *relative* abundance of these four species. In the Mediterranean, assemblages dominated by sheep and, usually to a lesser extent, goats are common, especially in the earliest phases of the Neolithic, whereas a more balanced mix of caprines (again usually sheep more than goats), cattle and pigs is often encountered in later phases (e.g., Halstead and Isaakidou, 2013; Bonsall et al., 2013; Rowley-Conwy et al., 2013; Saña, 2013). Conversely, at Neolithic sites in temperate Europe, cattle and pigs are more abundant and the former often dominant (e.g., Manning et al., 2013b; Arbogast and Jeunesse, 2013; Rowley-Conwy, 2013). The exploitation of wild animals falls beyond the scope of this review, but through most of the Neolithic, in most parts of Europe, game is far less well represented in the faunal record than domesticates (e.g., Manning et al., 2013a, 1051 Fig. 2).

Of course, the reliability of these apparent regional contrasts is not beyond question. Many assemblages were recovered with methods that favour representation of large cattle bones at the expense of small caprine specimens. The apparently decreasing dominance of caprines in the later phases of the Mediterranean Neolithic might thus reflect, at least in part, declining interest of excavators in faunal evidence from contexts postdating the Neolithic transition (Payne, 1985, 223). Moreover, in the west Mediterranean, earlier Neolithic cave and rock-shelter sites often exhibit higher proportions of wild animals and, among domesticates, of caprines than contemporary open-air settlements (e.g., Vigne, 1998, 39–40; Rowley-Conwy et al., 2013, 165, 178; Saña, 2013, 206), while cave and rock-shelter sites in Greece of later Neolithic date (they are rare for the earlier Neolithic) tend to yield much higher proportions of caprines, and more balanced numbers of sheep and goats, than contemporary open-air settlements (Halstead, 1996, 31 Fig. 2). On a much smaller spatial scale, Marciniak (2006) attributes the spatially segregated deposition of cattle and sheep bones at Early Neolithic Bozejewice in Poland to consumption in collective and domestic commensal contexts, respectively. For practical reasons of carcass size, it is likely that cattle were widely favoured over smaller domesticates for collective consumption (e.g., Hachem, 2018; Legge, 2008) and, in regions where collective and domestic commensality tended to spatial segregation, this may have skewed the taxonomic composition of faunal assemblages. Moreover, the very few extensively excavated earlier Neolithic settlements have revealed some marked differences between constituent 'clans' or 'households' in the relative proportions of cattle, sheep and pigs and also of domestic and wild mammals (Bogaard et al., 2016; Hachem, 2018; Isaakidou et al., 2018). Given the large number of assemblages contributing taxonomic composition data, however, differences of recovery method, site function and intra-site contextual variation are less likely to have created the patterns outlined above than to be the source of some of the numerous exceptions to apparent trends.

Taxonomic composition has thus far been discussed in terms of *deadstock* (discarded dead animals), appropriate to analysis of the consumption of carcass products (below, 2.3), whereas proportions of *livestock* are relevant to analysis of secondary products usage or the relationship between domestic animals and different pasture types. Estimation of livestock proportions from deadstock data takes account of differences between species in lifespan (e.g., Payne, 1985; Albarella, 1999) and thus also birth-rates and so *tends* to raise the representation of cattle relative to sheep/goats and especially pigs. Conversion of deadstock to livestock proportions, however, would need to be undertaken assemblage by assemblage, would only be possible where mortality data of sufficient resolution were available, and might well run counter to allowances for variable bone survival and recovery.

Remaining with deadstock proportions, therefore, the wealth of evidence for the *relative* abundance of the four common domestic species is unfortunately not matched by direct evidence of *absolute* numbers of animals. Estimated 'minimum numbers of individuals' per site/phase sub-assemblage are almost invariably far too small, spread over the temporal span of the deposits in question, to be demographically credible – unsurprisingly, given the incomplete excavation of most sites, the coarse dating of their habitation phases, and the incomplete preservation and recovery of discarded faunal material. Indeed, even in the unusually propitious conditions of lake-side settlements in the Alpine Foreland (northern fringe of the Alps), where precise dating of short-lived habitation episodes is combined with good preservation of bone discarded *in situ*, comparison of quantities of recovered bone with estimated minimum numbers of animals represented suggests the loss of at least 90–98% of discarded material; losses are likely to be significantly higher in the dryland assemblages more typical of the faunal record for

Neolithic Europe (Bogaard et al., 2017, 123-4).

Nonetheless, the combination of exceptional chronological resolution and unusually good preservation in the Alpine Foreland has enabled calculation of the *absolute* density of bone accumulation per square metre in habitation phases of approximately 20 years duration (Schibler et al., 1997). On this basis, a striking increase has been inferred in the *scale* of discard of domestic deadstock (especially cattle) between the late 5th and mid-3rd millennia BCE (Schibler and Jacomet, 1999; Bogaard et al., 2017, 126). Although this trajectory could in principle be an artefact of diachronic change in the proportion and types of bone discarded off-site, it is consistent with other lines of bioarchaeological evidence. Bones of wild mammals and birds indicate replacement over time of woodland species by those typical of open country, while weeds in grain stores suggest that cultivated plots were initially limited to small clearings, but from the late fourth millennium BCE were larger in scale and used alternately for crops and pasture (Schibler and Jacomet, 1999).

The Alpine Foreland is of course not only exceptionally rich in bioarchaeological evidence, but may also be atypical of early European farming, thanks to the considerable constraints on both crop and livestock husbandry posed by its terrain and climate. Elsewhere in Europe, we are usually limited to relative evaluations of the overall scale of animal husbandry, based on the estimated carrying capacity of the local landscape and/or some proxy measure of anthropogenic impact thereon. For example, the present author has argued (Halstead, 1981) that the heavy dominance of sheep in earlier Neolithic Greece, in a more or less well wooded landscape better suited to cattle, pigs and goats, implies the maintenance of livestock mainly on small areas of cleared land (i.e. fallow/stubble garden plots) and thus in modest numbers. From the later Neolithic, more balanced representation of sheep, cattle and pigs (in fertile lowlands) or sheep and goats (in agriculturally more marginal areas) might then reflect greater use of the wider, uncultivated landscape for livestock maintained in larger numbers. Support for this model was claimed (Halstead, 1994, 202) in the failure of available palynological data to register earlier Neolithic human impact on *regional* vegetation (Bottema, 1982; Willis and Bennett, 1994), whereas greater anthropogenic impact in the later Neolithic might be reflected in the widespread expansion of arboreal species (hornbeams) that flourish (*inter alia*) under pressure from browsing and cutting and in geoarchaeological indications of increased alluvial deposition (van Andel et al., 1990). Moreover, despite the co-existence of domestic cattle and pigs with wild aurochs and boar through the Neolithic and Bronze Age in Greece, the domestic forms decreased in size over time (von den Driesch, 1987), implying that they rarely interbred with their wild relatives and so were kept in small enough numbers to enable close control (Halstead, 1996, 31). This argument for small-scale stock-rearing in the (especially earlier) Neolithic of Greece was based on evidence of a circumstantial nature, open to alternative interpretations, but is now supported by more direct proxy evidence from stable-isotope analysis of domestic faunal material, consistent with limited mobility (Whelton et al., 2018a; Vaiglova et al., 2018, 2020) and a more or less close dietary association of livestock with cultivated land subject to intensive crop husbandry (Halstead and Isaakidou, 2020; Isaakidou et al., 2022; Vaiglova et al., 2021).

Broadly similar arguments can be advanced elsewhere in Europe. For example, even in temperate regions, where cattle and to a lesser extent pigs make up a larger proportion of early farming faunal assemblages than further south, aDNA (Scheu et al., 2015; Scheu, 2018; Larson et al., 2007) and biometric (Rowley-Conwy et al., 2012) data indicate a level of isolation from wild aurochs and boar, respectively, that implies close herding of the domesticates. Likewise, stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of faunal remains suggests that early Neolithic domestic animals across Europe were often closely associated with the cultivated landscape (e.g., Gron and Rowley-Conwy, 2017; Ivanova, 2020, 22–24), on which grain crops were widely grown under conditions of intensive, and thus probably small-scale, husbandry (e.g., Bogaard et al., 2013). Thus, while direct evidence of the scale of Neolithic stock keeping is usually entirely absent, modelling of this variable based on more indirect proxies suggests that livestock were initially raised on a very modest scale across much of Europe.

2.3. For what products or services were livestock kept?

The faunal record for the Neolithic of Europe is dominated by commingled assemblages of fragmented bones from mixed body parts and species, consistent with the overwhelming majority of domestic animals ultimately being exploited for their carcass products. Butchery marks and fragmentation patterns, when reported, suggest that these products routinely included meat, marrow and hides (e.g., Becker, 1981, 26–31; Isaakidou, 2007; Isaakidou et al., 2018; Marciniak, 2006; Iborra Eres and Martínez Valle, 2009).

The extent to which the domestic ruminants were also exploited *during life for their secondary products* is more subject to debate. Sherratt cited a range of artistic, artefactual and geoarchaeological evidence for the use of cattle to draw ards and carts from the 4th or 3rd millennium BCE onwards, but osteological evidence (degeneration and remodelling of joints) consistent with earlier draught use of cattle has since been reported from the 6th millennium BCE onwards in southern and central Europe (Balasescu et al., 2006; Isaakidou, 2006; Gaastra et al., 2018; Helmer et al., 2018; Höltkemeier, 2018). This evidence could in principle be due to old age, excessive weight or genetic factors, but its apparent concentration in the hip and foot joints and in cattle rather than other domesticates favours attribution to 'traction stress' (Isaakidou, 2006). Sherratt's conviction (previously shared by the present author – e.g., Halstead, 1981), that earlier Neolithic farmers cultivated with hand-tools, rested in part on the assumption that knowledge of how to construct a yoke and ard was the key to adoption of tillage with draught animals (Sherratt, 2006). Interviews with small-scale farmers in the pre-mechanised Mediterranean, however, highlight their reluctance to cultivate grain crops by hand if draught animals could be borrowed or hired from a neighbour and identify the cost of rearing and maintaining such animals, rather than knowhow, as the key constraint on their ownership (Halstead, 2014a). At Neolithic Knossos, at least, these costs were apparently minimised by using cows, also capable of bearing calves, rather than castrated male oxen, for draught (Isaakidou, 2006). While the osteological evidence for draught use of cattle in Neolithic Europe is geographically and chronologically patchy and open to alternative interpretations, it would be surprising if the ubiquitous domestic cattle were not used for this arduous task.

Isotopic analyses of lipid residues preserved in Neolithic ceramic vessels have revealed that milk was consumed widely across Europe by early farmers, but there is local and regional variation in the proportions of analyses attributed to milk, ruminant adipose and non-ruminant adipose fats (e.g., Salque et al., 2012; Roffet-Salque et al., 2018, 133, Fig. 7.1; Ivanova, 2020, 27 Fig. 1.4). For example, milk residues are much more common in the earlier Neolithic of the west Mediterranean than of the east Mediterranean and Greece (Debono Spiteri et al., 2016, 3 Fig. 2), but the former sample is dominated by caves and rock-shelters and the latter by open-air settlements so this apparent contrast may be an artefact of differences in site function (Ethier et al., 2017). Milk residues are also more frequent on earlier Neolithic open-air settlements in the north Balkans than in similar sites in the neighbouring southern Balkans and Greece, a contrast that has been attributed to greater reliance on dairying in response to a scarcity of pigs and hence pig fat (Ethier et al., 2017), although it might conversely be argued that analyses have underestimated the frequency of milk residues further south thanks to the confounding effect of more abundant pig fat (Whelton et al., 2018b, 133). A more fundamental obstacle to tracking the importance of milk consumption using lipid residue frequencies is that such residues are only likely to be detected if the sampled vessels were used to *heat* milk. Alternatively, however, milk can be consumed fresh or, posing less problems for the lactose intolerant (e.g., Burger and Thomas, 2011; see also Leonardi et al., 2012), converted to other forms (e.g., soft cheeses, butter) using organic containers (cf. McCormick, 1992, 206) such as those often imitated by early ceramic vessels. As a further complication, while milk produced only seasonally or in large quantities is often heated for conversion to storable cheese, that produced year-round (e.g., as argued for Early Neolithic southern Scandinavia – Gron et al., 2015) or in small quantities that do not warrant labour-intensive processing may be consumed rapidly (e.g., fresh or in fermented form or as soft cheese – all with a short shelf-life) without prior heating (e.g., Zygouris, 1914, 52; McGee, 2004, 55–60; author's unpublished field notes from Greece and Spain). The frequencies of milk residues relative to those of adipose fats will likewise depend on the extent to which animal carcasses were routinely cooked in ceramic vessels of typically small capacity rather than in larger pits or ovens or on open fires. Moreover, the frequencies of all types of lipid residue will be influenced by variation in the use-life of ceramics and this in turn depends on the properties of their fabrics which differ between both vessel types and regions. Lastly, Neolithic ceramics exhibit considerable local and regional variability and evidently – together with the foods and beverages prepared and consumed in them – played an important role in forging social relationships and identities. It is inherently unlikely, therefore, that the relative frequencies of milk and adipose fats in sampled ceramics provide a reliable guide to regional variation in the dietary importance of different categories of animal fats.

An alternative approach to assessing the relative importance of meat and dairy production explores mortality patterns in domestic ruminants: in herds reared for meat, most males should be slaughtered during the juvenile-subadult period of rapid growth, to achieve favourable returns (in carcass weights) on costs (in forage, human labour, perhaps housing); in dairy herds, most male offspring should be killed in infancy, to maximise the availability of milk for human consumption; and, in both cases, most females should be kept alive into adulthood as breeding stock and sources of milk for their offspring or the herder, respectively (Payne, 1973; Legge, 1981). These idealised models are subject to disagreements, however, regarding both their formulation and the analysis and interpretation of ancient mortality data. As regards their formulation, some analysts insist that primitive breeds of domestic cattle do not let down milk in the absence of the calf, so that early dairying should be characterised by slaughter of male calves at the end rather than near the beginning of the mother's lactation (e.g., McCormick, 1992; Balasse and Tresset, 2002; Balasse, 2003), but others argue that the choice between early- and post-lactation slaughter instead reflects the relative importance to the herder of milk production versus calf rearing (Legge, 1981; Halstead and Isaakidou, 2017). A contentious point of analytical detail is the suggestion that numbers of recorded mandibles attributed to very young deaths should be 'corrected' upwards by a factor that takes account of the very short duration of the youngest age classes (Vigne and Helmer, 2007). This manipulation of the raw data has been criticised as statistically invalid (Brochier, 2013), however, and the resulting patterns are misleadingly interpreted by comparison with modern mortality models that have not been similarly corrected. Both the post-lactation slaughter hypothesis and enhancement of the number of very young deaths have the effect of increasing the frequency of mortality profiles attributed to milk rather than meat production. In either case, however, the slaughter patterns for most domestic ruminants in much of Neolithic Europe approximate to the 'meat' model, being dominated by juveniles/subadults (e.g., Debono Spiteri et al., 2016; Gillis et al., 2017) rather than infants (characteristic of specialised dairying) or adults (as would be expected if the small and fragile infant components of dairy assemblages had been overlooked during excavation or destroyed by scavengers prior to burial – e.g., Munson and Garniewicz, 2003). Nonetheless, an emphasis on dairying is apparent in some early assemblages in the northwest Mediterranean (Rowley-Conwy et al., 2013), at some slightly later sites in the Alpine Foreland (Legge, 1981; Halstead, 1989) and perhaps (inferred more indirectly from slaughter of young adult females in ceremonial consumption contexts) in southern England (Legge, 2008; Rowley-Conwy and Legge, 2015). A broader issue is that ancient mortality profiles are interpreted by comparison with idealised models representing optimisation for alternative production goals (Payne, 1973; Halstead, 1998). Accordingly, mortality profiles approximating to either model neither demonstrate nor preclude the production of milk or meat (consumption of which may be confirmed by lipid residues in ceramics, butchery marks on bones, etc.), but rather indicate whether culling decisions were conducive to maximising output of one or the other commodity. Assessment of the scale of milk production requires both lines of evidence, together with some idea of relevant livestock numbers. The latter task has hitherto been complicated by the difficulty of determining biochemically which ruminant species were milked (Craig, 2002; Craig et al., 2005) and by the dangers of inferring this from a correlation between milk residues in ceramics and the taxonomic composition of faunal assemblages (Halstead, 2014b, 421). Recent analysis of proteins on ceramics, however, has perhaps unsurprisingly identified milk traces of sheep, goats and cattle at 6th millennium BCE Çatal Höyük in central Anatolia (Hendy et al., 2018).

Wool, the third of Sherratt's secondary products, probably was indeed a relatively late focus of European and Near Eastern stock husbandry because Neolithic sheep are thought to have had a hairy coat, but one further, important output from *live*stock is manure. Earlier Neolithic cereal crops from several sites across Europe, from Crete in the southeast to southern Scandinavia and Britain in the northwest, exhibit raised δ^{15}N values suggestive of fairly heavy manuring, whether applied directly by grazing/penned livestock or by the spreading of dung accumulated in byres (e.g., Bogaard et al., 2013; Gron et al., 2017; Jones and Bogaard, 2017; Halstead and Isaakidou, 2020).

While available evidence is again geographically patchy and draws heavily on indirect proxies, early European domestic animals evidently provided a range of secondary (labour, milk, also manure) and carcass (meat, fat, hides) services and products. To some extent, the different domesticates provided complementary resources (notably labour from cattle; milk from ruminants; adipose fat also from pigs; meat for collective consumption perhaps especially from cattle), but culling decisions generally favoured mixed rather than specialised exploitation of each species (e.g., Halstead and Isaakidou, 2013, 131–133; Bogaard et al., 2016, 18–21).

2.4. *The contribution of domestic stock to subsistence*

Zooarchaeological and archaeobotanical evidence alike shed no direct light on the relative contributions of animal and plant foods to human diet. Stable isotope analysis of human skeletal remains is also less conclusive in this respect than once hoped (e.g., Styring et al., 2015), not least because consumption of both animal protein (meat or milk) and manured cereal crops may raise δ^{15}N values (Bogaard et al., 2007). Given the probable dietary importance of plant foods to Late Palaeolithic and Mesolithic foragers in at least southern Europe (Kuhn and Stiner, 2001; cf. Lee, 1968), one might expect the apparently much denser populations (e.g., Shennan, 2009) of early farmers in our continent to have been sustained primarily by (cultivated) plants. Certainly, attempts to model the scale and productivity of early cereal-pulse cultivation suggest that even the relatively nucleated early farming communities of Greece (Isaakidou, 2008, 103 table 6.2) and central Europe (Bogaard et al., 2016, 43–45) could have been sustained by crops grown intensively within just a few minutes' walk of the settlement. Conversely, livestock under most circumstances are an order of magnitude less efficient than grain crops in converting solar energy to human food. An animal-dominated diet would be least implausible if herds were intensively exploited for dairy rather than carcass products (yielding far more energy and protein per head of livestock and unit of pasture – Legge, 1981, 89 table 15) or were kept in very large numbers relative to human population (in turn requiring extensive pasture and potentially exceeding available labour for herding – Halstead, 1996, 24). As noted above, however, mortality data for Neolithic domesticates mostly approximate to a 'meat' or mixed strategy (i.e. with modest potential for dairy production), while available proxy data for the scale of Neolithic animal husbandry suggest livestock numbers were often modest. Moreover, the relatively few dairy-focussed faunal assemblages may be concentrated in contexts of relatively small livestock numbers and restricted areas of pasture (e.g., Legge, 1981, 89).

Across most of Neolithic Europe, therefore, the *direct* contribution of domestic animals to early farmers' subsistence was arguably very much secondary to that of staple crops, although dairy and carcass products doubtless enhanced the nutritional quality and aesthetic appeal of a grain-based diet. Probably more important were their *indirect* contributions to human subsistence and society. First, as sources of manure, probably of bovine draught power and perhaps also of ovine control of excessive cereal growth on heavily manured plots (Halstead, 2006), livestock greatly facilitated the cultivation of staple crops. Secondly, occasional finds of cereal grain in Neolithic animal dung (e.g., Robinson and Rasmussen, 1989; more tentatively, Valamoti and Charles, 2005) suggest the use of livestock for 'indirect storage' of surplus grain (cf. Flannery, 1969, 87), which may have been crucial to survival in bad years by encouraging the production of 'normal surplus' in good years (Halstead, 1990, 152). Thirdly, the sharing beyond the 'household' of carcasses of domestic animals, and especially so cattle, arguably played a central role in commensal negotiation and reaffirmation of relations of solidarity that were critical to social reproduction and to mutual support in times of need (e.g., Halstead, 2004).

2.5. Summary: partial answers to these basic questions

Direct (zoo)archaeological evidence is reassuringly abundant and probably robust for the relative frequency of the commonest domestic animal species and likewise for the exploitation of their carcass products. Evidence for the extent of use of secondary products is sparse and somewhat ambiguous in the case of traction and indirect and subject to dispute in the case of dairy products, but non-specialised management for a mixture of products was probably the norm. Direct zooarchaeological evidence is particularly sparse for the absolute scale of stock-keeping, although there are quite widespread indirect indications that livestock numbers were modest and perhaps especially so in the earlier Neolithic. These uncertainties regarding husbandry priorities and the scale of animal husbandry, and the resulting difficulty of assessing the contribution to subsistence of stock rearing relative to crops, in turn pose problems in interpreting geographical and chronological variation in zooarchaeological data.

3. Interpreting geographical and chronological variation in early animal husbandry in Europe

Spatial and temporal trends in the taxonomic composition of European Neolithic faunal assemblages have invited interpretation in both environmental and cultural terms. For example, observing a positive relationship between annual precipitation and the proportion of cattle among domesticates in southwest Asia and southeast Europe, Conolly and co-authors concluded that 'the growth of Neolithic communities in more temperate environments provided opportunities for the expansion of cattle use, which are less drought-tolerant than ovicaprines' (Conolly et al., 2012, 1008). Manning et al. (2013a) extended this approach to Europe as a whole, concluding that increased proportions of cattle and pigs at the expense of sheep and goats in the Early Neolithic of central and northwest Europe, relative to that of the Mediterranean area, could again be accounted for, to a significant degree, by a suite of environmental variables (including higher annual precipitation, lower mean temperature, etc.). Focussing more narrowly on the Balkans and central Europe, however, and thus encompassing a narrower range of ecological variation, the same team of researchers (Manning et al., 2013b) found that environmental variables accounted for very little of the observed patterning in faunal taxonomic composition. Instead, they suggested that the contrast between caprine-rich sites in the Aegean and Adriatic regions and cattle-rich sites in the Balkan interior might be attributed to their origins in the spread of farming by maritime and continental routes, respectively, while increasing proportions of cattle during the Early Neolithic of central Europe might reflect changes in the role of cattle as a means of wealth accumulation (Manning et al., 2013b, 250).

Such comparative spatial analysis of faunal data and environmental variables is a potentially fruitful heuristic basis for identifying both the ecological constraints on animal keeping and, by default (as in the last example), the complementary influence of cultural imperatives. The relevance of many environmental variables depends, however, on answers to some of the questions reviewed in the previous section. For example, while the frequency of cattle on Early Neolithic sites in Europe increases from south to north, and thus in parallel with increasing precipitation, this is unlikely to be because this species is 'less drought-tolerant than ovicaprines' (*pace* Conolly et al., 2012), given that African pastoralists widely run large herds of milked cattle in landscapes more arid than any part of Europe. Water requirements are much higher in lactating than dry cattle, but there is only patchy evidence for intensive dairying of Neolithic European cows. Moreover, depending on the balance between fresh and dry forage, water requirements may substantially have been met from ingested plants. Precipitation of course also affects the availability of forage, both quantitatively and qualitatively, but, among recent mixed farmers in the Mediterranean, forage, water and shelter were not usually limiting factors on the maintenance of domestic animals in *small* numbers (perhaps the norm in the earlier Neolithic), while labour for herding a few animals close to home was often provided by household members too young or too old for more demanding tasks (e.g., Halstead, 2014a, 104, 292). Anyway, stable isotope (particularly δ^{15}N) values of domestic animal bones suggest that Neolithic livestock was widely maintained primarily on the cleared, agricultural landscape, such that the availability of forage will have been shaped more by crop husbandry practices than by regional variation in 'natural' pasture. Finally, if domestic animals were reared overwhelmingly for their carcasses, such that the four species were largely interchangeable, their relative proportions might have been substantially shaped by ecological constraints on their feeding and watering. Conversely, if these species played different practical or symbolic roles in early farming subsistence (most obviously in the yoking of cattle for traction or their consumption in collective feasting), their relative frequencies may have been shaped as much by the demand for their distinctive services or products as by their ease of rearing – and, again, especially so if total livestock numbers were small so that a few additional individuals of one species might significantly influence their proportional representation. Moreover, in regions both south (e.g., Cantuel et al., 2008, 285-6 Fig. 2a–c; Saña et al., 2020, 168) and north (e.g., Arbogast and Jeunesse, 2013, 277 Fig. 14.4; Bogaard et al., 2017, 126 Fig. 9.3) of the Alps, the relative proportions of the common species exhibit some marked changes through the Neolithic that cannot simply be attributed to known climatic changes or their impacts on vegetation. Rather, as persuasively argued for the Alpine Foreland using an impressively diverse range of proxies (Schibler and Jacomet, 1999; Ebersbach et al., 2012; Jacomet et al., 2016; Bogaard et al., 2017; Doppler et al., 2017), they also reflect the choices of different cultural groups, progressive anthropogenic alterations of local landscapes, and diachronic differences in the uses to which domestic animals were put, in the scale of stock-rearing, and in the types and sources of forage used to support livestock. Variation in domesticate taxonomic composition between houses of different sizes, in the Early Neolithic of northern France (Hachem, 2018), further suggest that choice of livestock species may sometimes have been shaped by availability of human labour, whether for herding or provision of fodder, rather than by the availability of forage.

Regional variation in the importance of dairying may tell a similar story. Possible ambiguities were noted above in apparent evidence for a dairy emphasis in the earlier Neolithic of the west Mediterranean (concentrated in caves and rock-shelters) and north Balkans (where abundant milk lipids in ceramics contrast with a lack of support for intensive dairying in available mortality data – Greenfield, 2005; Bartosiewicz, 2007, 303 Fig. 14.12; *pace* Vigne and Helmer, 2007, 21 Fig. 3). High frequencies of dairy lipids in the British Isles (Ivanova, 2020, 27 Fig. 1.4d), however, are matched by cattle mortality probably compatible with dairying in Early Neolithic southern England (Rowley-Conwy and Legge, 2015) and unambiguously so from the Neolithic to early historic era in the Western and Northern Isles of Scotland (Halstead, 1998, 12–13). While dairying in these North Atlantic islands might be seen as a response to the difficulty of overwintering larger numbers of beef cattle, winters here are in fact milder than in most of mainland Europe north of the Alps and arguably the greatest problem facing early farmers will have been that of ripening grain crops during the cool summers. If the management of cattle for dairy production was shaped by ecological pressures, therefore, it was arguably practised to buffer against the risk of *crop* failure (Halstead, 1998, 15; Cubas et al., 2020). Examples of mortality evidence possibly consistent with dairy management of cattle and sheep in the Neolithic Alpine Foreland may likewise be related to the unreliability of crop production as well as the scarcity of pasture in this particular landscape (Legge, 1981; Halstead, 1989; cf. Bogaard et al., 2017, 131).

An intriguing aspect of the diffusion of farming northwards through Europe is the gradual shift from early winter to early summer in the ideal season of parturition for livestock species domesticated in southwest Asia (Balasse and Tresset, 2007). If domesticates spreading northwards were slow to adjust to the later onset of spring, they may have incurred increased mortality among both breeding females and their young (Ivanova, 2020, 13–14), although livestock kept in small numbers could more easily have been sheltered from harsh weather and provided with adequate forage (Balasse et al., 2013, 4). Incremental oxygen and carbon stable isotope analysis of Early Neolithic domesticate teeth suggests that, while cattle and sheep widely retained restricted breeding seasons in the Balkans and central Europe (Balasse et al., 2020, 2021), sheep in the west Mediterranean (Tornero et al., 2020) and cattle in southern Scandinavia (Gron et al., 2015) produced young through much of the year. Year-round births would have made fresh milk potentially available to human consumers more or less throughout the year (Balasse et al., 2012; Gron et al., 2015), although seasonal calving/lambing would have been more conducive to the production of storable (and low-lactose) cheese and so may have been more compatible with milk making a significant contribution to subsistence. It has further been argued that year-round births among west Mediterranean sheep and southern Scandinavian cattle are evidence of advanced zootechnical skills (Gron et al., 2015; Tornero et al., 2020). The timing of reproduction (and hence of parturition), however, in early sheep, goats, probably cattle and possibly pigs was controlled by a photoperiod response (Ortavant et al., 1964), interacting with other factors including nutrition (e.g., Rosa and Bryant, 2003; Menassol et al., 2012), while the strength of the photoperiod response in modern domesticates varies between species, breeds and individuals. Neolithic changes in seasonality of parturition might thus be unintended by-products of practices such as the provision of fodder or shelter or the periodic separation of adult male and female livestock, rather than the intended outcome of human management decisions, let alone decisions so sophisticated (*pace* Gron et al., 2015) that they are more likely to have been taken by colonists with a long history of animal husbandry than by acculturated foragers.

4. Conclusion

- In recent years, the study of early animal husbandry in Europe has been dramatically enriched by a massive increase in the volume and diversity of macroscopic zooarchaeological data and an explosion in the range and resolution of biomolecular evidence.
- Macroscopic data have revealed fairly consistent regional differences and diachronic changes in the *relative* frequency of the four principal livestock species – cattle, sheep, goats and pigs – but rarely shed any direct light on the scale of animal keeping. A range of indirect proxies, however, suggests that livestock were normally kept in modest numbers, consistent with their apparent dietary association primarily with pasture on cultivated rather than uncleared land.
- Macroscopic data confirm that domestic animals were routinely exploited for their carcass products (meat, marrow, hides) and suggest that cattle may widely have been used for draught purposes, while biomolecular evidence for human use of milk from livestock is now fairly ubiquitous. The latter does not reliably indicate the relative contributions to human diet of dairy and adipose fat, since both may be consumed without prior heating in ceramic vessels and thus without leaving retrievable lipid traces, but macroscopic mortality data for domestic ruminants suggest that intensive dairying was not commonplace.
- If livestock, especially in the earlier Neolithic, were kept in modest numbers and their milk was not normally exploited intensively, their direct contribution to the subsistence of early European farmers was necessarily secondary to that of staple crops. Livestock played an important role, however, in facilitating cultivation (as draught animals, sources of manure, aids to controlling excessive cereal growth), in enriching and (as means of 'indirect storage') stabilising grain-based diets, and in sustaining relations of mutual solidarity within and between local communities.
- If livestock were few in number and primarily pastured on cultivated land and if the uses of different species were to some extent complementary (cattle for draught; ruminants for milk; pigs perhaps for fat; cattle for larger-scale commensality than sheep or goats), geographical and temporal variation in the proportions of livestock species is unlikely to have been shaped directly by regional climate or vegetation, and should instead be understood within the wider context of regional and local crop husbandry regimes, culinary cultures and strategies of social integration.
- In this respect, while recent large-scale syntheses have been of great heuristic value in revealing regional and diachronic patterns in the growing body of evidence for early European animal husbandry, these patterns need to be interrogated in the light of overarching models of land use, subsistence and political economy, that integrate multiple complementary categories of zooarchaeological and other evidence, rather than seeking to interpret single classes of 'big data' in isolation.

Author contributions

Paul Halstead conceived of, wrote and revised this paper.

Data availability

All data discussed are presented in the sources cited in the text.

Declaration of competing interest

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

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