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Culling profiles: the indeterminacy of archaeozoological data to survivorship curve modelling of sheep and goat herd maintenance strategies

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ABSTRACT

The comparison of survivorship curves derived from seven different models aiming to reconstruct ancient sheep and goat herd maintenance strategies (e.g. optimization of wool, meat, and milk production) shows that many of these models cannot be distinguished statistically. This observation renders the current theoretical framework for reconstructing ancient herd maintenance strategies problematic, due to the possible indeterminacy of model data analysis. In order to assign empirically observed age-at-death data to a model of herd maintenance strategy, it is suggested that a direct fit of observed data to survivorship curves be forgone in favor of a binning procedure highlighting the differences between fewer and more distinguishable models. The incorporation of high-resolution sexing and taxonomic determination to coarse-grained age-at-death models may go a long way towards solving the current problem of indeterminacy.

1. Introduction

Age-at-death distributions presented as mortality profiles are commonly applied in zooarchaeological research to determine ancient culling and herd management practices as reflected in sheep and goat bone assemblages. The reconstructed culling patterns serve to infer hunting behavior or herd maintenance strategies (e.g. Atici and Stutz, 2002; Marean and Kim, 1998; Steele, 2003; Stiner, 1991), origins of livestock domestication (e.g. Hesse, 1978; Perkins, 1964; Zeder, 2005; Zeder et al., 2006; Zeder and Hesse, 2000), specialized production strategies (Payne, 1973) and the use of secondary products (Greenfield, 1988; Vigne and Helmer, 2007), as well as to suggest trade interactions between different economic units (Stein, 1986). Over the last three decades, influential theoretical models, founded on ethnographic observations, have been published for sheep and goat management strategies (Helmer et al., 2007; Payne, 1973; Redding, 1981; Stein, 1988; Vigne and Helmer, 2007). They quickly became templates for plotting empirical data to interpret a given age-at-death distribution in an archaeological assemblage (e.g. Marom et al., in press; Wasse, 2002). These models are often presented as survivorship curves, which show the percentage of an age cohort of a sheep and goat herd which survived consecutive time segments (in a high-resolution scale of months or consecutive years).

One of the most widely applied sets of herd maintenance strategies associated with culling practices of sheep and goat livestock is Payne's (1973) pioneering work, which distinguished specialized meat production from wool and milk production based on ethnographic work in Turkey. Specialized meat production is identifiable by a sharp drop in the survivorship curve between 1 and 3 years of age, when sheep and goats attain their optimal weight. Milk production typically involves culling of most males during the first quarter of the first year of life, when the milk supply of the lactating females is secure, since continued lactation decreases the amount of milk available for sale or exchange. Specialized wool production involves some culling of lambs during the first year of life, but the majority of the herd, often consisting of castrated males and females, is retained into adulthood (Greenfield, 1988).

In his 1981 dissertation, Redding presented a slightly different way of reconstructing exploitation strategies among domestic animals. He discussed the implications of age-at-death distributions generated by different Near Eastern sheep and goat herding strategies, and suggested two new models applicable to archaeological data: optimization of energy production (from both milk and meat), and optimization of herd security. Optimization of energy production (maximal annual calorific off-take from each

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ewe or doe) is achieved by weaning lambs/kids at an early age, so that milk may be exploited by herders; and culling of excess males when their growth rate curve approaches a plateau at about 1–2 years. Optimization of herd security, defined as the minimization of fluctuations in herd size which may result in decreased annual yield from the flock, involves retaining some lambs/kids alive until the end of their second year of life to back up possible failure in the lamb/kid cohort born the year after.

Vigne and Helmer (2007) and Helmer and colleagues have introduced a new culling profiles system based on ethnographic work in France (Blaise, 2006; Helmer, 1992). This system distinguishes two different classes of utilization for meat: type A meat, in which the majority of lambs are culled between 6 months to 1 year of age, and type B meat, in which most lambs are culled as subadults, at 1–2 years. Utilization of herds for milk likewise differentiates between two strategies: type A milk, in which unweaned lambs are culled at 0–3 months, and type B, in which lambs are weaned and kept apart from the ewes. A type B milk mortality profile is marked by a culling peak of animals 2–4 years old, made up of females past their production peak. Fleece utilization is typified by high mortality rates of animals beyond the age of 4–6 years, and may be hard to differentiate from type B milk profiles.

Do these ethnographically observed and theoretically deduced models allow discrimination between different sheep and goat maintenance strategies in the archaeozoological record? The seeming similarity in the shape of the different survivorship curves (see below) calls for a re-examination of how significantly different from each other the models really are, and whether they can be securely interpreted to reflect discrete herd maintenance strategies when applied to empirical zooarchaeological data for sheep and goats. To answer this question, cardinal to a discussion of livestock culling practices, a statistical analysis of the theoretical survivorship curves is required.

2. Methods

We used the 10 published sheep and goat age-at-death distributions from the ethnographically based case studies, which represent a number of herd maintenance strategies (Fig. 1). The percentages of survivorship predicted by the different models are presented in Table 1, in increments fitting both Payne's (1973) and Vigne and Helmer's (2007) conventions. These models include the expected mortality profile for a sheep and goat herd maintained to maximize energy production (Redding, 1981), herd security (Redding, 1981), milk production (Payne, 1973), wool production

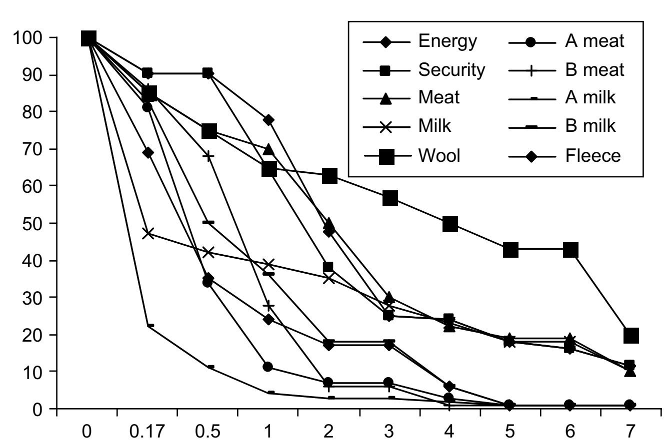

Fig. 1. Model mortality curves drawn on the same coordinate system. Data and references from Table 1. X-axis values are years, Y-axis values are percentage of survival.

(Payne, 1973), meat production (Payne, 1973), meat type A meat, Type B meat, type A milk, type B milk and fleece production (Vigne and Helmer, 2007).

The age-at-death distributions considered in this study are products of meticulous economic and ecological modelling, backed up by ethnographic data. The distributions can be presented as survivorship curves which are continuous variables, unlike those derived from archaeological age-at-death data using epiphyseal fusion and tooth eruption and wear sequences to assign age to specimens (which are discrete variables). As theoretical models are at the focus of this paper, there is no importance to the specific means used to construct an age-at-death profile from a set of archaeozoological data, be they tooth eruption and wear sequences or epiphyseal fusion.

Frequently, visual inspection is used to fit an empirical mortality profile with a theoretical one. This method, however, may be affected by subjectivity and is also prone to mistakes caused by the manner in which the results are graphed (e.g. the ratio of the lengths between the abscissa and the *Y*-axis).

In order to test for similarity between the survivorship curves, a Kolmogorov–Smirnov (K–S) test for continuous variables was used. It is appropriate for testing similarity between curves generated by continuous variables, such as on the data from Table 1, which lists the decreasing fraction of the herd expected to survive each consecutive age category as listed in the left-most column. The null hypothesis was that each pair of data sets compared was similar, with an error tolerance limit of 0.05. The choice of the K–S test for comparing the shapes of the mortality curves under discussion was affected by the fact that these curves, which are theoretical, are described as percentages; otherwise the test statistic would be a function of sample size. Percentages are not as a rule permitted in chi-squared based analyses. Statistical analysis was carried out using Palaeontological Statistics (PAST ver. 1.79) software (Hammer et al., 2001).

3. Results

It is clear from the Kolmogorov–Smirnov tests' results (Table 2) that most mortality profiles are not distinguishable from each other. The statistical analysis shows that the survivorship curves which are best distinguished from the others are the meat type A and meat type B models proposed by Helmer and colleagues. However, even these are indistinguishable from other models proposed by the same authors.

Many theoretical survivorship curves are not statistically different. For example, an archaeozoological analyst may derive a survivorship curve from his age-at-death data which he may alternatively interpret as specialized production of meat, milk, wool, or the promotion of herd security – all within the statistical error margin of 0.05. A mortality curve fitting perfectly Vigne and Helmer's (2007) milk type B profile may be interpreted as anything but Payne's wool production model.

4. Discussion

The inability to demonstrate a statistically significant difference between the survivorship curves resulting from various different sheep and goat herd maintenance strategies poses a severe problem to archaeologists interested in detailed modelling of herd production strategies in ancient times, a problem previously noted by Greenfield (1988). The problem is exacerbated by the inherently inaccurate nature of the zooarchaeological data sets used for determining age-at-death. Although many important studies on epiphyseal fusion ages and tooth wear patterns have enhanced the ability to collect age-at-death data (Balasse and Ambrose, 2005;

Table 1
The theoretical survivorship rate in percentages for a caprovine herd managed in accordance with the herd maintenance strategies listed in the header row.

Age (in years)	Energy	Security	Meat	Milk	Wool	A meat	B meat	A milk	B milk	Fleece
	Redding (1981)		Payne (1973)			Vigne and Helmer (2007)				
0	100	100	100	100	100	100	100	100	100	100
0.17	90.4	90.4	85	47	85	81	86	22	83	69
0.5	90.4	90.4	75	42	75	34	68	11	50	35
1	77.6	64.5	70	39	65	11	28	4	36	24
2	47.6	38	50	35	63	7	6	3	18	17
3	25	25	30	28	57	7	6	3	18	17
4	23.9	23.9	22	23	50	3	1	2	6	6
5	18.2	18.2	19	18	43	1	1	1	1	1
6	16.1	16.1	19	18	43	1	1	1	1	1
7	11.8	11.8	10	10	20	1	1	1	1	1

Grant, 1982; Greenfield and Arnold, 2008; Halstead and Collins, 2002; Payne, 1987; Silver, 1969; Zeder, 2001), one should remember the wide margin of error caused by pooling male and female sheep and goats into a single analytic group. Other factors, such as differences in breeds and environment (for epiphyseal fusion data and tooth wear) or in the amount of abrasive material in the sheep and goat feed, which varies spatially and annually (tooth wear), introduce additional biases. Various depositional and taphonomic processes also affect the age-at-death distribution at each site (Munson, 2000; Munson and Garniewicz, 2003). Our approximations of the ages-at-death are thus compounded by the similarity between survivorship curves, injecting a healthy dose of doubt into the attempt to distinguish between different high-resolution models of herd management strategies.

This plethora of elaborate models might cause confusion when trying to fit empirical data into a theoretical framework if the models are not distinct, as was demonstrated above. This problem is often called *indeterminacy of data to theory*, or *underdetermination*. A theory is underdetermined if, given the available evidence, there is a rival theory which is inconsistent with the first and is as consistent with the evidence. This is exactly the case with theories linking observed survivorship curves with different herd maintenance strategies: each empirically observed survivorship curve can equally fit more than one theoretical model.

The firm theoretical and observational grounds in which models of herd maintenance strategies are rooted does not call for their re-evaluation, although a re-assessment of the way chosen to describe empirical data is needed. One fruitful approach may involve binning different age classes into larger groups, in a way suited to tackle specific research questions.

Binning of age classes allows testing hypotheses concerning specific points in the theoretical survivorship distributions. For example, if a strategy meant to extract commercial amounts of milk from a herd is suspected to have been employed by herders, binning age classes to "younger than half a year" and "older than half a year" may be employed. This hypothesis specific method reduces the number of models to which the data can be fitted.

Such an approach was used by Greenfield (1988) to detect changes in herd demography during the transition from the Late Neolithic to the Bronze Age of the Balkans, as a possible indicator to the utilization of herds for secondary products (milk, wool and traction). To demonstrate the possible demographic changes, the author used triangular plots, which meant that the specimens were binned into only three age classes in order to emphasize the differences between the harvest profiles (very immature, up to 1 year; subadult, 1–3 years; and adult, over 3 years). The premises of the model were simple and explicit: wool and traction production would be manifest in more specimens in the 'adult' category, and milk production in more 'very immature' specimens. Meat production would be manifest in a more balanced representation of counts between all three age categories. These expectations were derived from Payne's classical models, and a lower resolution scale into which age-at-death data were fitted focused on particular points in which the survivorship curves were expected to diverge. These measures controlled for indeterminacy by reducing the number of models to which empirical data could be fitted, and by reducing 'noise' in the age-at-death data by not trying to fit them into too fine a scale.

By adopting Greenfield's binning method based on Payne's work, a very simple and testable model can be applied: if there is a high proportion (~80%) of very immature animals in the assemblage, specialized milk production is suggested; if subadults (most of which are male), very immature individuals and adults are represented in equal ratios (~30%), meat consumption is inferred; and if the large majority is adults (60%), with some very immature (30%) and subadults (10%), and especially if both sexes are well-represented, specialized wool or traction production may have been practiced. Furthermore, if many adult animals are present, but few are males, meat consumption of culled females from a herd grown for meat exchange can be claimed (Marom et al., in press).

The inference of specialized wool, meat and milk production can be greatly strengthened by knowledge of the sex ratios in the archaeological sheep and goat herd. This is especially true if the ratio of sexes can be determined for each taxon separately. Tooth

Table 2
The results of a Kolmogorov–Smirnov test comparing the theoretical mortality curves associated with different herd maintenance strategies. Italicized entries show a significant difference between the models in the respective rows and columns. Data and references from Table 1.

	Energy	Security	Meat	Milk	Wool	A meat	B meat	A milk	B milk	Fleece
Energy	*	D = 0.1, 1	D = 0.2, 0.97	D = 0.4, 0.31	D = 0.4, 0.31	*D = 0.7, 0.007*	*D = 0.6, 0.03*	*D = 0.8, 0.001*	D = 0.4, 0.31	D = 0.4, 0.31
Security	D = 0.1, 1	*	D = 0.2, 0.97	D = 0.3, 0.68	D = 0.5, 0.11	*D = 0.7, 0.007*	*D = 0.6, 0.03*	*D = 0.8, 0.001*	D = 0.4, 0.31	D = 0.4, 0.31
Meat	D = 0.2, 0.97	D = 0.2, 0.97	*	D = 0.4, 0.31	D = 0.4, 0.31	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.7, 0.007*	D = 0.5, 0.11	D = 0.5, 0.11
Milk	D = 0.4, 0.31	D = 0.3, 0.68	D = 0.4, 0.31	*	*D = 0.7, 0.007*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.7, 0.007*	D = 0.4, 0.31	D = 0.5, 0.11
Wool	D = 0.4, 0.31	D = 0.5, 0.11	D = 0.4, 0.31	*D = 0.7, 0.007*	*	*D = 0.7, 0.007*	*D = 0.6, 0.03*	*D = 0.8, 0.001*	*D = 0.6, 0.03*	*D = 0.7, 0.007*
A meat	*D = 0.7, 0.007*	*D = 0.7, 0.007*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.7, 0.007*	*	*D = 0.6, 0.03*	D = 0.2, 0.97	D = 0.3, 0.68	D = 0.3, 0.68
B meat	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*D = 0.6, 0.03*	*	D = 0.3, 0.68	D = 0.2, 0.97	D = 0.2, 0.97
A milk	*D = 0.8, 0.001*	*D = 0.8, 0.001*	*D = 0.7, 0.007*	*D = 0.7, 0.007*	*D = 0.8, 0.001*	D = 0.2, 0.97	D = 0.3, 0.68	*	D = 0.4, 0.31	D = 0.4, 0.31
B milk	D = 0.4, 0.31	D = 0.4, 0.31	D = 0.5, 0.11	D = 0.4, 0.31	*D = 0.6, 0.03*	D = 0.3, 0.68	D = 0.2, 0.97	D = 0.4, 0.31	*	D = 0.2, 0.97
Fleece	D = 0.4, 0.31	D = 0.4, 0.31	D = 0.5, 0.11	D = 0.5, 0.11	*D = 0.7, 0.007*	D = 0.3, 0.68	D = 0.2, 0.97	D = 0.4, 0.31	D = 0.2, 0.97	*

wear data, while allowing the determination of age-at-death distributions, which are less biased by density-mediated attrition and are statistically continuous, cannot be used to discriminate between taxa and sexes in a useful way (but see Payne, 1985). To achieve the desired resolution for demographic analyses, long bone epiphyses, which can be used to distinguish the different taxa and sexes based on morphological (e.g., Boessneck, 1969) and morphometrical (Payne, 1969) criteria, are needed.

The distal metapodials and the distal humerus are ideal in this respect, as both elements can be easily used for determining taxa, and both are sexually dimorphic (Zeder, 2001). The distal humerus and metapodials also fuse to their respective diaphyses in consecutive years: the humerus around the end of the first year of life, and the metapodials around the end of the second year of life (Silver, 1969). These epiphyses are quite durable, and are commonly found complete in archaeological assemblages (Grigson, 1995). Various techniques for facilitating the necessary determinations of sex ratios in these sexually dimorphic elements, not available during the 1970s and 1980s, exist today. These include better understanding of the components of size variation in caprines (Zeder, 2001), use of mixture analysis (Monchot et al., 2005) and of support vector machines (Cristianini and Shawe-Taylor, 2000) – a type of linear classifier recently applied to sheep and goat sexing by Marom et al. (in press). These advances allow more complete demographic analyses with less reliance on fine-scale age determination.

The incorporation of age-at-death, sex, and taxon data derived from distal metapodials and humeri, to the primary binned age distribution data based on tooth wear can be useful in determining dissimilarities in the utilization pattern of zooarchaeological sheep and goat herds. Hypothetically, one may discover that the major component culled from a herd during the first year of life was male goats. In such a case, use of goat milk and sheep meat may be suggested.

Fitting archaeological age-at-death data to fewer coarse-grained models, while incorporating taxonomic and sex ratio data to demographic analyses, may well solve the problems of fitting taxonomic variability and indeterminacy of data to theory in the current state of affairs, where too few data sets are fitted to many fine-grained models.

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