ARTICLES

MORTALITY MODELS AND MILKING: PROBLEMS OF UNIFORMITARIANISM, OPTIMALITY AND EQUIFINALITY RECONSIDERED*

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"We rob her of her children that we may rob her of her milk"
(Fussell, 1966).

Summary

The use of mortality models in archaeozoological recognition of stock husbandry goals, particularly milking, has been criticised on three grounds: (1) primitive livestock do not "let down" milk in the absence of their offspring, so the infant slaughter characteristic of the "milk model" actually suppresses lactation; (2) pre-modern herders do not optimise for a single product, but also raise for meat the offspring from milk-animals; (3) mortality approximating to the "milk model" might reflect biased sampling of infant disposal areas or heavy natural infant mortality.

These problems of uniformitarianism, optimality and equifinality are reviewed in turn. (1) uniformitarianism: it is argued that cattle, sheep and goats are "pre-adapted" to milking, and that problems of let down are related to husbandry conditions (nutrition, housing) and can be overcome in various ways. (2) optimality: the culling decisions of recent Greek herders, specialising in dairy production for market, conform to optimising expectations. (3) equifinality: assemblage formation can be explored through comparative analysis at intra- and inter-site level. It is concluded that, although mortality models measure potential rather than actual exploitation and although milking is consistent with a range of mortality patterns, only mortality approximating to the "milk model" can be cited as evidence in favour of intensive dairying.

Résumé

Modèles d'abattage et traite laitière : reconsidération des questions d'actualisme, d'optimisation et d'ambiguïté.

L'utilisation des modèles d'abattage dans la détermination archéozoologique des finalités de l'élevage, notamment en ce qui concerne la traite laitière, a fait l'objet de trois types de critiques : (1) les formes primitives d'animaux domestiques ne délivrant pas de lait en l'absence des petits, l'abattage des très jeunes, diagnostique du "modèle lait", inhibe la lactation; (2) les anciens éleveurs ne recherchent pas la production exclusive d'un produit, mais élèvent également pour la viande les jeunes issus des femelles laitières; (3) des structures d'abattage proches de celles du "modèle lait" peuvent tout aussi bien résulter de biais d'échantillonnage (dépôt local d'ossements de jeunes animaux) ou bien d'une forte mortalité juvénile.

Ces questions d'actualisme, d'optimisation et d'ambiguïté sont tour à tour examinées. (1) actualisme : l'auteur avance que les bovins, les moutons et les chèvres sont "pré-adaptés" à la traite, et que les difficultés de lactation dépendent des conditions de l'élevage (nutrition, hébergement) et peuvent être résolues de différentes manières. (2) optimisation : la stratégie d'abattage des éleveurs Grecs modernes, spécialisés dans la production laitière de marché, est conforme aux prédictions optimisées. (3) ambiguïté : les modalités d'accumulation des assemblages fauniques peuvent être reconstituées grâce aux analyses comparatives intra- et intersites. L'auteur conclut que, bien que les modèles d'abattage rendent compte de systèmes d'exploitation plus potentiels qu'effectifs et que la traite laitière puisse aboutir à différents schémas d'abattage, seuls les profils proches du "modèle lait" peuvent être considérés comme des témoignages en faveur de l'exploitation laitière intensive.

Key Words

Archaeozoology, Dairying, Milking, Mortality models.

Mots clés

Archéozoologie, Production laitière, Traite, Modèles d'abattage.

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Thanks in no small measure to Sherratt's influential model of a "secondary products revolution" in fourth-third millennium BC Europe (Sherratt, 1981), archaeologists and archaeozoologists alike are keenly aware of the need to distinguish between the exploitation of domestic animals for their carcases and for their "secondary products" of milk, wool/hair and traction. Sherratt's model was supported by an impressive range of artefactual and other evidence, which unambiguously demonstrates a knowledge of secondary products. It is less clear whether models of yoked oxen or engravings of milking represent everyday farming practice or the latest advances in stock-rearing theory, and whether ard marks under burial mounds represent normal tillage methods or an unusual mortuary ritual (Rowley-Conwy, 1987).

Archaeozoological evidence of animal husbandry played a very minor role in Sherratt's original model and is less readily interpretable than some artefactual evidence, but may potentially enable a distinction to be drawn between regular farming practice and arcane agronomic knowledge or infrequent ceremonial activity. While the use of carcase products (meat, hides/furs, marrow, bone grease, horn/antler, etc.) may be inferred relatively directly from traces of butchery and bone fragmentation (e.g. Driesch and Boessneck, 1975; Binford, 1978), archaeozoological recognition of the exploitation of secondary products tends to rely on two less direct approaches.

First, milking and traction *may* be reflected in bone chemistry (Runia, 1987; Horwitz and Smith, 1991) and stress-related pathologies in limb joints (Baker, 1984) respectively, but the osteological effects of management may be hard to disentangle from other factors such as sexual dimorphism, nutritional stress and, in particular, old age (e.g. Mulville, 1993; Baker and Brothwell, 1980). Moreover, the analysis of bone chemistry is relatively costly in time and equipment, while macroscopically visible joint pathologies are encountered relatively infrequently, thus limiting the potential of this approach for the routine investigation of stock husbandry goals.

Secondly, production goals may be reflected in patterns of mortality. Following earlier applications of this principle in the context of both textual (e.g. Killen, 1964) and archaeozoological evidence (e.g. Higham, 1967), explicit mortality models for alternative production strategies were elaborated by Payne (1973). For a given size of herd, area of pasture or quantity of fodder, most milk is available for human consumption if male lambs, kids or calves are slaughtered soon after birth; most meat is raised if males are killed as they approach adult body weight; the most (and best) wool and the most effective traction are secured by keeping castrated male sheep and cattle respectively alive until well into adulthood. Thus an emphasis on dairy products, on meat, and on wool/hair or traction should be characterised by heavy slaughter of males as infants, juveniles/subadults and adults respectively (Payne, 1973; Killen, 1964; Higham, 1967; Legge, 1981a). Such models have been widely and more or less explicitly applied to the recognition of stock husbandry goals in protohistoric texts (e.g. Postgate and Payne, 1975; Green, 1980), historical records (Campbell, 1992) and archaeozoological assemblages (e.g. Legge, 1981a, 1981b, 1987; Maltby, 1981; Bogucki, 1982; Davis, 1984, 1993; Jacomet and Schibler, 1985; Payne, 1985, 1988; Becker, 1986, 1991; Halstead, 1987, 1989, 1996; Greenfield, 1988, 1991; Bökönyi, 1989; Driesch and Boessneck, 1990; McGovern, 1992; Rowley-Conwy, 1992; Kotjabopoulou and Trantalidou, 1993) and also widely criticised (e.g. Clutton-Brock, 1981; Cribb, 1984, 1985; Chang and Koster, 1986; Entwistle and Grant, 1989; McCormick, 1992). The study of mortality patterns is a relatively low-cost and standard element of faunal analysis and, in these terms at least, has great potential for the routine investigation of stock husbandry goals. The purpose of this paper is to evaluate the archaeozoological potential of mortality models, particularly in the recognition of dairying.

The application of Payne's mortality models has been questioned on three principal grounds. First, the basis of the models is that the economic potential of domestic animals is broadly predictable from their age and sex. This entails the *uniformitarian* assumption that the biological development of prehistoric livestock resembled that observed today (cf. Binford, 1977: 8-9). Allowance must be made, however, for the strong probability that prehistoric livestock existed on a far lower nutritional plane and so were substantially less productive than modern European farmyard animals (Noddle, 1990). Domesticate genotypes have also been subjected to long-term human selection for particular productive traits such as the wooly fleece which evolved in sheep after domestication (Ryder, 1984). Most contentiously, it has been argued that the slaughter of infant offspring suppresses the let down of milk in primitive breeds of domestic livestock (Clutton-Brock, 1981), thus negating the underlying logic of the milk model. (The separate uniformitarian problem of lactose intolerance in humans [Sherratt, 1981] is ignored here because of rich early textual evidence that milk was converted into more digestible forms such as cheese [e.g. Stol, 1993].)

Secondly, even if uniformitarian assumptions concerning the biology of livestock are legitimate, the mortality models represent *optimising* strategies by human herders, even though there are no empirical or theoretical grounds for expecting people to behave optimally (Foley, 1985). Moreover, the mortality models simplify reality in considering optimisation for a single goal (milk or meat or wool etc.), whereas in practice herders usually aim for a mixture of products under complicating constraints of labour, pasture, and so on (Payne, 1973; Koster, 1977; Cribb, 1984, 1985).

Thirdly, archaeozoological mortality data may be unrepresentative of prehistoric slaughter patterns because of partial survival, partial retrieval or partial sampling of activity areas and sites (e.g. Noddle, 1990: 39; Cribb, 1984: 167, 1985; Entwistle and Grant, 1989). For example, a milk mortality pattern might be concealed by carnivore destruction of infant remains or, more worryingly, might be artificially created by sampling a disposal area for infant deaths. Alternatively, infant remains might be the result of natural mortality rather than deliberate slaughter (e.g. Ryder, 1993: 18). These are problems of *equifinality*: a "milk" mortality pattern might be the result of processes unrelated to management for dairy products.

These problems of uniformitarianism, optimality and equifinality are relevant to the application of mortality models in general, but they have been raised most frequently and most forcefully with reference to the milk model. This review addresses these three areas of debate in turn, with particular reference to their implications for the archaeozoological recognition of dairying.

Uniformitarianism and milk let down

In prehistoric livestock, did the slaughter of offspring in infancy (i.e. early in the lactation period) release milk for human consumption, as Payne and others have assumed, or cause the premature termination of lactation, as Clutton-Brock and McCormick argue? The argument of Clutton-Brock and McCormick, based on a variety of ethnographic and early historical sources, is essentially that primitive livestock will not let down milk in the absence of their offspring. To maintain the flow of milk, early historical farmers in Ireland had to keep calves alive through the lactation period until perhaps 6-9 months of age, giving rise to heavy juvenile mortality more typical of Payne's meat model (McCormick, 1992: 203). Conversely, Legge cites writers in medieval to early modern England who advised early weaning, slaughter or sale of infant calves to free up milk for human consumption (Legge, 1981c: 221); the Roman poet Virgil gave similar advice on the management of goats for milk in 1st century BC Italy (White, 1970: 314).

Although modern livestock bred for milk production may be misleading guides to the potential of their prehistoric counterparts, cattle, sheep, goats, camels and perhaps reindeer may be naturally predisposed to milking (Russell, 1988: 24-29). These species have capacious udder "cisterns", which can release significant quantities of milk in a short period of time, whereas species such as the pig, characterised by "alveolar" storage, release milk very gradually and so could only be milked by a dairyman prepared to spend much of the day lying prone in the sty. The filling of udder cisterns by the "milk ejection reflex" is typically initiated by the release of the hormone oxytocin, which is triggered naturally by recognition of the offspring or by suckling, and the simplest way for a herder to trigger the milk ejection reflex is to milk in the presence of the offspring or while the offspring is suckling. The importance of oxytocin and the role of visual and tactile stimuli in oxytocin release seem to vary, however, both between species and between individuals (Forsling, 1986: 31; Robinson, 1986: 155). The release of oxytocin appears to be inessential in goats (Robinson, 1986: 165) and can be conditioned in cows by the milking regime (Robinson, 1986: 163-65). There is also some evidence that milking may be as effective as suckling in triggering the release of oxytocin (Forsling, 1986: 31). In general, species with udder cisterns "allow removal of a sizeable fraction of milk by passive withdrawal by the suckling young, whereas animals whose milk stores are mainly "alveolar" require an active [milk ejection] response" (Robinson, 1986: 155). Significantly, udder cisterns appear to be a long-standing natural adaptation to the dangers of suckling in open terrain rather than a recent result of human selection (Russell, 1988). Research into the physiology of lactation thus suggests that the prehistoric ancestors of modern dairy cattle, sheep and goats will have been "preadapted" to letting down milk in response to the stimulus of human milking.

Studies of recent livestock suggest that nutrition, temperature and housing also play an important part in milk let down. Although specialised dairy breeds of cattle, sheep and goats can "milk off their backs" (Noddle, 1990: 33), well-nourished individuals are better able than underfed animals to mobilise their own fat reserves in early lactation when milk production outstrips dietary intake (Vernon and Flint, 1984: 120-22). Modern dairy cattle yield more milk when sheltered from cold and well fed (e.g. Russell, 1952: 30-31; Bigelow, 1987: 34) and dairy farmers consider that wiping a cow's udder and teats with a *warm* cloth helps to stimulate the let down of milk as well as promoting hygiene (e.g. Russell, 1952: 127). A recently retired dairy farmer from Whitby in N. England reports that, while cows in beef herds can successfully produce enough milk to suckle a calf with little or no housing, dairy cows require more intensive husbandry to maintain the higher milk yields expected of them. Dairy cows exposed to sudden cold and wet weather must be brought indoors and fed well to avoid a severe and irreversible drop in milk yield and, on a cold morning, even a brief walk from the byre to a separate milking shed could trigger difficulties in letting down milk in his own Friesian dairy cows. Given good feeding and housing, however, problems with let down were only experienced by perhaps two of his 26 cows in any one year, despite removal of the calf after 36-48 hours, and these problems could normally be solved by massaging the udder and simulating the butting action of a calf (R. Nellis, pers. comm.).

In Greece, some transhumant Vlach shepherds likewise now stall-feed their milking ewes over winter, while the non-productive animals are left to graze outdoors (Nitsiakos, 1985: 41). In flocks which are not stalled, sedentary (non-Vlach) shepherds report that a late lamb, born when temperatures are warm and good pasture is abundant, can be lost without affecting milk supply, while the loss of an early lamb, when temperatures are still low and grazing poor, may well lead to the end of a ewe's lactation (Halstead, field notes: Assiros, Central Macedonia, 1991; also Koster, 1977: 303). The importance of quality of husbandry is reinforced by the experiences of a sheep-farmer from a village at 1200 m in the Pindos mountains of NW Greece where, because of depth of snow cover, livestock are stall-fed for several months over winter. The animals are stalled in solidly built and well-insulated byres and, even if a lamb dies at birth, the ewe can still be milked throughout a normal lactation - provided she is well fed. Once the sheep start grazing outdoors, however, milk yields decline rapidly if a late spring brings prolonged cold weather and delays the growth of new grass (Halstead, field notes: Plikati, 1992). Plainly, discussion of the ease of milk let down in livestock should not be divorced from consideration of quality of housing and nutrition and the contradictions between McCormick's Irish sources and Legge's English writers may partly reflect differing standards of husbandry: medieval and early modern accounts of cattle rearing in Ireland stress the minimal use of hay, lack of winter stalling, and consequent poor condition of animals (Lucas, 1989: 33-38; Evans, 1957: 152), while the English writers were addressing literate and moderately prosperous farmers able to maintain relatively high standards of husbandry.

Research into modern sheep also suggests that, while lambs of dairy breeds can be removed from the ewe at birth without threatening lactation, lambs of non-dairy breeds should be allowed to suckle for a week to establish lactation (Noddle, 1990: 40). The experiences of herders in lowland northern Greece during the 1940s and 1950s, working with unimproved local breeds of milk-cattle, -sheep and -goats, reinforce the importance of a period of suckling to establish lactation. For example, the new-born calf was left to suckle freely for a few days to consume the mother's initial colostrum; thereafter, the calf was allowed to start suckling in order to trigger let down, but was tied up while the cow was being milked, and was then allowed to feed on the milk remaining in the udder; gradually the calf was weaned onto solid foods. Estimates of the duration of this process vary, but it was reckoned that a first calf could be removed perhaps 40 days after birth and subsequent calves after as little as 10-15 days without endangering lactation. Similarly, while the removal of lambs at birth stressed milk-ewes, lambs could safely be slaughtered after a month (Halstead, field notes: Assiros 1991-96). Although calves, lambs or kids might be allowed to suckle for much longer (below), all informants were agreed that the period of suckling necessary to establish lactation securely was a matter of days or weeks and not several months as argued by McCormick. Early Irish accounts of problems with milk let down should perhaps be reinterpreted in this light, because later 17th-19th century AD Irish sources suggest that male calves were normally culled at birth (Lucas, 1989: 224-26), before lactation could be securely established by suckling.

The contradictions between the Irish and English historical sources on early dairying may anyway be more apparent than real, in that much of McCormick's evidence survives in accounts of such deceptions (apparently successful) as the use of surrogate calves or stuffed calf skins as substitutes for dead offspring. The more invasive stimulus of blowing air into the cow's vagina or anus is also recorded historically from Ireland ("cow-blowing") and ethnographically from many parts of the Old World (Cranstone, 1969: 256; Clutton-Brock, 1981; Sherratt, 1981; Lucas, 1989: 55-58). While several recent Greek herders report cases where the early loss of a calf, lamb or kid resulted in the mother (especially a first-time mother) failing to lactate, most informants consider any female with a more or less full-term pregnancy (even if the offspring is still-born) capable of lactating, in response either to suckling a foster infant or to being milked; even barren ewes are reported to lactate in response to prolonged stimulus of attempted milking. The gradual stimulation of lactation by massaging and hitting the udders is very time-consuming, however, and is more likely to be undertaken by a farmer experiencing difficulties with one of two or three cows (as in the early Irish sources) than by a shepherd or goatherd with 200-300 females to milk two or three times daily (Halstead, field notes: Tharounia, Evvia, 1988; Assiros, 1991-96; Kipourio, Milia, Plikati, Pindos mountains, 1992-1996).

At first sight, artistic representations from 3rd millennium BC Mesopotamia, showing milking of cows and goats in the presence of the calf (Sherratt, 1981: 279, fig. 10.13) or kid (Ryder, 1993; 27 Fig. 6), may appear to support McCormick's case. There is abundant textual evidence of the same date, however, that the palatial authorities raised male calves to three years of age, when they were sacrificed or began work as draught oxen (Stol, 1995: 177). The calves represented in milking scenes, therefore, may not have been kept alive solely to facilitate let down of milk. Indeed, two Uruk III dairy production texts of 4th millennium BC date list cows and calves (both bull and heifer calves) together, but in a ratio of two adult cows to one calf (Englund, 1995: 38). Perhaps a compromise was reached between the demands for milk production and for raising steers, by slaughtering half of the calves and letting each live calf suckle two cows (as was the practice with cows, sheep and goats in the early 18th century Highlands of Scotland; Megaw, 1964: 213). In this context, it may be significant that, in the representation referred to above of milking in the presence of the calf, the cow is being stimulated by "blowing" with an insufflator (Sherratt, 1981: 279).

As species with udder cisterns, prehistoric cattle, sheep and goats were preadapted to let down milk in response to the stimulus of human milking, though ease of let down probably varied between species, populations and individuals. Milk let down will have been facilitated by good nutrition and shelter, and milking was doubtless easier, in the early stages of a lactation, in the presence of the calf, lamb or kid, but various other measures could be taken to encourage let down. There seems little reason to doubt that, at least under favourable conditions of temperature and nutrition and especially if lactation had been established by suckling for a few days or a few weeks, early slaughter of infant offspring will normally have enhanced rather than reduced the availability of milk for human consumption.

Optimality and specialised production

Payne's mortality models for milk, meat and wool production represent optimising strategies, not because herders necessarily exploit the biological potential of their livestock rationally and fully, but for the simple reason that optimisation strategies are the most clearly definable and so the most useful as yardsticks for measuring actual behaviour (cf. Binford, 1978: 38-45; Foley, 1985). Each model considers optimisation for a single goal because such simplification is the basis of the heuristic power of a model; problems only arise if this simplification is ignored in interpreting similarities and differences between the model and archaeozoological data. Inherent simplification and the heuristic assumption of optimisation do not undermine the explanatory value of mortality models, but rather call for appropriate caution in their application: archaeozoological data which more or less match, say, the milk model do not indicate that milk was exploited, far less that other products were not exploited; they do imply that herd management enhanced the *potential* for production of milk rather than of meat, wool/hair or traction.

Although Payne's models were informed by personal observation of herd management in Turkey and other parts of the Mediterranean, only limited ethnographic detail was offered in their support (Payne, 1973: 299-301) and some critics have questioned the plausibility of the milk model in particular. On the reasonable assumption that prehistoric milk yields were low, it has been argued that the deliberate killing of young animals to release milk for human consumption is an unlikely husbandry policy; rather the milk would be shared between herders and calves, and the latter would be reared for several years to provide meat (Entwistle and Grant, 1989: 206). Cattle pastoralists in Africa today exploit their herds principally for milk (e.g. Dahl and Hjort, 1976: 175, table 7.6), but also raise many male calves to adulthood. In Greece, where the management of sheep in dairy flocks broadly conforms to Payne's milk model, Chang and Koster argue that the early sale of lambs reflects the high market value of tender young meat; if a market existed for heavier lambs, the slaughter patterns of modern milk flocks would more closely match Payne's meat model (Chang and Koster, 1986: 109). Closer consideration of the slaughtering policies and husbandry goals of some recent Greek herders broadly supports Payne's original thesis, however, while adding some illuminating contextual detail concerning their decision-making environment.

(i) Mobile sheep pastoralists in the mountains of NW Greece. In the 1950s, semi-nomadic Sarakatsani shepherds, who spent summer on the upland pastures of the Zagori in the central Pindos mountains, overwintered in the coastal lowlands of Epirus. They allowed ewe lambs to suckle for 7-8 weeks to ensure healthy development of replacement breeding stock, but sold the male lambs as early as possible, usually by 4 weeks, to maximise milk yields. The main milking season began with the sale of the male lambs in early February, built up with the weaning of the ewe lambs in early March, and continued until late July, that is for a little over 5 months; during this period, milk was sold to the cheese merchant, while the more modest flow in January (while all the ewes were suckling their lambs) and early August (as the ewes dried off) was consumed domes-

tically (Campbell, 1964: 21-24). On the basis of information from Sarakatsani in several parts of Greece, Kavadias (1965: 94-95) gives a very similar account, with male lambs sold from the conventional biblical age of "40 days" onwards. In rainless winters, however, when pasture was scarce in the lowlands, elderly herders recall that lambs were slaughtered soon after birth to ensure the survival of the undernourished breeding ewes (Halstead, field notes: Koukouli, Zagori, 1986); presumably the ewes were not milked for the same reason.

Transhumant Vlachs from the summer village of Aetomilitsa in the northern Pindos overwinter in the lowlands of Thessaly or Macedonia. The ideal lambing time is November or February, so that "40 day" old lambs can be sold in the Christmas or Easter markets; again the real milking season begins when the male lambs have been sold and the ewe lambs weaned (Nitsiakos, 1985: 40-41). The profitable sale of lambs at Christmas depends on early lambing in autumn, which is a recent development made possible by supplementing natural pasture with sown pasture and fodder crops. In this same community, lambing used to take place in January, with the male lambs being sold off in March (at a younger age and lower weight than nowadays) and the main milking season lasting for 6 months until August. As with the Sarakatsani, all healthy female lambs used to be retained because losses were heavy and barrenness commonplace among replacement breeding stock (Halstead, field notes: Aetomilitsa, 1986; Rodia, winter village near Larisa, Thessaly, 1987). One elderly Vlach from the summer village of Samarina in the northern Pindos suggested that male lambs used to be killed at as much as 2.5-3 months (Halstead field notes: Ambelonas, winter village near Larisa, Thessaly, 1987). Conversely, a semi-nomadic Vlach at a summer camp near Aetomilitsa recalled that the winter of 1948 was so dry (and the grazing so sparse) that lambs were killed at birth (Halstead, field notes: Plikati 1988), while the slaughter and discarding of almost new-born lambs, in order to save scarce pasture for the productive ewes, is reported as commonplace in the 1950s among Vlach herders from Sirrako in the central Pindos (Psikhogios, 1987: 43 n2).

(ii) Large-scale sedentary sheep herders in lowland N Greece. A similar picture emerges from the larger sedentary flocks around the agricultural village of Assiros (Halstead, field notes: Assiros, 1986-1995). Substantial flocks of sheep have been run primarily for milk, from at least the early 20th century by long-term village residents and latterly by recently settled Sarakatsani semi-nomads; the sale of lambs (or, in the past, wool) was a secondary goal. Nowadays, with intensive feeding, lambing takes place in autumn but, in earlier decades, sheep were poorly fed and lambing mostly took place between Christmas and February. Traditionally, male and surplus female lambs were sold at 30-50 (typically "40") days, while ewe lambs retained as future breeding stock were suckled for 2 months. The main milking season lasted from weaning in March or April until the end of August or September. Some herders with flocks of intermediate size, who claimed milk and lambs as equal production goals, recall delaying weaning and slaughter to 50-60 days (perhaps even 3 months) if undernourished lambs were too small or the market too saturated for an earlier sale. Herders geared primarily to milk production, however, often sold lambs at the minimum weight acceptable to the butcher (in the early 20th century, perhaps as little as 3.5-4 kg meat weight, achieved at 1-2 months age depending on quality of pasture for the ewes); early slaughter of at least male lambs always seems to have been the norm in large flocks and was explicitly perceived as a means of increasing milk production.

Some ex-herders suggested that slaughter at 30-50 days was partly timed to coincide with the beginning of warmer weather and appearance of new grass and sown pasture from February onwards, as the lambs could then be removed without endangering the flow of milk. In a late spring, slaughter might be delayed for 5-10 days so that the ewes were suckled until the onset of warmer weather and appearance of new pasture; if the flow of milk was allowed to drop after early slaughter or weaning, it would not recover with the arrival of warm weather. The slaughter of early lambs was often delayed also because it was not considered worthwhile to collect the milk from just a few ewes (for similar reasons, a ewe losing an early lamb at under one month would be given a foster lamb instead of being milked to maintain her lactation). The first batch of lambs for slaughter thus tended to be large, while thereafter lambs could be slaughtered in small numbers as needed or as they reached the appropriate size. Late lambs (born in warm weather) were likely to be slaughtered very early, however, partly because this could be done without risk to the milk supply and partly because it was more convenient not to run separate flocks of milking and suckling ewes. An optimal strategy for specialised milk production in this locality characterised by cold winters would, in the opinion of one ex-shepherd, be the earliest possible slaughter of surplus lambs coupled with late lambing (though early lambing might be more advantageous in the warmer south of Greece; Koster, 1977: 304).

Elderly shepherds report similar norms for the slaughter of lambs in large-scale sedentary flocks elsewhere in

Greece: 35-40 days in a southern lowland village (Halstead, field notes: Berbati, Argolid, 1990) and two months or "1-3 months, depending on the butcher" in mountain villages in the northwest of the country (Halstead, field notes: Aristi, Zagori, 1987; Plikati 1989). An additional factor favouring early slaughter in dairy flocks is that, after early weaning to maximise the availability of milk for human consumption, lambs sometimes lose condition temporarily and may then be unacceptable to the butcher until the following autumn (Halstead, field notes: Kipourio, central Pindos, 1996).

Kids are likewise sold early, and for similar reasons, by extensive goat herders in southern (Koster, 1977: 224) and northern Greece (Halstead, field notes: Vertisko, near Thessaloniki, 1996). Again, in herds of intermediate size, slaughter is more likely to be delayed until 3-4 months to coincide with Easter, or delayed until the autumn to secure a larger carcase (Halstead, field notes: Kleidonia, near Konitsa, northern Pindos, 1986; Vikos, Zagori, 1987).

(iii) Small-scale sedentary herders in lowland and upland Greece. In the lowland village of Assiros, many households kept one or two cows, partly for their milk and partly for their calves. The milk was largely consumed by the household, but the calf was usually sold - beef was rarely eaten in the village before the arrival of electric fridges from the late 1960s onwards. The sale of calves was sufficiently important to the family budget that weaning usually took place gradually, with the calf suckling one teat and the family milking the rest. Few households had the labour or stalling to keep calves to the preferred selling age of two years, however, and it seems to have been more usual to sell the calf at 5-6 months, as soon as it was large enough to be taken by the butcher. In addition to the large flocks belonging to the bigger arable farmers and to a few pastoral specialists, most households also used to keep a few sheep and/or goats to meet domestic needs of milk, meat and perhaps wool. Lambs and kids might be slaughtered young at Easter, but were often weaned later and so might grow substantially larger than lambs and kids of the same age in the big flocks. In addition, some households bought a lamb (often one of a pair of twins, too thin for sale at "40 days") from a Sarakatsani shepherd and raised it on the milk of the family cow for slaughter as a yearling, at a size large enough to justify salting the meat for gradual consumption during winter.

In a lowland vine-growing village near Nemea in southern mainland Greece, a few families keep a handful of sheep (perhaps up to 10 per household) for domestic consumption. The owners report that, whereas specialised mobile pastoralists in the region wean and slaughter lambs early to maximise milk sales, they themselves do not need to wean prematurely, as they aim only to satisfy domestic milk consumption, and they do not consume their lambs until 6 months age or more (Halstead, field notes: Heraklion, 1991). In the lowland farming village of Potamia on the island of Naxos, a man born in 1941 recalled that his family used to keep about 15 sheep and goats for milk and used to slaughter the lambs and kids gradually through their first year "at one-month intervals because there was no fridge" (Halstead, field notes: 1996). Likewise, sedentary households in the mountain village of Plikati in the northern Pindos each keep perhaps 5-20 sheep and goats (15-40 until the 1940s) to supply milk, butter and cheese for domestic consumption. A few suckling lambs and kids are consumed, but most are weaned late and are killed at about 3-5 months or even as yearlings (Halstead, field notes: 1987-1992).

To varying degrees, these accounts do not represent systematic or objective records, but rather the idealised and sometimes anecdotal recollections of often elderly herders. Nonetheless, or perhaps precisely because of these qualities, they offer some useful insights into 20th century herd management strategies. Herders who perceive themselves to be geared primarily to milk production normally slaughter male and any surplus female lambs or kids at between one and two (less commonly three) months of age; the most frequently cited norm is the biblical figure of "40 days". Slaughter at 1-3 months is consistent with Payne's milk model and may leave as much as 3-6 months of full lactation available solely for human use. Herders who perceive themselves to be geared to both milk and meat production may slaughter male and surplus female lambs or kids equally young, but are far more likely than dairy specialists to defer slaughter until 3-12 months or even older. Slaughter from one year upwards is consistent with Payne's meat model; Payne suggests that slaughter at 6-9 months is likely when sheep or goats are kept for both milk and meat under constraints of scarce winter feed (Payne, 1973: 282) but, as the lactation ends at this time, the causal link between the timing of slaughter and milking is less strong.

As Chang and Koster (1986: 109) argued, the early sale of lambs and kids reflects the high market value of tender young meat: pastoralists have made the most of the opportunities afforded by the market for suckling lamb and kid, particularly at Christmas and Easter. Equally clearly, however, herders perceive a conflict between the benefits of raising young lambs and kids for market and the costs of losing milk by extending the period during which these lambs and kids are allowed to suckle. Moreover, some herders consider it necessary to raise lambs to at least one month in order to establish lactation and, significantly, the norm of slaughtering at "40 days" is not only quoted by recent pastoralists, who have undoubtedly benefitted greatly from the high market price of young lamb and kid. This norm is equally widely cited by elderly informants whose active herding days fell in the 1920s and 1930s, when the price of meat was far lower relative to that of milk, partly because "everyone kept animals" and partly because there was far less demand for meat in what was a much less affluent society (Koster, 1977; Psikhogios and Papapetrou, 1984; Halstead, field notes: northern Pindos, 1983-95). The marginal value of lambs in the early 20th century dairy economy (and likewise in early 19th century Iceland; Adalsteinsson, 1991: 289) is harshly underlined by accounts of their slaughter at birth in bad years in order to save the productive ewes. Contrary to the argument of Chang and Koster, it seems that the effect of the market for tender young meat in 20th century Greece has not been to *hasten* the slaughter of lambs and kids from dairy flocks but, if anything, to delay their slaughter past the age necessary to establish lactation until they reach the minimum meat weight acceptable to the butcher.

Evidently, some recent Greek herders have specialised in milk production to the extent that their slaughtering policy for male lambs or kids approximates to the expectations of Payne's milk model. The degree to which herders specialise in milk production, and the extent to which flock management conforms to the milk model, is a function of several interacting contextual variables, notably degree of market orientation, relative value of different animal products, size of flock, and constraints of labour and pasture.

Herders who are principally dependent on the sale of animal produce to buy staple foods and other essential goods and services, tend to be dairy specialists because, although both cheese and meat now have a high market value, the recurrent income from milking their ewes or does exceeds the non-recurrent income from slaughtering their lambs or kids. They slaughter their lambs or kids young in order to release milk for human consumption and to take advantage of the high price of suckling young. Dairy specialists, dependent on the sale of milk for subsistence, run large flocks to ensure an absolute level of production sufficient to maintain a household. In consequence, a further strong reason for slaughtering lambs and kids early is to avoid competition with milking females for scarce pasture and herding labour. The herding of small stock is labour-intensive, particularly in the case of large dairy flocks, because milking females, unproductive animals (males, barren and yearling females) and any weaned or partly weaned young should be herded separately to make the best use of different qualities of pasture (e.g. Campbell, 1964: 26-27; Kavadias, 1965: 89-90; Nitsiakos, 1985: 104; Koster, 1977: 198).

Herders who merely seek to meet domestic requirements for animal produce, typically aim for a more balanced supply of milk or cheese and meat, and so are less likely to sacrifice a suckling animal for the sake of a little extra milk and more likely to delay weaning and slaughter to secure a heavier carcase. A tendency to stagger slaughter, in order to secure a more continuous meat supply, also favours a more gradual pattern of mortality. Such herders tend to have small flocks, partly because only a few animals are needed to meet domestic consumption of milk and meat, and partly because expansion to sell a significant level of animal produce may well exceed the capacity of the domestic labour force (cf. Kavadias, 1965: 176; Koster, 1977: 396-97; Nitsiakos, 1985: 49-57, 85; Halstead, field notes: Assiros, 1986-95), especially where production for market involves the labour-intensive manufacture of hard cheeses with a long storage life (cf. Ryder, 1993; Teuber, 1995: 25, table 2). As long as flocks are small, however, it is relatively easy even for a child to find adequate patches of good grazing, so that neither pasture nor labour is an obstacle to delaying slaughter in accordance with the meat rather than the milk model.

In 20th century Greece, therefore, dairy specialisation and a pattern of slaughter approximating to the milk model are particularly characteristic of large-scale, market-dependent herders of sheep and goats. In 17th-19th century Ireland, cattle farmers apparently adhered even more closely to the milk model. Male calves not raised for breeding or as oxen were slaughtered in large numbers in order "that themselves may have more abundance of milk". In this case, however, the discarding of newborn bull calves was particularly prevalent among the poorer smallholders who would use all the available milk to make butter for sale, keeping only the buttermilk by-product to accompany their families' staple potatoes (Lucas, 1989: 224-26).

It could be argued, with some justification, that the slaughtering decisions of 20th century Greek shepherds and goatherds and 17th-19th century Irish cattle farmers were responses to the relative prices of dairy products and meat. Thus in 19th century Orkney, where milk was produced for home consumption and butter for the payment of rent, bull calves were killed at only a few days old because there was "no outlet for the disposal of young animals" (Firth, 1974: 118). If there had been a market for mutton, goat meat and beef but not for dairy products, then the Greek and Irish herders might well have raised lambs, kids and calves to a greater age, more compatible with Payne's meat model. Conversely, if the market economy had collapsed altogether and if, through choice or necessity, these herders had continued to be wholly or heavily dependent on livestock for subsistence, intensive dairying would have been the most productive strategy for harvesting energy from their animals (Legge, 1981a; Redding, 1981). If the risk of failure of the milk supply was high, and if neither pasture nor labour for herding was severely limiting, it might have been sensible for such herders to sacrifice some milk production and to raise as many male lambs, kids and calves as possible to adulthood, so building up a "walking bank" of meat to be consumed in a bad year. This is the strategy pursued by the recent African pastoralists, referred to by Entwistle and Grant (1989: 206), who are primarily dependent on milking their cows but also keep many male cattle alive until adulthood to be consumed (or sold!) in periods of famine (Dahl and Hjort, 1976: 166-67). If the milk supply was reliable, however, or if pasture or labour was severely limiting, a pattern of mortality which approximated to the milk mortality model might have been more likely, as in the heavily populated landscape of 17th-19th century Ireland where the poorer farmers frequently had too little fodder even to keep their few animals alive over winter (Lucas, 1989: 38).

Entwistle and Grant have suggested that prehistoric cattle will have yielded too little milk to sustain specialised dairying, but one tentative attempt to infer milk yields in 3rd millennium BC Mesopotamia may offer grounds for a more optimistic assessment. Cattle herders in the pre-Sargonic Lagash period were expected to deliver 15 litres of butter fat per cow, which is equivalent to 375 litres of milk with a 4% fat content. If suckling calves consumed half of the milk produced and if the herders did not consume a significant amount of milk or butter fat, this would imply a total lactation of 750 litres (Englund, 1995: 39), which compares not unfavourably with estimates of ca 500-1100 litres per head (including perhaps 400-500 litres consumed by the calf) for the cows of recent African pastoralists (Dahl and Hjort, 1976: 144-45).

It might also be argued that poor nutrition is likely to have exacerbated any difficulties of milk let down experienced by early dairy animals and so have enforced the dual milk-meat strategy favoured by Entwistle and Grant. Poor nutrition will also have lowered the body fat reserves of livestock, however, making meat a nutritionally unsatisfactory or even deleterious alternative to milk as a source of energy (Speth and Spielmann, 1983). In these circumstances, it is equally arguable that milk will have remained the most attractive animal-based source of energy and that low milk yields from poorly nourished ewes, does or cows would have reinforced the need to maximise the human share of the lactation. In consequence, herders might have come under considerable pressure to slaughter surplus male livestock as early as possible (thereby also conserving scarce pasture or fodder for lactating females) and to deploy the various available cultural mechanisms to establish and maintain lactation.

Studies of recent herders show that decisions on the timing of slaughter are influenced by a number of interacting variables. Under certain sets of circumstances, herders do favour milk over meat production to the extent that slaughtering approximates to Payne's milk mortality model. Precisely the same sets of circumstances are unlikely to have prevailed in the distant past: in particular, a substantial market for animal produce may not be a very ancient phenomenon. There are no convincing *a priori* reasons, however, to preclude the possibility of dairy specialisation in prehistory, and a corresponding approximation to the milk model pattern of slaughter, particularly in times and places where natural or cultural constraints on cultivation and foraging enforced heavy reliance on livestock for subsistence.

Equifinality and assemblage formation

Perhaps the most obvious sources of equifinality in archaeozoological mortality patterns are partial and biased survival and retrieval: a "milk" pattern of mortality might easily be obscured through non-survival or non-retrieval of the small and fragile remains of animals slaughtered in infancy. The potential effects of such biases must ultimately be evaluated, by looking for evidence of such destructive agents as gnawing by carnivores and by testing the effectiveness of retrieval methods, for each individual assemblage. It should be noted, however, that the deletion of infant deaths from a classic milk mortality pattern would leave an assemblage dominated by adults. Thus the many archaeozoological assemblages from prehistoric Europe dominated by juvenile or subadult deaths of domestic ruminants, and so resembling the meat model, are not most parsimoniously interpreted as milk mortality patterns obscured by partial survival and recovery.

There are also archaeozoological assemblages in which, despite the severe biases of survival and retrieval, infant remains abound. Noddle (1990: 39) has suggested that the high frequency of immature bone at neolithic Knapp of Howar on Orkney results from the removal of adult bone for tool-making, as a substitute for iron, but not all ageable body parts are suitable for tool-making and, anyway, the same pattern of mortality occurs widely on later, iron-using sites in the same region (below). A perhaps more likely way of artificially creating a milk mortality pattern is through biased sampling of sites or deposits where infant remains were discarded. The likelihood of biased sampling can be explored by analysing faunal variability at the inter- and intra-site levels.

For example, in the iron age Outer Hebrides, a concentration of cattle mortality among infants and adults is found both at the broch site of Dun Vulan (Parker Pearson *et al.*, 1996) and at the wheelhouse sites of the Udal (Finlay, 1984, cited in Parker Pearson *et al.*, 1996), Kildonan (ul-Haq, 1989; Hamshaw-Thomas, 1991), Sollas (Finlay, 1991), Baleshare and Hornish Point (Halstead, in press). Moreover, at the wheelhouse sites, this pattern of mortality recurs in contexts as varied as occupation deposits, middens and cultivation layers. Conversely, at both broch and wheelhouse sites, sheep mortality is concentrated among yearlings and adults, with a much lower level of infant deaths. Unusually, with the exception of Sollas, the possibility can be ruled out that the scarcity of infant lamb remains reflects biased retrieval, because of the intensity of sieving; likewise, differential attrition by dogs is not consistent with the higher frequency of juveniles and subadults among sheep than among cattle.

The possibility remains that juvenile or subadult cattle were slaughtered either at other unexcavated and perhaps unknown sites or off-site in contexts which are archaeologically irretrievable. At Hornish Point, a group of four pits together contained the remains of a juvenile human and substantial parts of two juvenile or subadult cattle (sex unknown) and of one subadult-young adult and one adult sheep (both female). The cattle had been skinned, dismembered and filleted, and their long bones cracked open to extract marrow; the sheep had at least been skinned and dismembered. The disarticulated and splintered bones had then been collected up and buried with the human remains, underlining the social or ritual significance of the funerary feast from which they presumably resulted (Barber *et al.*, 1989). Significantly, both cattle died during the period between infancy and adulthood when evidence for mortality is otherwise very scarce; likewise, one of the two sheep falls between the two peaks of mortality among yearlings and adults. Similarly, at Sollas, the construction of wheelhouse B was marked by "ritual" deposition of several animal skeletons and part-skeletons, including juvenile and subadult cattle and sheep, as well as infants and adults of both species (Finlay, 1991: fiche 3: F6 table 24). The inhumation at Hornish Point is as yet the only complete human burial known from the iron age Outer Hebrides and so is an insecure basis for generalisation, but it does raise the possibility that juvenile and subadult cattle were routinely slaughtered at the many "missing" funerary ceremonies represented on excavated sites only by isolated human bones. Alternatively, the juvenile and subadult cattle in the Hornish Point inhumation and the Sollas foundation deposits may reflect the sacrifice (economically as well as ritually) of animals which would normally have been considered too valuable for consumption, because they represented the next generation of productive adults. Their slaughter may have been a "special gesture of negation" (I. Lewis, 1963, cited in Dahl and Hjort, 1976: 161), made special by the fact that cattle normally died in infancy or adulthood, and only rarely as juveniles or subadults. On present evidence, at least, the most parsimonious interpretation is that cattle mortality in the iron age Outer Hebrides was indeed concentrated among infants and mature adults.

Even if abundant infant remains do represent heavy infant mortality, a further source of equifinality remains to be considered: these deaths might represent heavy *natural* infant mortality (e.g. Ryder, 1993: 18) rather than deliberate slaughter. The distinction might not be critical if lactating females which lost their infant offspring through natural death were likely to be milked anyway (Ryder, 1993: 18), although early deaths might cause problems with milk let down - particularly if infant mortality was partly attributable to the poor nutritional state of the adult females (above). Natural and anthropogenic causes for infant mortality may be difficult to distinguish archaeozoologically. The analysis of butchery traces or depositional patterns is of little avail, because natural deaths might be consumed, while deliberately culled infants might be "cast out to be eaten by Crowes and Wolves" as in 17th century Ireland (Lucas, 1989: 225).

Consideration of the geographical and temporal distribution of archaeozoological examples of a milk mortality pattern, however, cautions against wholesale explanation in terms of natural infant mortality. In cattle assemblages from the Swiss Alpine Foreland, mortality more or less similar to the milk model at neolithic settlements contrasts with a meat pattern at bronze age sites (Legge, 1981a; also Becker, 1981; Jacomet and Schibler, 1985; Halstead, 1989). This decline over time in calf mortality could possibly be explained in terms of an improvement in the nutritional condition of breeding cows, resulting in turn from the increasing availability of pasture with progressive forest clearance (cf. Higham, 1967), but the *number* of cattle kept in successive periods and the quality and quantity of winter fodder provided are equally critical determinants of nutrition (cf. Behre and Jacomet, 1991: 84-85). Moreover, while the more selective grazing habit of sheep is advantageous during periods of scarce pasture, the larger size of cattle better equips them to tolerate a diet of low quality (cf. Bell, 1971). Winter malnutrition might, therefore, be expected to affect sheep as well as cattle. At these neolithic sites, however, sheep deaths occur through much of the first year (Halstead, 1989), suggesting that the main cause of ovine mortality was not natural deaths during the season of scarcity but gradual deliberate culling.

In a number of archaeozoological assemblages from the North Atlantic, ranging in date from the Neolithic to the historic period, the ageable remains of cattle approximate to the milk mortality model, while those of sheep are usually closer to the meat mortality model. In addition to the iron age sites in the Outer Hebrides discussed above, these contrasting patterns of mortality in cattle and sheep recur more or less clearly in the historical period in the Outer Hebrides (Serjeantson, nd), in neolithic (Legge, 1981b: 180; Noddle, 1983) and iron age Orkney (Smith, 1994), in Norse Shetland at both the southern estate farm of Jarlshof and the small northern farmstead of Sandwick (Bigelow, 1992), and in Norse Greenland on sites in both the main Eastern Settlement and the smaller Western Settlement more marginal to herding (McGovern, 1992). The same contrast may be reflected in the sparse mortality data from Norse Birsay (Rackham, 1996) and from pre-Norse and Norse Saevar Howe (Rowley-Conwy, 1983) in Orkney. Also in Orkney, cattle mortality at iron age Warebeth Broch (no infant, few juvenile and many adult deaths; Sellar, 1989) appears to diverge from this picture, but *might* represent a milk pattern altered by taphonomic loss of infants; and at neolithic Pierowall Quarry (McCormick, 1984) and pre-Norse and Norse Buckquoy (Noddle, 1976-77), coarse ageing of young deaths obscures the issue. In the Inner Hebrides at the iron age broch of Dun Mor Vaul, cattle mortality is more clearly atypical (few newborn, several juvenile-subadult, and no adult deaths; Noddle, 1974), but even here lack of detail on the distinction between "newborn" and "juvenile" leaves some room for ambiguity. Over such a wide chronological and geographical range, including sites of both low and high status, it is questionable whether cattle can normally have been more vulnerable than sheep to infant mortality, especially since cattle are much larger and so generally more resilient to both disease and malnutrition (e.g. Dahl and Hjort, 1976: 230-31). Especially in winter, a cow might struggle to find a sufficient quantity and quality of graze or browse in degraded pasture adequate for a smaller sheep (Grant *et al.*, 1987: 1000; Hodgson *et al.*, 1991: 222; also Darling, 1945: 117) but, as noted above, such problems are a product of cultural decisions on stocking densities as well as of climatic constraints on plant growth (e.g. Handley, 1953: 68-69; Fenton, 1978: 428).

The strongest evidence for heavy natural infant mortality comes from the Norse to early modern site of Svalbard in Iceland (Amorosi, 1992), where archaeozoologically attested infant mortality among *sheep* fluctuates between ca 1% and 6% during the 11th-14th centuries AD, but climbs to nearly 18% in the 17th-18th centuries, when worsening climate is recorded historically as causing heavy losses at lambing time (Amorosi, 1992: 127). At the same time, however, infant mortality among cattle *drops* from ca 25-45% in the earlier periods to ca 15% in the 17th-18th centuries, suggesting that increasing natural infant mortality as a result of cold and wet weather in spring is, at best, only part of the story.

A further complicating variable in natural infant mortality is the stalling of young animals. In hardy primitive breeds, at least, infant mortality tends to be heavier when stock are stalled indoors for lengthy periods of time, because of the increased risk of spreading any infections (H. Sangster, pers. comm.). If cattle were overwintered indoors and sheep outdoors, the relative scarcity of infant lamb remains archaeozoologically might reflect both a lower risk of infection outside the byre and a greater likelihood of any deaths taking place off-site. Stalling and stall-feeding are amenable to investigation in a number of ways (e.g. Bigelow, 1987; Rasmussen, 1993). In the case of iron age Baleshare, in the Outer Hebrides, rare finds of shed deciduous teeth with eroded roots perhaps imply the stalling on-site (cf. Helmer, 1984: 44) of both live cattle (3 cases) and live sheep (1 or 2 cases). The deciduous teeth in question, the fourth mandibular premolars, should be shed at about 21-24 months in sheep and 28-36 months in cattle (Silver, 1969; Payne, 1984), which in each case overlaps with the period when young females might be stalled for lambing or calving. For Baleshare, at least, there is as yet no evidence that a particularly high level of infant mortality in cattle is attributable to infections spreading among stalled animals.

In recent centuries in northern Scotland, cattle have indeed tended to be stalled over winter and sheep to be left outdoors (e.g. Firth, 1974; Fenton, 1978: 428, 446): partly because the smaller and more selectively feeding sheep can thrive on pasture too short for cattle (above), while stalling is the most convenient way to provide supplementary winter fodder to cattle (I. Mainland, pers. comm.); partly because trampling by the heavier cattle may damage pasture in wet weather (H. Sangster, pers. comm.); and partly perhaps because the larger and more slow growing cattle represented a more valuable asset (I. Mainland, pers.

comm.). The contrasting approach to stalling and stall-feeding cannot be divorced from divergent management goals, however, with cattle rather than sheep being the main source of milk (e.g. Fenton, 1978, 1987: 151-52). For example, on a Shetland croft in the 1930s, when cattle were raised as a source of milk and sheep as a source of wool and meat, regular stall-feeding was reserved for milking cows and their young replacements and for young, growing sheep; breeding ewes, which were not milked, foraged outdoors and were only given fodder in bad weather (M. Cameron, pers. comm.). Because of the importance of winter shelter and stall-feeding (with attendant risks of infectious disease among calves) to the milk yields of adult cows, therefore, heavy *natural* infant mortality might be an indirect reflection of dairying.

The interpretation of archaeozoological mortality patterns poses complex problems of equifinality, but biased survival and retrieval are likely to obscure rather than create a milk mortality pattern. Such a pattern could be an artefact of biased sampling of contexts or sites, coupled with marked spatial variability in the slaughter or deposition of carcases of particular ages, but this possibility can be evaluated by comparative analysis at the intra- and inter-site levels. Slaughter and natural deaths during infancy are not easy to distinguish, but the recurrent contrast on North Atlantic sites of neolithic to medieval date between high mortality among infant calves and low mortality among infant lambs is somewhat at odds with the generally greater resilience of the larger animal to cold, poor nutrition and disease. Natural infant mortality among calves, associated with greater winter stalling for cattle than sheep, is difficult to rule out definitively on present evidence, but should be amenable to investigation in the future. The alternative interpretation is that infant cattle were selectively culled at all or many of these sites and, for recent centuries, this is consistent with documentary evidence that cattle were intensively milked and sheep raised mainly for meat and wool (e.g. Fenton, 1978; Shaw, 1980: 108-18; also McGovern, 1992: 201).

Conclusions

This review has explored issues of uniformitarianism, optimality and equifinality in the use of mortality patterns to identify husbandry goals, and more particularly dairying, in human management of domestic livestock. Whether or not primitive livestock will let down milk in the absence of their offspring is a more complex uniformitarian problem than some recent debate implies. Even modern dairy breeds may experience difficulties in letting down milk, but the risk of such problems can be greatly reduced by good housing and feeding or by deferring the removal of the offspring until lactation is securely established. Any problems which do arise can often be tackled by measures such as fostering, massaging the udder, or "cow-blowing". The correct uniformitarian assumption is probably not that prehistoric cows, sheep and goats will or will not have let down milk, but that the ease of let down will have varied, partly in response to the quality of management. Thus archaeological evidence for the stall-feeding of livestock over winter in neolithic Switzerland (e.g. Rasmussen, 1989, 1993) may lend support to Legge's inference that the high infant mortality among cattle will have enhanced the availability of milk for human consumption. Under poor conditions of housing and nutrition, early removal of offspring is more likely to cause problems with let down, but the need to secure sole use of the lactation may be commensurately greater and let down can be eased by practices such as "cow-blowing", which is documented from the 3rd millennium BC. The artificial stimulation of let down can be very time-consuming and so is perhaps more likely to be attempted with small numbers of livestock than with large herds, but the experiences of recent herders suggest that the period of suckling needed to establish lactation more naturally is, again depending on quality of housing and feeding, on the order of only a few days or a few weeks, and not the duration of the lactation as McCormick argues. Slaughter during the first few weeks of life is thus more likely than the concentration of deaths at the end of the lactation period to have maximised the availability of milk for human consumption under pre-modern conditions of husbandry.

Some authors have argued that, contrary to the optimising assumptions underpinning the milk mortality model, herders are unlikely to "sacrifice" young calves, lambs or kids to maximise the flow of milk for human use. Such sacrifices are made by 20th century Greek shepherds and goatherds, however, and were made by 17th-19th century Irish cattle farmers, in each case with the explicit purpose of increasing the yields from milking. Among Greek herders, early slaughter is particularly characteristic of large-scale dairy specialists; in Ireland, it was most prevalent among small-holders. Significantly, both groups are or were dependent for their subsistence on the sale of dairy produce. Conversely, the slaughter of older lambs or kids is more characteristic of small-scale Greek herders, producing for domestic consumption alone, or for the household and a modest level of sales; in Ireland, the slaughter of older calves was presumably prevalent among richer farmers less dependent on maximising milk yields. At least in later medieval faunal assemblages from the North Atlantic, mortality approximating to the milk model may similarly reflect reliance on dairy produce for exchange (cf. Bigelow, 1992).

Given the small size and fragility of infant bones and teeth, the common biases of survival and retrieval are more likely to obscure than create a milk pattern of mortality in an archaeozoological assemblage. The biased sampling of sites or deposits, in which infant animal remains have been discarded, is another potential source of equifinality, which can be explored by comparison of different sites and different contexts. For example, the recurrence of heavy infant mortality in North Atlantic cattle assemblages, across a wide range of locations, dates, types of site and types of deposit, is less easily explained in terms of sampling bias than of natural mortality or deliberate slaughter. The risks of natural mortality are complex, in that shelter and good nutrition should enhance infant survival, but stalling may also facilitate the transmission of disease and so have the opposite effect; stalling may also increase the chances that natural infant deaths will be disposed of on-site and so be archaeologically visible. Overall, the incidence of natural infant mortality should have varied in both time and space, in response to fluctuations in weather, fodder and diseases, with sheep tending overall to be more vulnerable than the larger and more resilient cattle. In almost all assemblages where mortality among cattle approximates to the milk model, however, sheep exhibit a much lower level of infant mortality and tend towards a meat exploitation pattern. Unless cattle were normally stall-fed and sheep left outdoors overwinter (perhaps because cattle were the principal dairy animal!), this suggests that deliberate slaughter rather than natural mortality was the main cause of early cattle deaths. The fact that sheep regularly exhibit a much higher level of juvenile (as opposed to infant) mortality than cattle also implies that the contrast between the two species reflects a fundamental divergence of management strategy rather than a difference merely in stalling arrangements. In future, with more detailed comparative analysis of depositional processes (e.g. Parker Pearson *et al.*, 1996) and with more attention to other contextual factors such as the diet and housing of livestock of different species and ages (cf. Mainland, 1995a, 1995b; Buckland and Sadler, 1991; Buckland *et al.*, 1993), it should be possible to resolve these problems of equifinality with greater clarity and greater confidence.

Even if biased sampling and natural infant mortality can be discounted, mortality approximating to the milk model does not prove intensive dairying nor even indicate that livestock was milked. Mortality models are measures of possible rather than actual production and so heavy infant mortality only indicates that herd management maximised the potential for dairying. Ultimately, interpretation of mortality data should be "tested" against analyses of bone chemistry, although the relationship between milking and either calcium depletion or strontium enrichment of bone is complex and again depends, *inter alia*, on nutrition: moderate milking of a poorly-fed animal may have more impact on bone chemistry than intensive milking of a well-fed individual. For this reason and for reasons of cost, the analysis of mortality patterns is likely to remain in the forefront of attempts to identify stock husbandry goals.

A systematic survey and interpretation of archaeozoological evidence for milking in prehistoric Europe lies beyond the scope of this review, but the evidence reviewed above does favour the argument that intensive dairying may be of considerable antiquity in Europe (Legge, 1981a, 1981b). It may then be significant that, on the North Atlantic islands, at early farming sites in Switzerland, and at Grimes Graves on the Breckland of Eastern England, where a milk mortality pattern has been found in cattle, opportunities for crop production will have been restricted by a short and poor growing season or by poor soils (Legge, 1981a; Halstead, 1989). This raises the intriguing possibility that, just as intensive dairying for the *sale* of milk products has historically been a vital subsistence strategy of stock farmers in marginal ecological or social situations, so likewise dairying for *consumption* was a marginal adaptation in prehistory.

The critical conclusion at this juncture, however, is that mortality models, applied with due circumspection and attention to available contextual evidence, have a valid and vital role to play in future archaeozoological investigation of stock husbandry goals. More particularly, as Payne and Legge have argued (and contrary to the assertions of Clutton-Brock and McCormick), the potential for intensive milking is maximised by heavy slaughter of surplus infants, coupled with a sufficiently high standard of housing and nutrition among adult females to ensure that the lactation is not adversely affected. The absence of mortality conforming to the milk model is not evidence against the practice of *milking*, but only mortality approximating to the milk model can be adduced as evidence in favour of *intensive dairying*.

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