9th ICAZ Conference, Durham 2002
Colonisation, Migration, and Marginal Areas, (ed. M. Mondini, S. Muñoz & S. Wickler) pp. 74–85

10. Identifying Dietary Stress in Marginal Environments: Bone Fats, Optimal Foraging Theory and the Seasonal Round

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The importance of fat in the diet is outlined and the importance of bones as a reliable source of fat is explained. Different patterns of bone marrow and grease exploitation are discussed with particular reference to marginal environments and how levels of exploitation will be related to levels of dietary stress. The possible role of Optimal Foraging Theory in addressing this issue is outlined and adaptations of Marginal Value Theorem and Diet Breadth specific to bone fat exploitation are put forward and described. The methodologies for studying patterns of bone fat exploitation within archaeological assemblages are outlined and four example applications relating to Norse and Paleo-Eskimo Greenland, Norse Iceland and Middle Neolithic Gotland are used to illustrate what these methods can show. These case studies are discussed with specific reference to identifying dietary stress in marginal environments and the role of seasonality to this issue.

Introduction

The importance of fat has often been underestimated in zooarchaeological studies, with more attention being paid to the acquisition of meat. This is not because information on the essential role that fats play in the diet has not been documented or because the subject has lacked academic champions, but is probably more related to Western society's subconsciously negative view of fat in terms of both health and body image. This negative view of fat is, of course, a relatively modern phenomenon that really only gained momentum within the 1960's (Beardsworth and Keil 1997, 176).

In terms of energy, fat can provide 225% the number of calories compared to equal quantities of either carbohydrate or protein (Mead *et al.* 1986; Erasmus 1986). Within subsistence economies, therefore, sources of fat are likely to be very highly valued. Within economically marginal environments operating marginal subsistence economies the full exploitation of available fat resources may make the difference between the viability of that society and starvation. In dietary terms, fat becomes an even more important resource when reliable sources of carbohydrate are absent. Speth (1983; 1987; 1991) and Speth and Spielmann (1983) made a highly significant contribution to archaeologists' understanding of this issue with their work on the body's reaction to high protein diets. If the body is reliant upon protein for almost all its energy, amino acids are broken down to meet energy needs rather than fulfilling their normal function of replenishing body protein. In severe cases, existing muscle protein will also be broken down. Very high protein diets are, therefore, very dangerous. Carbohydrates are best at averting this metabolic problem (Speth and Spielmann 1983, 14), but in many environmental and economic regimes, sources of carbohydrate are almost totally absent and, therefore, an adequate supply of dietary fat becomes essential. Speth and Spielmann (1983, 4) cite several ethnographic and historical examples of hunters' practical awareness of this problem. Another important dietary issue is that small quantities of certain types of fat are required within the diet for the proper functioning of the body. These are referred to as 'essential fatty acids' (Erasmus 1986; Mead *et al.* 1986). Furthermore, fats can be important in the supply of lipid-soluble vitamins such as A, D, E, and K (Mead *et al.* 1986, 459). So, it can be clearly demonstrated that the levels of fat exploitation within subsistence economies can be critical and all the more critical in economies dependant upon animal products (hunting or pastoral economies) due to the limited availability of carbohydrate under such regimes. The more marginal the economy, in terms of meeting calorific needs, the more essential fat becomes.

Dietary fat can be obtained from a number of sources. Plant foods, particularly nuts, can provide dietary fats, but much larger quantities are available from animal products. Fat can be found within meat and in quite rich quantities in dairy products, but also in almost pure form in the depot fats to be found under the skin (adipose fat) and within bones (marrow fat and bone grease). If one is to study the exploitation of animal fats archaeologically, the best option is to concentrate upon bone fats. There are a number of reasons for this.

Firstly, bones frequently survive archaeologically and in order to exploit bone fats the bones need to be deliberately broken into. The exploitation of bone fats, therefore, leaves direct archaeological evidence. To exploit bone marrow, one needs to access the medullary cavity to be found in long-bone shafts and a few other elements. To exploit bone grease, one must break up bones into pieces and render them. The detailed patterns created by bone marrow and grease exploitation and how to recognise them are discussed in more detail below.

It is true that the presence of the bones also implies the presence of quantities of meat and adipose fats as well, but there is no direct evidence for their exploitation. In particular, it will not be clear just how much fat would have been present. The amount of adipose and meat fats to be found on an animal varies wildly in relation to season, health and life cycle. If one takes red deer (*Cervus elaphus*) as an example, though this point applies to most mammals, levels of 'rump fat' can be almost negligible for large parts of the year but there can be quite substantial reserves built up in particular seasons. A further complication is that the pattern is very different for males and females (Mitchell, McCowan and Nicholson 1976; Clutton-Brock and Albon 1989). Archaeological animal bone assemblages might also indicate the exploitation of animals for dairy products. This is a proxy indicator of the exploitation of animal fats, but a rather indirect and difficult to quantify one. The exploitation of bone fats themselves can be far more readily quantified by direct analysis.

The second reason for concentrating upon bone fats relates back to extreme variation in quantities of depot fats that can be seen in animals. Animals store depot fats as an energy reserve. When they need to call upon this reserve, they call upon some depots in preference to others. Within this 'fat-mobilization sequence', bone fats are usually the last reserve to be called upon (Cheatum 1949; Brookes *et al.* 1977; Peterson *et al.* 1982; Davis *et al.* 1987). In fact, in many cases, the animal could have died from starvation but still have significant levels of fat within its bones (Peterson *et al.* 1982, 550). Bones are, therefore, a very reliable source of fat when animals have little other fat in their bodies. Levels of fat within bones can change with the condition of animals, but not as drastically as other depots and only in a serious way when the animal is in a very poor state. As well as being a good source of fat to target, amounts of bone fat available can be more easily quantified than other fat sources. This can be done by employing indices calculated using modern specimens (see below for further discussion) or simply by quantification of amounts of archaeological bone present. Medullary cavities, that would have been filled with marrow fat, could, in theory, actually be measured. Brink (1997) found, during experimental studies of bison, that dry bone mass was an accurate predictor of an element's bone grease yield.

So far we have established that bones would be sort after as a reliable source of fat, that the amount of fat available is more quantifiable than other sources and that the exploitation of bone fats is more directly demonstrable within archaeological assemblages. The final, and key, reason for studying bone fat exploitation is that there is a clear rank order of utility within the resource. Different elements contain different amounts of marrow and grease. Marrow is easily exploited, whilst bone grease exploitation requires far more effort. There is a range of utility from bones with large medullary cavities, filled with fat, that can be accessed and consumed within seconds, to bones that contain very little fat but require much effort to obtain it. If one can successfully assess the extent to which bone fats are being exploited, one might have a very good indicator of the relative needs of people within different economies and environments. Given that bone fats are such an important resource, and their exploitation could be a matter of life and death, this type of study could be key in identifying economic and dietary stress and help us understand more about the palaeoeconomics of marginal environments.

Patterns of Bone Marrow and Grease Exploitation

The exploitation of bone marrow as a food is very well known and accounts of its use can be found within ethnographic accounts of a very wide range of peoples in very varied environments. For example, good descriptions of the use of bone marrow can be found in accounts of Inuit peoples (*e.g.* Binford 1978), Native Americans (*e.g.* Little Bear 1982), the peoples of Siberia (Levin and Potapov 1964), the Hadza of Tanzania (O'Connell and Hawkes 1988), the Kalahari San (Yellen 1991; Kent 1993) and Alyawara of Australia (O'Connell and Marshall 1989). One could probably obtain a decent account of the use of bone marrow from an elderly person in almost any culture in any part of the world. Bone marrow is found principally in the long bones, but also in very small cavities in other appendicular elements like phalanges and in larger quantities in the mandible. The pattern associated with its exploitation is simple; the bone's medullary cavity will have been deliberately broken into, whilst the bone is still in a relatively fresh condition (for detailed discussion see Outram 1998; 2002).

'Bone grease' refers to bone fat which is chemically much like the fat in medullary cavities but is trapped

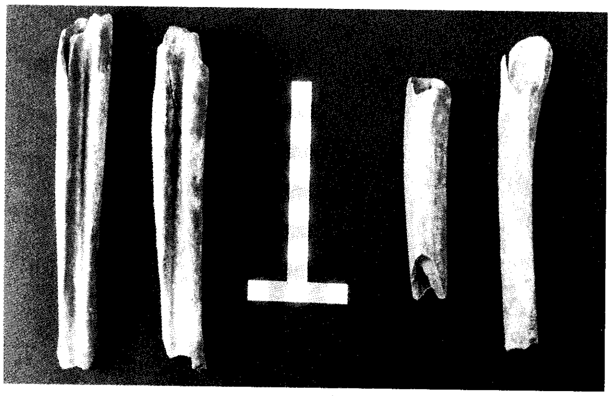

Fig. 1. Caribou shaft cylinders from tibia (right) and metatarsals (left) from the Paleo-Eskimo site of Itivnera, Western Greenland (scale in 1cm divisions).

within the structure of the bone. The articular ends of long bones and almost all the axial skeleton are made up of spongy or 'cancellous' bone that contains much fat within its structure. This fat can only be easily extracted by breaking up cancellous bone into small pieces and boiling the pieces to melt the fat out. The fat will come to the surface of the water where it can be solidified as it cools and removed. A very detailed description of this process can be found in Binford's (1978) account of the Nunamiut, but there are also good accounts of very similar practices by the Loucheux Indians (Leechman 1951; 1954) and the Hidatsa (Wilson 1924). According to Binford (1978), the processing of bone for grease can be on a fairly industrial scale. Long bone ends and axial elements are saved up in piles until there are sufficient to make rendering worthwhile. Long bones are often broken next to the articulation at both the proximal and distal ends so that the marrow can be poked out for consumption and the ends saved up. This can produce many very deliberately created long bone cylinders. Such cylinders are present in very large numbers at the Paleo-Eskimo site of Itivnera in Greenland (Møhl 1972; Outram 1998; 1999), which can be seen pictured in Fig. 1. The axial and articular units are then comminuted into small pieces and boiled. This process is incredibly labour intensive, especially when compared to the amount of fat that can be obtained from marrow cavities following a single blow. The pattern created by this activity is fairly distinctive, in terms of what gets broken up into small pieces and what remains relatively unfragmented. Detailed discussion of these patterns can be found in Outram (1998; 2001a).

An issue of great importance is that there is a definite rank order to the exploitation of bone fat resources. With regard to marrow bones, it is clear that some bones have larger marrow cavities than others and the degree to which one bothers with the lesser resources is very dependent upon people's needs at the time. There is a traditional saying amongst the Nunamiut that says that "the wolf moves when he hears the Eskimo breaking mandible for marrow" (Binford 1978, 150). This is, in fact, well backed up by observations of the Nunamiut bone fat exploitation habits. Using Binford's records of Nunamiut marrow processing decisions and processing efficiencies, Jones and Metcalfe (1988, 422) made the calculation that it appears that the Nunamiut were, under normal conditions, unwilling to process elements that yielded less that 500 kcal/hr. This just excludes the mandible. The yield rate of elements and this cut-off point are displayed in Fig. 2.

With regard to bone grease, it is clear that different elements will contain different levels of grease, but there are other issues related to the rank order of grease production. Blood is created within bone marrow and bone marrow that contains a lot of blood is often referred to as red marrow. Red marrow contains less fat and more protein. In adult animals red marrow is concentrated within the cancellous tissues of the skull, ribs and vertebrae, whilst most of the marrow in long bones is principally fat (Rixson 2000, 11). This makes the long bone ends better for bone grease production than axial elements. This distinction can be seen in the ethnographic accounts. Binford (1978, 32) notes that appendicular and axial elements are stored and processed separately and there is a preference for the use of the appendicular bone grease. This distinction is backed up by Wilson (1924), with reference to the Hidatsa. Binford (1978, 146) also notes that in times of desperation, the Nunamiut also resort to the rendering of dense shaft fragments, which yield very little indeed.

The implication of these patterns is clear. The choices people make about which types of bone to process and how much of them to process can tell us much about the state of their subsistence economy and indicate whether they are suffering from dietary stress or not. If evidence of such activities is preserved archaeologically and can be identified and quantified, then there is great potential for understanding the extent of subsistence stress amongst people apparently living in marginal environments.

Using Optimal Foraging Theory as a Framework

The above discussion of resource ranking implies that something akin to optimal foraging theory (OFT) needs to be applied to the study of bone grease exploitation. Below is a discussion of how bone fat exploitation decisions might fit in with existent OFT models.

There are two selective processes that need to be considered with regard to bone fat exploitation strategies. Firstly, if the animal or animals to be exploited have been killed some distance from the site where fat processing will take place, one has to consider element transport choices. One needs to understand which fat resources arrived at the site in order to understand the selection for fat processing. Also, the transport decisions themselves might relate to economic strategy (see Binford 1978).

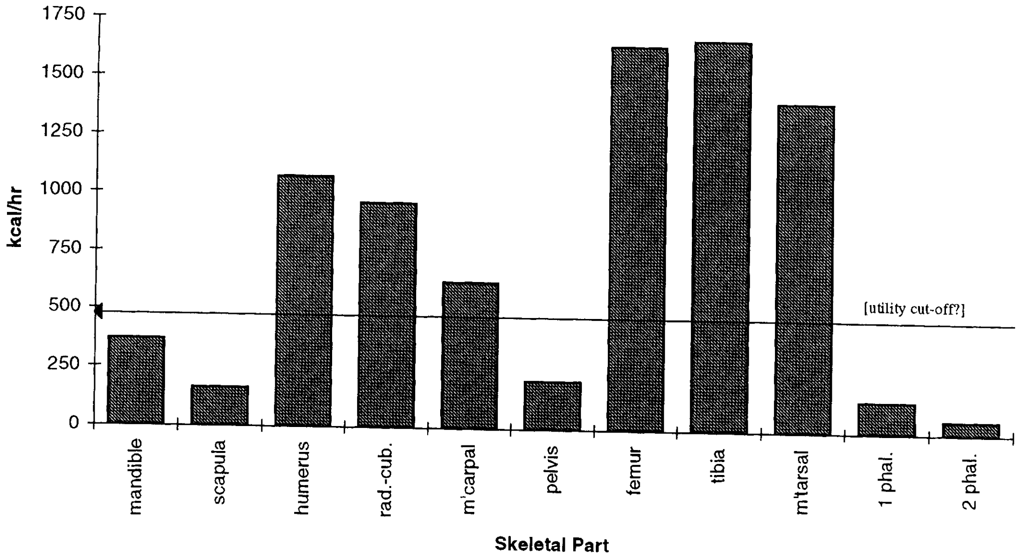

Fig. 2. A graph to show marrow extraction efficiencies from different caribou skeletal parts by the Nunamiut people and the processing threshold (values derived from Jones and Metcalfe 1988, table 3).

This is likely to apply much more to hunter/gatherer societies than to farming ones, where animals are more likely to be slaughtered where they are needed. There has been much discussion in the literature of differential skeletal part transport and the very many considerations that need to be taken into account when considering it (*e.g.* Binford 1978; Metcalfe and Jones 1988; O'Connell, Hawks and Blurton Jones 1990; Outram 2001b). Below, element transport choices will be modelled within the framework of an adaptation of Marginal Value Theorem (MVT).

Marginal Value Theorem (Charnov 1976) was originally created within the field of ecology to model an organism's use of different patches of resource, but it can easily be applied to human behaviour as well. Anyone with experience of collecting berries from wild hedgerows will understand this model very well. A berry collector will stop at a bush (or patch) and collect berries for a period of time. They are likely to leave that patch before all the berries on that bush are used up. This is because it gets harder and harder to find the berries on that bush and the rate of return gets lower and lower. At some point, one makes the judgement that it is probably better to go and find another bush. If there are lots of good bushes about, this point is likely to come sooner rather than later, but if bushes themselves are hard to find, one may stay longer at the present bush. MVT is all about predicting the optimal point at which one should move from one patch of resource to another.

A graphical solution for MVT can be seen in Fig. 3 (after Bettinger 1991, fig. 4.3). One can see that the energy acquired in the patch (expressed as a rate of return, usually energy/time) drops off as more time is spent at the patch. The dotted line represents the overall average rate of energy return of the environment, taking into account travel time, search time and handling time. If the overall return rate is higher than that from the present patch, then one would be better off leaving and looking for another patch. Where the straight overall return line touches the curved patch line is the optimum time to leave. The distance along the x-axis from the origin to the departure time is the optimal foraging time. The distance in the opposite direction along the x-axis from the origin, to the intersection of the axis by overall return line, represents the time that it is worth travelling to find other resources. The better the environment is, the steeper the overall line will be. It will touch the patch curve earlier and create a shorter optimal foraging time and a shorter acceptable travel time. If the environment is poorer, the reverse is true.

This model can easily be adapted to apply to the hunting of an animal and the exploitation of its carcass. A graphical solution for the adapted MVT can be seen in Fig. 4. This works in a very similar way. In this case the curved line represents a particular kill and the rate of return one can get from it as one field-butchers it for transport, selecting to take the highest return elements first (like picking the easiest to find berries). The dotted line represents the overall return for the environment in terms of finding, killing and transporting another animal. The same rules apply. The relationship between these two lines gives one the acceptable hunting time and optimal butchery/transport time. This time the model will dictate how many and which bones get transported back to the site. This model, however, also sees the introduction of the notion of total need. Infinite need is assumed within the standard MVT model, as the type of resource being dealt with is small and slowly accrued. Hunting can be different if a very large prey is captured. Total need might be met from the one carcass, if storage

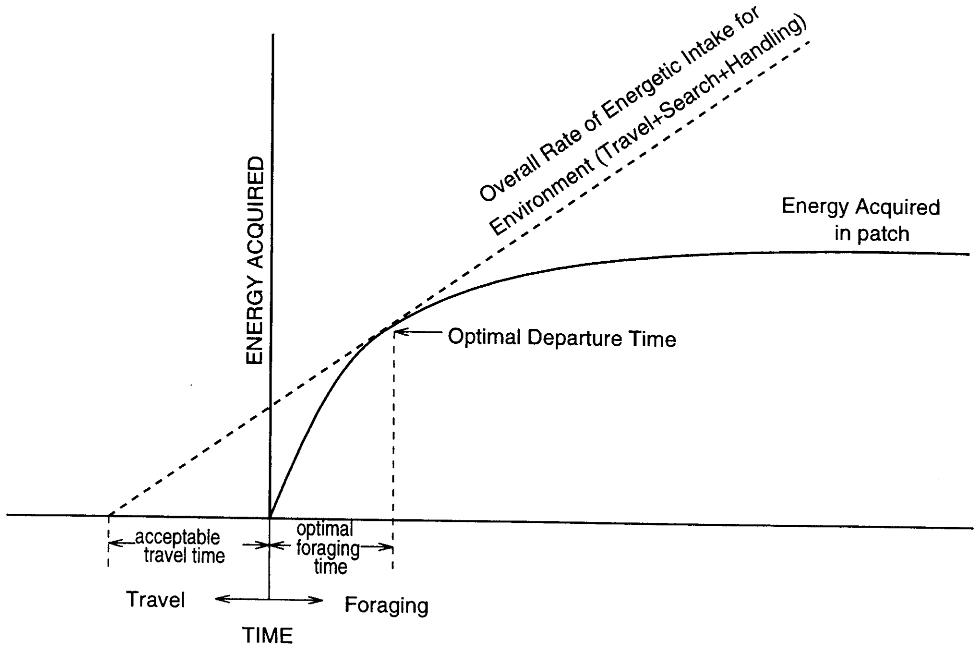

Fig. 3. A visual representation of Marginal Value Theorem (after Bettinger 1991, fig. 4.3)

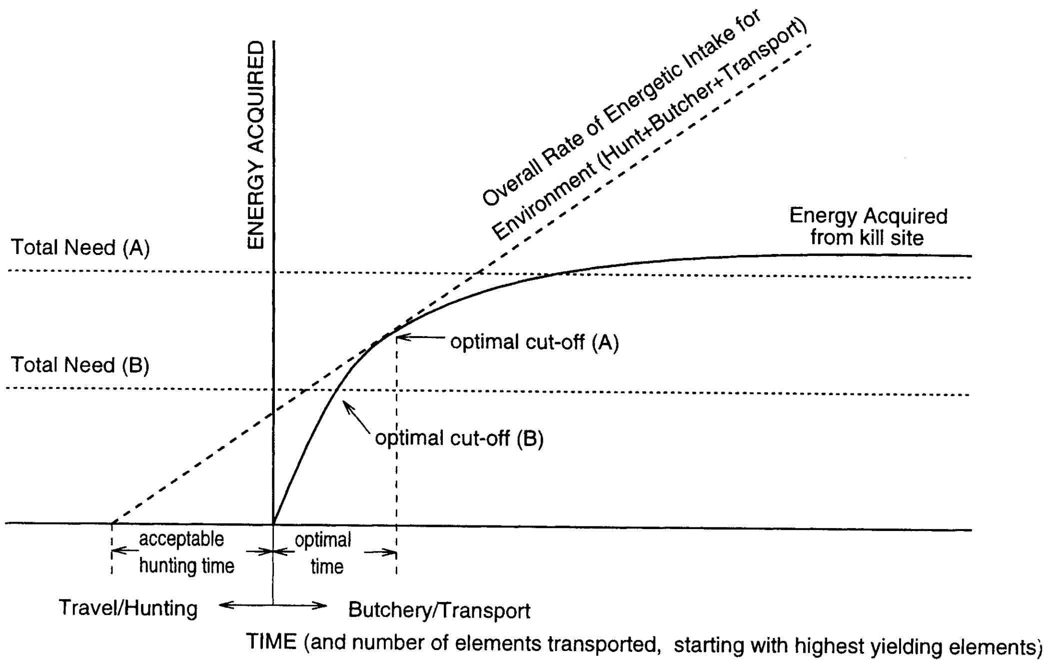

Fig. 4. A visual representation of Marginal Value Theorem as adapted to the consideration of hunters' element transport choices.

is not possible. If total need is reached before the intersection of the two lines, as in the case of total need B, the optimal cut-off will be earlier (cut-off point B), but if total need is higher (A) then normal rules apply.

Bettinger (1991, 108) suggested that element transport choices could be dictated by the theory of Diet Breadth. This is certainly true, but the adapted MVT model presented in Fig. 4 is possibly a more powerful tool because it effectively combines MVT with Diet Breadth. The model assumes that higher-ranking elements, in terms of energetic intake, will be exploited before lower ones. This assumption underlies the Diet Breadth Model (see below),

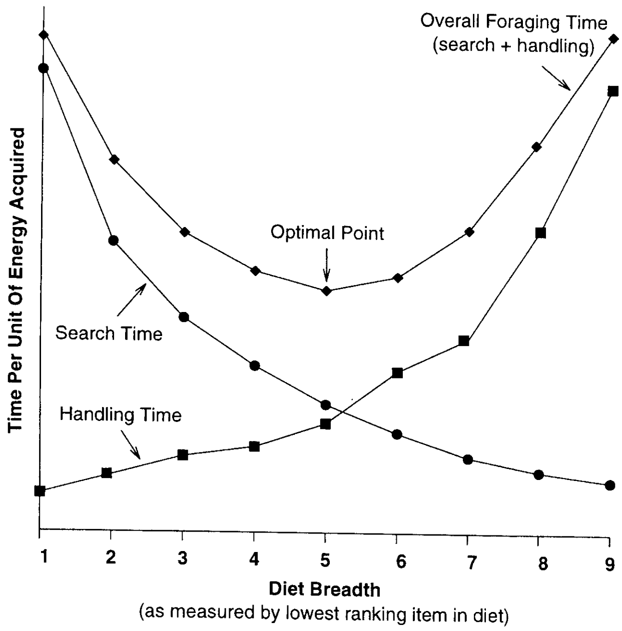

Fig. 5. A visual representation of the Diet Breadth Model (after Bettinger 1991, fig. 4.1).

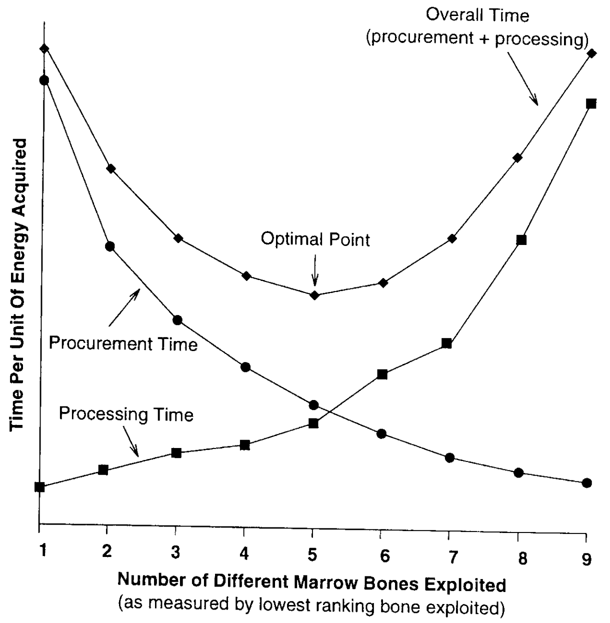

Fig. 6. A visual representation of the Diet Breadth Model as adapted to the consideration of bone fat exploitation choices.

but is not normally present in MVT because the units being collected are normally assumed to be equal in value. In the adapted MVT model, both the rank order of exploitation and the optimal cut-off point are predicted.

Diet Breadth comes into its own in considering the choices people must make regarding which elements to process for their fat content. The Diet Breadth theory (MacArthur and Pianka 1966) can be seen graphically displayed in Fig. 5 (after Bettinger 1991, fig. 4.1). Dietary items are arranged along the x-axis in decreasing order of the food value of that item. This food value represents the energy yield divided by the handling time. A high-ranking item would be something like a large soft fruit, rich in sugar and easy to handle, whilst a low-ranking item might be something like a very small nut in a very hard shell. It would, in an ideal world, be best if one could just exploit the very high-ranking items, but this is where the search time comes in. The more items there are in one's diet, the greater the chance of encountering them whilst searching for food. Diet Breadth suggests the best balance between ease of handling and ease of searching.

In the graph (Fig. 5), it can be seen that as items are added to the diet (lower and lower ranking ones) the amount of handling time goes up, but at the same time the time needed to procure items goes down. The optimal number of items to include in the diet is then determined by where the two lines cross. Alternatively, if the two factors are combined into one line representing total time spent per unit of energy gained, the optimal point is where the time spent per unit of energy is lowest. If procurement is a problem (*i.e.* a low general yield from the environment), then this point will be reached later and more low-ranking items will be included. If procurement is not a problem then the optimal point will be reached early and only highly-ranked food items will be included in the diet.

This model can easily be adapted to consider bone fat exploitation more explicitly (see Fig. 6). This time the different fat-bearing bones are put in rank order according to processing efficiency. As suggested by the above discussion of bone fat exploitation patterns, this will not simply be a list of which bones contain the most fat. Highest ranking resources will be large, easily accessed marrow cavities, then smaller cavities will follow. One then has to move down to much less efficient grease processing and start with large appendicular ends, then smaller ones, then lower quality greasy elements from the axial skeleton and, perhaps, finally attempts to extract tiny amounts of fat from long bone shaft fragments. Clearly the more different types of bone fat resources one exploits, the easier it will be to procure the raw materials. The important question is how easy is it to procure fat resources. The harder it is to procure resources of fat (and one should perhaps be thinking about sources of fat holistically, rather than just bone fat), the later the cut-off point will be in terms of the exploitation of low-ranking bone fat resources.

From the above discussion of OFT models, it is clear to see how peoples' animal processing decisions, particularly for fat resources, can be very clearly linked to the environment around them. Optimal behaviour will change depending on just how marginal the environment is. By applying OFT in this way, is one being 'environmentally determinist', as some would charge? Correctly used, OFT is not deterministic, but rather provides a measuring stick against which actual human behaviour can be compared (Foley 1985, 222; Bettinger 1991, 106). Without such a measuring stick it is very difficult to ascribe meaning to different human activities. How can one discuss the issue of marginality at all without reference to models that deal with resource availability within an environment and how people can best live in such an environment?

It is certainly true that optimal models do not determine human action, but having said that it can be argued that they can limit it. Higgs and Jarman (1975, 2) stated that "...ultimately all human culture and society is based upon and is only made possible by biological and economic viability...and however unfashionable the terms and ideas behind determinism may be, the very existence of natural laws presupposes a degree of determinism." This statement is extremely difficult to refute. People have to be able biologically to survive to have any sort of culture at all! Optimal models give us an idea of the best that can be done in a given environment, in terms of efficiency of resource exploitation. This is an upper limit that people may not necessarily adhere to. However, there is also a lower limit. People need so many calories and certain nutrients to survive. Almost by definition, in an economically marginal environment, these two limits will be close together and at the very edge of viability they are one and the same thing. One has to exploit efficiently all available resources to live. In a marginal environment, the chosen mode of economy WILL be heavily determined by that environment. As such, optimal models become highly relevant to understanding how that economy functions. Within this type of theoretical framework, the study of bone fat exploitation patterns could represent a powerful tool for assessing marginality and levels of dietary stress.

Methods

In order to understand the exploitation of bone fats, within a theoretical framework like the one presented above, one has to have some understanding of the rank order of elements, and portions of elements, in terms of their fat yield and processing efficiency. Lewis Binford (1978) revolutionised this field of study in two ways. Firstly, he created indices of fat utility (both for marrow and grease) for the different elements of two species, sheep and caribou. Secondly, he recorded efficiencies for grease processing by the Nunamiut using traditional techniques. Jones and Metcalfe (1988) further refined and discussed these data. Whilst many food utility indices and meat utility indices have been produced since 1978, many do not refer specifically to bone fats. Some exceptions are Brink and Dawe's (1989) work on bison, Blumenschine and Madrigal's (1993) work on East African ungulates and Outram and Rowley-Conwy's (1998) work on horses. Despite the relative lack of attention given to bone fat utility in the production of indices, we now have a fair range of information on the relative yields of bone fats from sample species with different stature and locomotor characteristics. It is also extremely useful that Brink's (1997) experimental work showed that fat content is very closely correlated to dry bone mass.

In order to take this line of enquiry further, one needs to be able to assess exactly which bone resources have been exploited for their fat content, and quantify this exploitation. The development of just such an analytical protocol, for application to archaeological bone assemblages, has been the subject of much of this author's recent work. Detailed explanations of this methodology can be found in Outram (1998; 2001a; 2002) and detailed discussion of example applications of the methodology can be found in Outram (1998; 1999; in press; forthcoming). What follows is a very brief summary and should be treated as such. The method relies upon the three strands of evidence, the fragmentation levels of different types of bone, the fracture patterns within the assemblage and the holistic consideration of a wide range of taphonomic indicators.

With regard to fragmentation level, one clearly needs to consider what types of bone have been broken up with regard to their potential value as a fat resource. The method used for recording the levels of fragmentation is as follows. All fragments are included, whether identifiable or not. Whilst identification to species and element may not be possible, such fragments still carry valuable information in the form of size, fracture patterns and bone type. It is possible to tell cancellous bone from diaphysis bone on even very small fragments and such information is very important in the context of a study like this. The entire assemblage is divided into size classes (by maximum dimension). The size classes used are <20mm, 20–30mm, 30–40mm, 40–50mm, 50–60mm, 60–80mm, 80–100mm, 100+mm and part and whole bones. Whole bones clearly have not been exploited for grease at all. Part bones include bones that are not whole, but represent whole units that could have been exploited for grease but were not broken up. Part bones include entire epiphyses and complete vertebral centra.

Quantification of the size classes is by number and mass. Whilst numerical data is collected, mass data tends to be more useful because it represents actual amounts of bone present. Clearly one unbroken large bone represents the same amount of potential fat as a similar element broken into many pieces, yet the latter would be represented by many hundreds on a numerical count. By mass, both would be suitably equal. Also, as previously mentioned, Brink (1997) concluded that dry bone mass was an accurate predictor of elements' bone grease utility.

For each size class, a distinction is made between whether the bone is cancellous or cortical in nature. For large size classes, distinction is made between axial cancellous bone (other than ribs), ribs, articular bone from appendicular elements and diaphysis bone. This enables one to see, in terms of bone fat utility, which types of bone had been fragmented and to what level.

The study of fracture patterns is essential in establishing whether the fragmentation was the result of human agency and, if it was, to quantify the extent of deliberate comminution. When dynamically fractured in a fresh state, dense diaphysis bone creates a very distinctive fracture pattern. Such fractures are characterised by helical fracture lines radiating out from the point of impact. The fracture surface will form either an acute or obtuse angle to the cortical surface of the bone. This fracture surface will also tend to be smooth in texture (Johnson 1985; Morlan 1984; Outram 1998; 2001a; 2002). As bones dry out they develop small cracks that interfere with the fracture line, creating roughness or steps, hence affecting the fracture shape and surface texture. As bones lose their organic content they react differently to force. Loss of elasticity results in bones snapping in straight lines that tend to be perpendicular to the cortical surface. A largely mineralised bone will break with a straight, rough edge that is close to being at right-angles to the cortical surface.

The three criteria of fracture outline (shape), fracture angle (to cortical surface) and fracture texture (smooth or rough) can be used to characterise large assemblages of fragments in terms of the amount of deliberate fracturing of fresh bones versus levels of post-depositional breakage of dry bones (Villa and Mahieu 1991; Outram 1998; 2001a; 2002). An indexing system has been developed and tested experimentally by Outram (1998; 2002).

All diaphysis fragments of 30mm or more in length are studied for fracture type providing that preservation is good enough. For each of the three criteria, a score of 0, 1 or 2 is awarded. In broad terms, a score of 0 denotes that that criterion is consistent with fracture of a fresh bone, a score of one denotes a mixture of fresh and unfresh features (but with fresh still dominating) and 2 denotes that unfresh features are dominant. Much greater detail is available in Outram (2002). Shape, angle and roughness are all estimated by eye. This is essential to make assessments of large samples practical. Individual misjudgements will be irrelevant as the method is being employed to characterise the assemblage in general and sample sizes are large. The angle and outline characteristics are fairly easily defined, but assessment of roughness is more subjective and relies upon the analyst having a good mental template (like much zooarchaeological analysis) of the possible range.

When the scores are added together one ends up with a score from 0 to 6 for each fragment, called the Fracture Freshness Index (FFI) score (Outram 2001a; 2002). Scores of 0, 1 and 2 will represent bones broken in a relatively fresh state. Scores of 3, 4, 5 represent either bones that were broken when becoming fairly dry (unlikely to be for fat extraction) or bones which had some fresh fracture on them but were further fragmented when unfresh. A score of 6 represents a bone with no evidence of fresh fracture. The profile of scores and overall average for a sample can be displayed.

The FFI score is a very good indicator of the taphonomic history of the assemblage, but other indicators can be recorded that provide more detail and help to deal with potential problems of equifinality within the FFI. If one records whether or not a fragment has an example of an individual mineralised break it is possible to distinguish between bones that had fresh features, but then got broken when mineralized, and bones that showed no fresh or completely mineralized features, but were dry when broken (*i.e.* scores 4, 5, 6). Such completely mineralised breaks are easy to spot (on their own they would score 6). New breaks (caused by excavation or storage) can also be recorded, as the fracture surfaces will be an obviously different colour. Dynamic impact scars, created at the point of impact on a fresh bone, can also be recorded as evidence of deliberate fracture, much like bulbs of percussion on flints. If the bone cylinder was broken on an anvil, there may be a rebound scar due to the opposing force of the anvil (see Outram 2002, fig. 6.8).

Several other criteria are important for understanding the taphonomic history of the assemblage. Shaft fragments are also studied for evidence of animal gnawing and butchery (chops, cuts, polish and sawing). Numbers of burnt fragments are counted for the entire sample at the level of size class and bone type. Butchery can clearly add to the overall level of deliberate breakage, however, the breakage of bones for butchery purposes will be restricted to particular elements for a particular purpose, such as an alternative to disarticulating a difficult joint. There is also likely to be a difference between the fractures produced by chopping through meat and bone and those created by direct impact to the bone. It is essential that all indicators (fragmentation level, bone types, fracture patterns, gnawing, butchery and burning) are considered holistically to effect a successful interpretation and avoid pitfalls of equifinality.

Case Studies

Below, four case studies of the analysis of bone fat exploitation patterns are outlined. The details of the results for each case study will not be displayed as these have been or will be published at some length elsewhere (Outram 1998; 1999; in press; forthcoming). The purpose of this section is to present the principal points of interest emerging from the results of each study, so that they can be discussed with reference to the question of marginality. All case studies relate to economies that were highly dependent upon animal products and would have had little access to large quantities of dietary carbohydrate. As such, fat becomes a key resource.

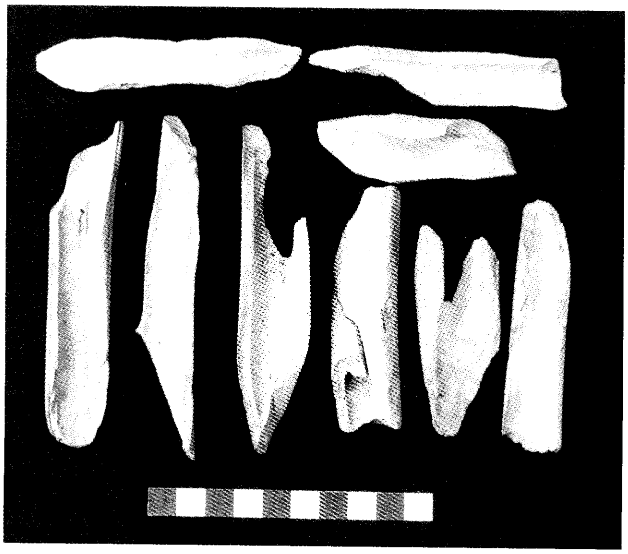

Fig. 7. Helically-fractured shaft splinters from the Norse settlement of Sandnes, Western Greenland, resulting from marrow extraction (scale in 1cm divisions).

Fig. 8. Heavily comminuted cancellous bone from the Norse settlement of Sandnes, Western Greenland, resulting from bone grease rendering (scale in 1cm divisions).

The first two case studies are set in Western Greenland (for detailed results see Outram 1999). Greenland, being physically difficult to reach, being at high latitude with a harsh climate and having difficult terrain with little suitable land for settlement, is perhaps a classic example of somewhere people think of as being marginal. The first study looked at two medieval Norse farmsteads called Sandnes (V51) and Niaquussat (V48). The Norse settled on Greenland in around AD 985 (Buckland *et al.* 1996) and operated a principally pastoral economy using cattle, sheep and goats. The diet was augmented with hunting of caribou, seals and wild birds, but fishing does not

Fig. 9. Large, unprocessed rib fragments from the Norse settlement of Sandnes, Western Greenland (scale in 1cm divisions).

appear to have occurred much at all (for detailed discussion of economy see McGovern 1985; McGovern *et al.* 1996; Buckland *et al.* 1996). It is clear that life was very harsh indeed and one of the key limiting factors in the economy was the short growing season and limited availability of winter fodder for animals (McGovern 1985). With the climatic downturn at the start of the Little Ice Age, matters became worse and the Norse finally abandoned Greenland by the end of the 15th Century (Buckland *et al.* 1996).

Before the study by this author, Buckland *et al.* (1996) had already suggested from entomological evidence that the Norse were so stressed that they needed to render bones extensively for fat before depositing them in their middens. The study of the bone fracture and fragmentation patterns very much confirmed this. The land mammal bones had been very heavily processed indeed, at both farms, and the pattern was very clear and consistent. Almost all long bone shafts had been deliberately fractured to extract marrow (see Fig. 7) and almost all cancellous bone (axial and appendicular) had been comminuted into very small pieces for rendering (see Fig. 8). The only exceptions to this were the ribs (see Fig. 9), which are quite poor in terms of their grease value and contain largely red marrow (see above). Seal bone tended not to be fragmented. It was also clear that this pattern was almost entirely the result of deliberate human action, when considering all the taphonomic data holistically. The conclusion is that the processing of land mammal bone extends a very long way along the x-axis of a diet breadth model, which suggests that procurement of sufficient fat resources, and probably food in general, was very difficult, forcing the exploitation of very marginal resources of bone fat. There will be more discussion of seal below.

The other case study involved the examination of two

Paleo-Eskimo sites of the Saqqaq culture, which dates to approximately 2400–1000 BC (Grønnow 1988, 24). Qeqertasussuk (see Grønnow 1988; Böcher and Fredskild 1993) is a specialist seal hunting site and Itivnera (see Møhl 1972) is a specialist caribou hunting site. Just like on the Norse sites, the seal bone was not fragmented much at all. There was no evidence for the extraction of fat from them. At Itivnera, however, it was clear that the caribou bones were being processed for both grease and marrow. The patterning and method of processing seemed to closely follow that described by Binford (1978) for the Nunamiut. Long bone ends had been deliberately removed to leave shaft cylinders (Fig. 1). There was good evidence for the grease rendering, but certainly not in the quantities encountered at the Norse sites. The Saqqaq people left quite a few axial and appendicular cancellous portions unexploited, leading to the conclusion that they were less stressed and did not need to extend their diet breadth, in fat terms, as far as the Norse.

The third case study continues the theme by examining early medieval Norse settlements on Iceland at two farms called Hofstaðir and Sveigakot in Northern Iceland (see Outram in press for detailed study). Iceland has some similar features to Greenland, in environmental terms, but it does not have quite such a harsh climate and has better land availability, in other words is less marginal. The economy of Norse Iceland was also primarily pastoral and based upon cattle, sheep and goat with additional exploitation of pig and seals (Amorosi 1992; Tinsley forthcoming). Caribou were not available as a hunted resource (Amorosi 1992, 123), but on Iceland there was much fishing of both fresh water and sea species (Amorosi 1992; Byock 2001). The results of bone fracture and fragmentation analysis on these sites were in stark contrast to the Greenlandic results. It was immediately apparent that, whilst there was evidence for a certain amount of marrow extraction, there was no evidence at all for bone grease rendering. Fragmentation levels were very low and many bones survived whole. This suggests that the procurement of sufficient fat was not at all difficult within the Icelandic economy and that perhaps their economy was indeed less marginal than that on Greenland.

The final study relates to a Middle Neolithic site on the Swedish Island of Gotland called Ajvide (for detailed discussion of results see Outram forthcoming). The Middle Neolithic culture on the island is referred to as the 'Pitted Ware' culture, which spans from about 2700–2300 Cal. BC (Burenhult 1997). Gotland had seen the introduction of domestic animals including cattle, sheep and pigs in the Early Neolithic, but, during the Pitted Ware phase, it seems that the inhabitants of the island reverted to hunting and gathering, exploiting various species of seal, wild/feral pigs and fish (Rowley-Conwy and Storå 1997). Just like on Iceland, the bone fracture and fragmentation study uncovered very little evidence for systematic bone grease rendering, but it was clear that marrow was regularly exploited.

Discussion

It is clear from the above results that the patterns of bone fat exploitation were very different within the economies discussed. On a simple level, one can argue the following, with regard to relationship between bone fat exploitation and marginality. The Norse settlers and Paleo-Eskimos on Greenland shared a very similar environment, but the Norse economy was a cultural import from elsewhere that was not ideally adapted to the environment of Greenland. The result was significant stress upon the subsistence economy. The difficulty in procuring sufficient fat resources forced an increase in the diet breadth for bone fat exploitation. The clear evidence that this pattern of bone fat exploitation left is detectable archaeologically in a way that other evidence of stress might not be. The Saqqaq peoples clearly needed to exploit some bone grease, but it is equally clear that they were not in such a desperate situation, and probably had an economy that was far better adapted to the environment.

It appears that the Norse Greenlanders were doing their best to optimise returns from their chosen economy, but it also seems that they had culturally chosen to operate an economy that fell some way short of optimal for their environment. This underlines the point that OFT models do not determine actual behaviour. People do make cultural choices about how they will live within a given environment. However, if we do not have optimal models, or at least some set measuring stick, how would we know whether cultural decisions were divergent from practical adaptations to environment and of particular interest. Having said this, one must return to the point that life is only viable within certain limits. Cultural variability is only possible within the limits of optimal models at the top end and economic and biological viability at the other. On Greenland, the Norse did optimise their economy as far as they could without fundamentally changing it, but they did not truly optimise it to the environment. With the onset of climatic downturn, the limits of optimality and viability came closer together and their culturally chosen economy began to fall outside those limits. Environment demanded adaptation, but culture refused and the result was the abandonment of Greenland.

The Icelandic and Gotlandic examples show two economies that do not appear to have been so dietarily stressed. In both cases it appears that only marrow was being exploited, which is relatively highly ranked in a diet breadth model indicating that fat and food procurement in general was not that difficult. The four studies taken together show that the fracture and fragmentation methods can pick up the full range of different fat exploitation patterns and that these patterns, once identified, can be very useful in interpreting levels of economic stress.

Looking in greater detail at some of the complexities of these case studies, it is necessary to draw attention to some important interpretative issues, however. The first and most important issue relates to the seasonal round within subsistence economies. It is extremely important to realise that economies are not static throughout the year and some times of year are likely to be far more stressed than others. It is highly likely that extreme patterns of bone fat exploitation will relate to particular seasonal dearths in food resources. This does not in any way negate the result for the settlement as a whole, however, as a subsistence economy is only as good as its weakest part. If one cannot weather the bad times through optimising resources (including use of storage where applicable), the good times are irrelevant.

In the case of the Greenlandic peoples, in both case studies the season of dearth was probably winter. In the Norse example there was food available from the pastoral economy during the summer, which would be nutritious and contain a good source of fat. The sealing appears to have taken place during spring (McGovern 1985, 101). Seals have vast amounts of fat in their blubber, so the bone fats would have been, in relative terms, much further down a diet breadth ranking list. This is no doubt why seal bones were not fragmented by either the Norse or Saqqaq peoples. The hunting of caribou would probably be best in Autumn, when they are at their fittest and domestic stock may well also have been slaughtered at this time, before over-wintering in the byres. This leaves winter, with only stored food available, including many bones from the autumn kills that could be rendered. In Iceland and at Ajvide there is not such a significant gap in the provisioning of food. On Iceland better environmental conditions could have led to the possibility of storing up more dairy products for winter, but, perhaps more importantly, the large amount of fishing carried out would have allowed stockfish to be kept for the winter period. At Ajvide there was also much fishing, but it was also clear that sealing was not so seasonally limited with different species being exploited through from autumn to the spring (Rowley-Conwy and Storå 1997). It can be seen that the seasonal availability of fat could be the critical factor in the study of these economies.

One final issue for discussion is a slight warning. Bone fats can be valued for industrial processes, for example waterproofing skins and treating bowstrings (Binford 1978, 24), tanning (Levin and Potapov 1964, 636) and lighting (Burch 1972, 362). As such, the consideration of bone fat exploitation as an indicator of dietary stress should not be taken out of the overall economic and archaeological context of the case study. Arguments about marginality and stress must use the full range of economic and environmental data holistically.

Conclusion

The study of patterns of bone fat exploitation in the archaeological record can be a powerful tool for understanding dietary stress within economically marginal environments. Our understanding of such environments can be enhanced by the use of appropriate models of optimal behaviour for such environments, when such models are correctly used as measuring sticks, not as determining laws. In considering marginal economies, special attention needs to be given to the identification of periods of seasonal stress. When using bone marrow and grease exploitation patterns as an indicator of dietary stress, this evidence should be fully integrated with other available economic and environmental data, and not treated in isolation.

Acknowledgements

I would like to thank Helen and Derek Outram for their comments on earlier drafts and Mariana Mondini and Sebastián Muñoz for organising the conference session in which I presented a paper on which this paper is based.

References

Amorosi, T. 1992. Climatic impact and human response in Northeast Iceland: archaeological investigations at Svalbarð, 1986–1988, pp. 103–38 in Morris, C. D. and Rackham, D. J. (eds), *Norse and Later Settlement and Subsistence in the North Atlantic*. Glasgow: University of Glasgow, Department of Archaeology.

Beardsworth, A. and Keil, T. 1997. *Sociology on the Menu*. London: Routledge.

Bettinger, R. L. 1991. *Hunter-Gatherers: Archaeological and Evolutionary Theory*. New York: Plenum Press.

Blumeschine, R. J. and Madrigal, T. G. 1993. Variability in long bone marrow yields of East African ungulates and its zooarchaeological implications. *Journal of Archaeological Science* **20**, 555–87.

Böcher, J. and Fredskild, B. 1993. Plant and arthropod remains from the Paleo-Eskimo site on Qeqertasussuk, West Greenland. *Meddelelser om Grønland; Geoscience* **30**.

Binford, L. R. 1978. *Nunamiut Ethnoarchaeology*. New York: Academic Press.

Brink, J. W. 1997. Fat content in leg bones of *Bison bison*, and applications to archaeology. *Journal of Archaeological Science* **24**, 259–74.

Brink, J. and Dawe, B. 1989. *Final Report of the 1985 and 1986 Field Season at Head-Smashed-In Buffalo Jump, Aberta*. Edmonton: Archaeological Survey of Alberta.

Brookes, P. M., Hanks, J. and Ludbrook, J. V. 1977. Bone marrow as an index of condition in African ungulates. *South African Journal of Wildlife Research* **7**, 61–6.

Buckland, P. C., Amorosi, T., Barlow, L. K., Dugmore, A. J., Mayewski, P. A., McGovern, T. H., Ogilvie, A. E. J., Sadler, J. P. and Skidmore, P. 1996. Bioarchaeological and climatological evidence for the fate of Norse farmers in Medieval Greenland. *Antiquity* **70**, 88–96.

Burch, E. S. 1972. The caribou/wild reindeer as human resource. *American Antiquity* **37**, 339–68.

Burenhult, G. 1997. Introduction, pp. IX–XXI in Burenhult, G. (ed.), *Remote Sensing, Volume 1* (Theses and Papers in North-European Archaeology 13a). Stockholm: Stockholm University.

Byock, J. L. 2001. *Viking Age Iceland*. London: Penguin.

Charnov, E. L. 1976. Optimal foraging: the marginal value theorem. *Theoretical Population Biology* **9**, 129–36.

Cheatum, E. L. 1949. Bone marrow as an index of malnutrition in deer. *New York State Conservation* **3**, 19–22.

Clutton-Brock, T. H. and Albon, S. D. 1989. *Red Deer in the Highlands*. Oxford: BSP Professional Books.
Davis, J. L., Valkenburg, P. and Reed, S. J. 1987. Correlation and depletion patterns of marrow fat in caribou bones. *Journal of Wildlife Management* **51**, 365–71.
Erasmus, U. 1986. *Fats and Oils: the Complete Guide to Fats and Oils in Health and Nutrition*. Vancouver: Alive Books.
Foley, R. 1985. Optimality theory in anthropology. *Man* **20**, 222–42.
Grønnow, B. 1988. Prehistory and permafrost: investigations at the Saqqaq site, Qeqertasussuk, Disco Bay, West Greenland. *Journal of Danish Archaeology* **7**, 24–39.
Higgs, E. S. and Jarman, M. R. 1975. Palaeoeconomy, pp. 1–7 in E. S. Higgs (ed.), *Palaeoeconomy*. Cambridge: Cambridge University Press.
Johnson, E. 1985. Current developments in bone technology, pp. 157–235, in Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory Vol. 8*. New York: Academic Press.
Jones, K. T. and Metcalfe, D. 1988. Bare bones archaeology: bone marrow indices and efficiency. *Journal of Archaeological Science* **15**, 415–423.
Kent, S. 1993. Variability in faunal assemblages: the influence of hunting skill, sharing, dogs, and mode of cooking on faunal remains at a sedentary Kalahari community. *Journal of Anthropological Archaeology* **10**, 1–26.
Leechman, D. 1951. Bone grease. *American Antiquity* **16**, 355–56.
Leechman, D. 1954. The Vanta Kutchin. *National Museum of Canada, Bulletin* **130**, 1–17.
Levin, M. G. and Potapov, L. P. 1964. *The Peoples of Siberia*. Chicago: Chicago University Press.
Little Bear, R. 1982. Grandmother in her house, in Hungry Wolf, B (ed.), *The Ways of My Grandmothers*. New York: Quill.
MacArthur, R. H. and Pianka, E. R. 1966. On optimal use of a patchy environment. *American Naturalist* **100**, 603–09.
McGovern, T. H. 1985. Contributions to the palaeoeconomy of Norse Greenland. *Acta Archaeologia* **54**, 73–122.
McGovern, T. H., Amorosi, T., Perdikaris, S. and Woollett, J. 1996. Vertebrate zooarchaeology of Sandnes V51: economic change at a chieftain's farm in West Greenland. *Arctic Anthropology* **33**, 94–121.
Mead, J. F., Alfin-Slater, R. B., Howton, D. R. and Popjak, G. 1986. *Lipids: Chemistry, Biochemistry and Nutrition*. New York: Plenum Press.
Metcalfe, D. and Jones, K. T. 1988. A reconsideration of animal body-part utility indices. *American Antiquity* **53**, 486–504.
Mitchell, B., McCowan, D. and Nicholson, I. A. 1976. Annual cycles of body weight and condition in Scottish red deer, *Cervus elaphus*. *Journal of Zoology* **180**, 107–27.
Møhl, U. 1972. Animal bones from Itivnera, West Greenland; a reindeer hunting site of the Sarqaq Culture. *Meddelelser om Grønland* **191**.
Morlan, R. E. 1984. Toward the definition of criteria for the recognition of artificial bone alterations. *Quaternary Research* **22**, 160–71.
O'Connell, J. F. and Hawkes, K. 1988. Hadza hunting, butchering, and bone transport and their archaeological implications. *Journal of Anthropological Research* **44**, 113–61.
O'Connell, J. F., Hawkes, K. and Blurton Jones, N. 1990. Reanalysis of large mammal body part transport among the Hadza. *Journal of Archaeological Science* **17**, 310–16.
O'Connell, J. F. and Marshall, B. 1989. Analysis of kangaroo body part transport amongst the Alyawara of Central Australia. *Journal of Archaeological Science* **16**, 393–405.
Outram, A. K. 1998. *The Identification and Palaeoeconomic Context of Prehistoric Bone Marrow and Grease Exploitation*. Unpublished Ph.D. Thesis, University of Durham.
Outram, A. K. 1999. A comparison of Paleo-Eskimo and medieval Norse bone fat exploitation in Western Greenland. *Arctic Anthropology* **36**, 103–17.
Outram, A. K. 2001a. A new approach to identifying bone marrow and grease exploitation: why the "indeterminate" fragments should not be ignored. *Journal of Archaeological Science* **28**, 401–10.
Outram, A. K. 2001b. FOCUS: The scapula representation could be the key: a further contribution to the 'Klasies Pattern' debate. *Journal of Archaeological Science* **28**, 1259–63.
Outram, A. K. 2002. Bone fracture and within-bone nutrients: An experimentally based method for investigating levels of marrow extraction, pp. 51–64 in Miracle, P. and Milner, N. (eds), *Consuming Passions and Patterns of Consumption*. Cambridge: McDonald Institute for Archaeological Research.
Outram, A. K. In Press. Comparing levels of subsistence stress amongst Norse settlers in Iceland and Greenland using levels of bone fat exploitation as an indicator. *Environmental Archaeology*.
Outram, A. K. Forthcoming. The identification of levels of bone marrow and grease exploitation and the place of bone marrow as a resource within seasonal rounds: case studies from Greenland and Sweden, in Mulville, J and Outram, A. K. (eds), *The Zooarchaeology of Animal Fats and Dairying* (Proceedings of ICAZ 2002). Oxford: Oxbow.
Outram, A. and Rowley-Conwy, P. 1998. Meat and marrow utility indices for horse (*Equus*). *Journal of Archaeological Science* **25**, 839–49.
Peterson, R. O., Allen, D. L. and Dietz, J. M. 1982. Depletion of bone marrow fat in moose and a correlation for dehydration. *Journal of Wildlife Management* **46**, 547–51.
Rixson, D. 2000. *The History of Meat Trading*. Nottingham: Nottingham University Press.
Rowley-Conwy, P. and Storå, J. 1997. Pitted Ware seals and pigs from Ajvide, Gotland: methods of study and first results, pp. 113-30 in Burenhult, G. (ed.), *Remote Sensing, Volume I* (Theses and Papers in North-European Archaeology 13a). Stockholm: Stockholm University.
Speth, J. D. 1983. *Bison Kills and Bone Counts: Decision Making by Ancient Hunters*. Chicago: University of Chicago Press.
Speth, J. D. 1987. Early hominid subsistence strategies in seasonal habitats. *Journal of Archaeological Science* **14**, 13–29.
Speth, J. D. 1991. Nutritional constraints and late glacial adaptive transformations: the importance of non-protein energy sources, pp. 169–78 in Barton, N., Roberts, A. J. and Roe, D. A. (eds), *The Late Glacial in North-West Europe: Human Adaptation and Environmental Change at the End of the Pleistocene*. York: Council for British Archaeology.
Speth, J. D. and Spielmann, K. A. 1983. Energy source, protein metabolism, and hunter-gatherer subsistence strategies. *Journal of Anthropological Research* **2**, 1–31.
Tinsley, C. M. Forthcoming. The Viking settlement of Northern Iceland: A preliminary zooarchaeological analysis, in Housley, R. A. and Coles, G. (eds), *Atlantic Connections and Adaptations: Economies, Environments and Subsistence in Lands Bordering the North Atlantic*. Oxford: Oxbow Monographs.
Villa, P. and Mahieu, E. 1991. Breakage patterns of human long bones. *Journal of Human Evolution* **21**, 27–48.
Wilson, G. L. 1924. *The Horse and Dog in Hidatsa Culture* (Anthropological Papers of the American Museum of Natural History 15, 2). New York: American Museum of Natural History.
Yellen, J. E. 1991. Small mammals: !Kung San utilization and the production of faunal assemblages. *Journal of Anthropological Archaeology* **10**, 1–26.

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