

Applied Models and Indices vs. High-Resolution, Observed Data: Detailed Fracture and Fragmentation Analyses for the Investigation of Skeletal Part Abundance Patterns

Alan K. Outram*

*Department of Archaeology, School of Geography, Archaeology and Earth Resources,
University of Exeter, Laver Building, North Park Road, Exeter, EX4 4QE, UK*

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The history and development of skeletal part abundance studies is briefly discussed. Two principal strands of this sub-discipline are the application of indices of food utility and bone mineral density to the interpretation of skeletal part abundance patterns. Both food utility and bone mineral density indices are derived from modern observations, underwritten by uniformitarian assumptions, and are used to model behavioural and taphonomic patterns in the selection and survival of bone elements. The application of such models is critiqued. It is argued that, whilst such models remain extremely valuable, they will always suffer from equifinality with regard to end interpretations. The solution to this problem does not lie in improving these models, or the data they derive from, though this may be desirable, but in the more time-consuming option of improving the resolution of archaeologically observed data. Several ways of doing this are briefly discussed. One of these options, fracture and fragmentation analysis, is outlined in detail. Sample applications of such an approach are presented and discussed. These include the use of fracture and fragmentation analysis to identify specific practices that can severely skew skeletal part abundances, such as bone grease rendering, and the identification of levels of pre-depositional and post-depositional fracturing within the taphonomic history of bone assemblages.

Keywords: BONE FRACTURE, FRAGMENTATION, BONE MINERAL DENSITY, FOOD UTILITY INDICES, SKELETAL PART ABUNDANCE

Introduction

Theodore White (1952, 1953) was one of the first archaeologists to understand that skeletal part abundances within zooarchaeological assemblages could shed

light upon past hunting and butchery strategies. It is clear that, having stalked, killed and tracked their prey, hunters have one further problem. They must transport their quarry to where they need it. They must decide whether to transport all of the

carcass or just the elements most valuable to them. These decisions will depend upon the size of animal, the number of hunters in the party, the distance back to camp, the amount of time available for the task, the needs of the group back at camp and the hunters' immediate needs (snacking at the kill site). In making their selection of elements, considerations will include the food value of the element, the hunters' taste preferences, the transportability of the element, its value for non-food raw materials and whether or not the bone part of that element should be transported along with the soft tissues (or *vice-versa*).

Such selective behaviour will produce different patterns of refuse at kill sites and camp sites. The patterning may become further complicated through the differential processing of different bone elements during butchery, extractive processes and craft activities. All of this patterning is imbued with meaning that can help archaeologists understand past behaviour. However, these patterns have to be viewed through a thick veil of post-depositional taphonomy. The action of animals, the weather and chemical and mechanical attrition all have differential effects upon different elements. The results of this 'natural' patterning can be hard to distinguish from anthropogenic activities, which, in turn can be hard to distinguish from each other. Zooarchaeologists attempting to make meaningful interpretations of skeletal part abundances are dogged by constant problems of equifinality.

It is worth quickly outlining the sort of basic data set that zooarchaeologists most commonly work from when making interpretations about skeletal part

abundances. Quantification takes the form of a count for each of the different skeletal elements present (or selected elements - some analysts deliberately discount certain elements from study). More detail is normally recorded for long bones, where the proximal and distal ends are usually counted separately. The actual way the final count is derived varies enormously. For a critique of different methods of quantification see Lyman (1994a) and Ringrose (1993).

In addition to quantification, analysts might also have recorded something about the surface alterations on bone fragments under such categories as animal gnawing, weathering and butchery marks. These data may be used to help understand the differential abundance of elements seen in the assemblage. The reason for outlining the above standard data set is that it, in itself, has changed very little for decades. There have been occasional attempts to do something different, and some are mentioned below, but the range of observed data has remained very static. Much of the debate and methodological discussion in this field of study has revolved around two tools used to interpret the standard data set, rather than on the quality of the original data.

These tools are utility indices and indices of bone density. Utility indices are created by obtaining an average measurement of the utility of elements within the carcass of a particular species of animal. The utility is normally expressed in terms of quantities of food. This is commonly expressed as the mass of edible tissues (meat, marrow, fat etc.) to be found on, or within, a bone. These indices are used to help one understand the economic

strategies behind element transport decisions. The first use of such indices can be credited to Lewis Binford (1978) in his ethnoarchaeological study of the Nunamuit. Indices of bone density, on the other hand, are intended to help zooarchaeologists account for some of the skewed, post-depositional attrition which might be related to the bone's density. C.K. Brain (1967, 1969) was probably the first to explore this issue through actualistic experimentation with bone attrition and through the measurement of bone densities.

Both these approaches use measurements taken in the present to form models for the interpretation of the past through uniformitarian principles. In both cases there has been a considerable amount of academic effort contributed to augmenting our datasets with more and more species. Furthermore, there has been a considerable degree of debate over the best way to measure, calculate and apply such indices. Below is a summary of some of the difficulties associated with the application of utility and bone density indices.

Problems in the Application of Utility Indices

Binford (1978) calculated utility indices for the different elements of sheep and caribou carcasses. He created indices for meat, marrow and bone grease yield (based upon body mass), as well as a combined 'General Utility Index' (GUI). A further step was to modify this index to create the 'MGUI'. This modification involved an averaging process with adjacent elements. More specifically, a low value part was assigned

"...the mean of the general utility value for the adjacent parts of higher value" (Binford, 1978: 74). The idea is that the likelihood that an element will be transported is influenced by adjoining elements. A low-yield element might well be transported as a 'rider' (Binford, 1978) with a high yield element.

Binford (1978) then applied his index to the ethnoarchaeological data he collected on Nunamuit element transport choices. This took the form of plotting standardized MAU values of transported elements against standardized MGUI values for those elements on a scattergraph. The shapes of the scatter appeared to indicate different strategies for transport. Figure 1 shows Binford's models. The gourmet model represents the transport of only the highest ranked elements, whereas the bulk model shows that only the lowest ranked elements would be abandoned at the kill site (Binford, 1978). There was a degree of circularity to Binford's study, because the raw data he took were modified in various ways (conversion to MGUI to account for riders, and other ways noted below) to better match his observations of Nunamuit behaviour. His indices were then tested on Nunamuit element transport patterns, so it is not surprising that his models appeared to work.

Since Binford's seminal work, more utility indices have been constructed for other species. Amongst these works, marine mammals have been well studied (Lyman, *et al.*, 1992; Savelle & Friesen, 1996; Savelle *et al.*, 1996). Metcalfe and Jones (1988) re-worked caribou, Emerson studied bison (in Lyman, 1994b, Table 7.4), Outram and Rowley-Conwy (1998) have done horse, Rowley-Conwy *et al.* (2002)

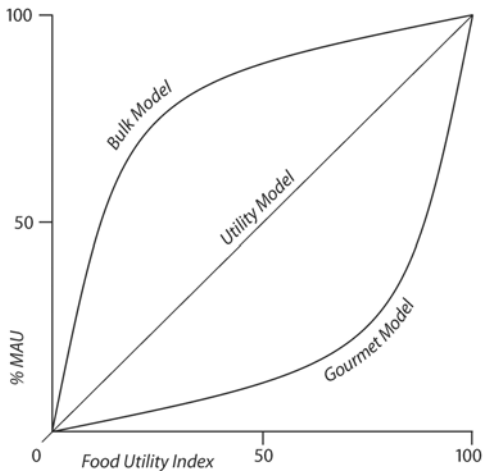


Figure 1: Models showing the relationship between element abundance and element utility, for three different transport strategies as represented at a transport destination (e.g. base camp) (after Binford, 1978).

did European wild boar and there have been various studies relating to bone marrow yields (e.g. Brink & Dawe, 1989; Blumenschine & Madrigal, 1993). However, there has also been substantial debate over the best way to both construct such indices and apply them.

In re-working Binford's (1978) indices, Metcalfe & Jones (1988) noted that Binford had introduced many mathematical modifiers into his calculations. These modifiers were applied to account for his ethnographic informers' taste and preferences, but, at the same time, reduced his indices into a subjective measure of one ethnographic groups' values rather than a neutral index that could be applied to the past under uniformitarian principles. Jones & Metcalfe (1988) looked particularly at Binford's application of his bone marrow

index (see also Marshall & Pilgram 1991) and found that raw, unmodified data on marrow cavity volumes were a much better predictor of marrow bone selection than Binford's (1978) index, which had been modified to take into account perceived Nunamuit preferences for marrow with high levels of oleic acid. Outram (2000, Figs. 3.4 & 3.5) demonstrates how Binford's subjective modifiers can totally reverse potential interpretations. More recent indices follow Metcalfe & Jones (1988) in not applying any modifiers to meat or marrow indices, though the production of their FUI (Food Utility Index) still accounts for 'riders' through an averaging procedure. The validity of the assumption regarding 'riders' is something else that is worthy of considerable discussion. As a result of the above, indices for different species may have been calculated in very different ways, yet these indices are in current use in the literature without reference to the potential problems this issue might create in interpretations. It is worth noting that even before reaching the calculation stage there are significant differences in the way measurements are gained. Binford (1978) calculated the amount of food on each limb by taking the difference in weight between the fleshed element and the dry bone. This includes considerable quantities of inedible connective tissue. Outram & Rowley-Conwy (1998) noted that this was not a realistic way of assessing food utility and they weighed the product resulting from actualistic butchery (i.e. only the *edible* materials that could actually be recovered from the cutting and manual marrow extraction were quantified). One effect of Binford's procedure may be to imply that there is more edible material on the lower

limb elements than there actually is.

In addition to problems associated with index construction are issues relating to their application. Outram (2001a, in press) has critiqued the scattergraph method and notes two main problems. Firstly, the scattergraph usually results in a consideration of the general pattern of skeletal part abundance rather than considering the relative abundance of individual elements that might be crucial to understanding past human behaviour. Secondly, there is ample evidence in the literature of false patterns being seen in the data. Outram (in press, Fig 1) provides an example of how this method can tempt the eye to see patterns that in reality do not mathematically adhere to Binford's (1978) models. An example of work with consistent errors of this type is Boyle's (1990) work on Upper Palaeolithic faunas.

More fundamentally, Binford's (1978) models assume that bones will, in general, be transported in accordance with that fleshed element's utility. This assumption clearly will not always hold true. Bones and meat do not have to be transported together. The values of muscle and bone can be considered separately. Bones might travel alone as a result of their marrow or craft value. Likewise, bones can be abandoned while filleted meat is bundled and transported. Binford's (1978) method did appear to work well for the Nunamiut, but, in that particular example Binford's assumptions held good. Where such assumptions are valid there is great potential for understanding procurement strategies within a framework of optimal foraging models (Outram, 2001a), but, sadly, it seems likely that such assumptions will not be valid in many cases.

Other ethnoarchaeological studies (e.g. O'Connell *et al.*, 1988, 1990) show that patterns of element transport can be considerably more complex and hard to predict than Binford's models might suggest. It is equally clear that gross animal size will have a distinct effect upon element transport decisions. This factor is the basis for Klein's (1976, 1989) interpretation of the differential representation of elements from small and large bovids at Klasies River Mouth, for example. It is clear that some small animals can and will be transported whole and, hence, all low utility elements effectively become 'riders'. On the other hand, some animals are so bulky that whole fleshed elements might be too much of a load to transport. Outram (in press) argues that this might be the case with horses hunted during the Upper Palaeolithic in Europe. Horse skeletal part abundances look very different from those of reindeer at many Upper Palaeolithic sites, and the case is made that horses are sufficiently large to require the subdivision of some major elements resulting in different field butchery techniques. Bones may well have been transported for their own utility (marrow, grease or raw material) rather than as riders to meat.

It is clear that there are considerable problems with the simplistic application of utility indices. There is certainly value to understanding the body part utility of different species, but zooarchaeologists should be deeply wary of highly modified indices and be constantly aware of the assumptions they are making when applying indices.

Indices of Bone Density

Since Brain's (1967, 1969) work on carnivore ravaging and the structural density of goat bones, many further indices of bone density have been created (for examples see Lyman, 1994b; Table 7.6). The methodologies for the creation of such indices have evolved, however. Measures used have been variously described as structural density, bulk density, true density and bone mineral density and there has been much discussion on how and where to take readings (see Lyman, 1994b: 234-258). This author will not attempt to summarize in detail the most recent technical debates about the construction and use of bone density indices, as others who are better qualified have done so (for recent debate see Lam *et al.*, 1999, 2003; Pickering & Carlson, 2002; Stiner, 2002; Symmons, 2004). Instead, it is worth considering the value of applying such indices on a more philosophical level.

As with utility indices, the best way to formulate bone density indices is not yet fully resolved. In the case of bone density indices, there is a distinct question mark over which measure of density actually correlates best with our theoretical concept of 'density mediated attrition'. Bones have different shapes and physical properties in every plane (including many voids) and vary among and between taxa. Therefore, the first philosophical objection is whether attempts to summarise the complex morphologies of bones through the use of selective scan sites and other mechanisms, have been successful. The constant debate over such issues (see above) suggests that no clear resolve has yet been reached.

Secondly, the observation that there is a general correlation between bone density and survival has been turned into something of a dogma that tends to be applied across the board, whether appropriate or not. The actual physical processes involved in density mediated attrition, particularly over the long duree, are far from well understood. Burial environments vary enormously and some are highly protective environments where it is clear that even the most fragile and low-density of elements survive well. The length of burial also varies considerably, from a few hundred to millions of years, yet the relationship between time and both physical and chemical diagenesis of bone is not clearly understood. High levels of density mediated attrition cannot be assumed in all cases.

Thirdly, where density mediated attrition has clearly occurred, density indices may be able to model some of the effects, but they cannot identify the actual cause of attrition. Such attrition can be caused by humans as they butcher, process and cook carcasses. These are things archaeologists want to know about. Attrition also occurs, as bones become incorporated into the archaeological record, through the agency of animals (gnawing and trampling) and the weather. This is followed by chemical and biological diagenesis in the soil as well as damage from invertebrates and roots and possibly freeze/thaw and other physical processes in the soil. Bones can be further damaged by redeposition in antiquity or by modern excavation and storage damage. All of the stages are density mediated. Even if a bone density index was utterly perfect, it would be insensitive to the cause of attrition.

Fourthly, one must investigate the relationship between density-mediated attrition, zooarchaeological identifications and quantification. Whilst density mediated attrition could result in greater destruction of some elements than others, identification and quantification of archaeological specimens does not necessarily depend upon the total preservation of elements. An element with low average density may well have a zone that is both hardy and easily identified. Through the process of quantifying by MNEs such an element might not actually be depressed in counts as much as the density of that element might suggest. Other low density elements may not possess either more hardy or particularly identifiable zones and may indeed have greatly depressed representation.

In summary, it is not wholly clear how best to measure bone density, what exact effect bone density has upon attrition in different circumstances or what the exact relationship between differential destruction and identification and quantification will be. The above discussion does not mean that work on bone density is not extremely valuable, but it does seriously question the uncritical application of such indices as a global answer to differential skeletal part abundance patterns.

The most important point is that both utility and bone density indices have received a vast amount of attention from zooarchaeologists and exceptionally detailed debates continue to rage about exactly how best to construct and apply these indices. Yet, when viewed critically, it is apparent that both fields of study involve assumption upon assumption in terms of, firstly, how well the sampled

indices describe the global population and, secondly, archaeological middle range theory. One can easily argue that the current debates rather miss the point and tend towards a degree of spurious accuracy. Minor modifications to methodologies pale into insignificance against a background of massive actualistic variability that could invalidate the fundamental assumptions that underlie those methods.

Equifinality and how to resolve it

Many past interpretations of skeletal part abundances have relied upon the application of utility or bone density indices. Beyond the difficulties noted above, the principal problem has been that interpretations have been dogged by equifinality. A common skeletal part abundance pattern is one where high utility elements are missing. Through the application of utility indices this might be interpreted as an inverse bulk pattern (Binford, 1978), but equally this might have been caused by the generally low density of those same elements (Lyman, 1985). Unfortunately, it is the case that there is a very broad (put not perfect) correlation between high utility and low density bones. Proponents of either utility indices or bone density studies have argued their cases and refined their indices in the hope of one solution winning out over the other, to no clear resolve.

This paper proposes that such equifinality of interpretation is unlikely to be resolved by continued refinement of applied indices, but instead by higher resolution analysis of the archaeological materials. This does not mean, in any way,

that well constructed and applied indices do not have value in contributing to interpretations, but, even if they were perfectly constructed, their application would not resolve the problem of equifinality. More effort needs to be concentrated upon extracting more information from zooarchaeological assemblages which might provide us with a much clearer understanding of that individual assemblage's taphonomic history. We need a far more detailed picture of what types of bone have survived and the processes by which bones in that assemblage have been destroyed than one sees in standard bone reports. Having done so, it may be possible to establish the degree to which density-mediated attrition has played a part and the degree to which patterns of human selection are still visible. The application of utility and density indices has always been attractive as it is economical in terms of analyst time and does not require the re-analysis of previous reported assemblages. The economy, however, may have been false in terms of the quality of the end interpretations.

Whilst it is clear that there are many methodological and theoretical problems with the application of utility and density indices, this paper is not an attack on their application in well constructed and judicious ways. This author has made use of both types of index and will continue to use them as appropriate. This paper does, however, encourage a shift of emphasis in zooarchaeological work, whilst also recognizing that such a shift is already occurring amongst some analysts (see for instance Bar-Oz & Dayan, 2002; Bar-Oz & Munro, this volume).

Attempts to improve the resolution of zooarchaeological datasets

Recent advances have been made in identifying ways in which analyses might result in more informative datasets, with regard to the issue of skeletal part abundances. One important contribution has been the realization that dense shaft fragments might much better represent original abundances than counts based only upon epiphyses, since all shafts are fairly resistant to destruction by carnivore and other attrition and there will be far less differential seen in the survival of different elements (Marean & Spencer, 1991; Marean & Frey, 1997). Many analysts do not give as much attention to shafts as epiphyses, since shaft fragments are far less diagnostic. Nonetheless, more exhaustive attempts to identify and quantify shaft fragments may well result in lessening of problems of equifinality. It should be noted that whilst many analysts only refer to proximal and distal ends of long bones in their reports, many do attempt to identify those shaft fragments that can be reliably identified and include them in counts according to whether that fragment came from the proximal or distal end of the bone. There is certainly an issue of how reliably one can really derive counts from small shaft fragments (see Klein, *et al.*, 1999: 1228). The argument that more thorough attempts to identify shaft fragments would improve interpretations remains valid, however.

Less valid is the generalized projection of assumptions regarding the differential survival of shafts and ends onto previously derived datasets. Bartram & Marean (1999) argued that the different

skeletal part abundance patterns in small and large bovids seen at Klasies River Mouth were not the result of differential transport strategies, but were an artifact of the Klein's (1976) original analysis not taking account of shaft fragments. The cause of the pattern was probably density-mediated carnivore ravaging, they argued. Their re-interpretation was not based upon re-analysis of the assemblage to include shaft fragments, but rather was simply a projection of their observed patterns of differential survival of shafts and ends onto that assemblage. This approach can be criticized because it did not pay sufficient attention to the actual analytical methods used in the original study or the patterns of carnivore ravaging noted between the large and small bovids (Klein *et al.*, 1999). Perhaps even more critically it did not pay sufficient attention to the actual 'Klasies Pattern', which is strongly characterized by the presence or absence of the scapula rather than long bones. Their study only addressed long bones and, hence, their argument was not applicable (Outram, 2001b).

The recommendation that should emerge from this is that the blanket assumption that particular effects will apply is probably not the way forward. Although re-analysis (even of just a sample) may be very arduous, it might have addressed the issue better. Routine higher resolution recording of the portions of bones present would reduce problems of equifinality and also deal with the shaft fragment issue. Such systems of recording have existed for many years, but are still not routinely applied. One particularly good system is the bone zonation system devised by Dobney & Rielly (1988) (see also Knüsel &

Outram 2004) which divides elements into zones along lines of common breakage. It is a very user-friendly system for analysts wanting a more detailed understanding of bone survival than is allowed for in the standard designation of proximal and distal ends. This methodology has recently been included in a comprehensive computer database system by Harland *et al.* (2003), which is freely available.

There are two types of data that are not routinely recorded in standard zooarchaeological analyses, that could be critical to the understanding of taphonomic histories and differential skeletal part patterns. These are the detailed recording of the degree of fragmentation of different types of bone (including fragments indeterminate to species and element) and detailed assessment of fracture patterns that might indicate when and how bones became fragmented. Below, is a summary of such methodologies and examples of how their application might assist us in resolving the issue of equifinality in skeletal part abundance interpretations.

Methods of fragmentation and fracture analysis

Many zooarchaeological reports do not attempt to quantify the extent to which an assemblage has become fragmented. Others present single measures of fragmentation that allow inter-site and inter-context comparisons to be made. It is worth describing some of the more commonly used methods. A NISP:MNE ratio (Lyman, 1994b: 336) compares the total number of identifiable fragments with the minimum number of such bones

present, providing a simple index of fragmentation without having to carry out any extra analysis. It only provides a very broad indication of fragmentation levels within the identifiable part of the assemblage. The problem is that in highly fragmented assemblages, a large proportion of fragments are not identifiable. To deal with this problem one might also calculate the 'percent identifiable' (Gifford-Gonzalez, 1989), which is effectively a total fragment:NISP ratio. This only requires that all fragments are counted. Morlan (1994) defines a more complex method of 'percent completeness' which requires one to have employed some kind of zonation system during the analysis. Within this method zones are referred to as portions. Any identifiable specimen (NISP) may have anything from one to all portions preserved, so a ratio of portions present to number of specimens can be calculated (PP/NISP) and this can be compared against the total number of portions defined (PD) for complete specimens and turned into a percentage ($100(\text{PP}/\text{NISP})/\text{PD}$). This is a highly effective system, if one employs zonation during analysis.

All the above measures are useful, but more detailed and descriptive methods of characterizing fragmentation are necessary to provide a depth of understanding of taphonomic histories. The only real way to achieve this is through the laborious categorization of the assemblage into fragment size classes (see Lyman & O'Brien, 1987; Villa & Mahieu, 1991). Outram (1999, 2001c, 2003) has taken this kind of method much further in an attempt to identify patterns resulting from bone grease rendering. However, both the practice of bone grease rendering and the

methods used to identify it have relevance to understanding skeletal part abundances. The method is described briefly below, but is more fully discussed elsewhere (see Outram, 2001c).

Fragments are separated into size classes by maximum dimensions. These classes are typically at 10mm intervals. The separation is achieved by passing fragments across plastic sheets with circles representing the maximum dimensions of each size class. Whole elements are always categorized separately, since they are not fragments and have not been broken. Whole epiphyses can also be treated separately and, in examples given below, are labelled as 'part' bones. Quantification of size classes is by both number and mass. Weighing the size classes is important, because small fragments can otherwise very quickly grossly outnumber larger fragments without actually representing very much actual bone. Mass is a more realistic way to represent the amount of bone in each size class (Outram, 2001c) (unless cancellous tissues are filled with heavy sediment). The way that this method differs from many previous works is that the fragments within size classes are also divided according to the 'type' of bone they represent.

Whilst many small fragments are indeterminate as to species and element, that does not mean we know nothing about that fragment in more general terms. For even very small 'indeterminate' fragments it is possible to tell whether it is composed of dense, cortical bone or cancellous, spongy bone. For larger fragments it may be possible to discern fragments of ribs, vertebrae, cranium, appendicular epiphysis or diaphysis even if that fragment is not identifiable to precise element or species.

Such information may not have been relevant to traditional zooarchaeological studies, but knowing what ‘types’ of bone have been fragmented and to what extent can be absolutely crucial in understanding taphonomic histories and issues like the presence or absence of bone rendering. Small ‘indeterminate’ fragments actually carry vast amounts of valuable information that is routinely discarded (Outram, 2001c).

Another type of information that ‘indeterminate’ fragments can carry is fracture patterns. Bones fracture in a fairly predictable fashion and the way they fracture depends upon how fresh that bone is, whether it has begun to lose moisture and organic content or not. Such patterns are best seen in dense cortical bone, so shaft fragments (both identifiable and indeterminate) will carry this information. Having established, through the fragmentation analysis, what types of bone have been broken to what extent, fracture analysis becomes the next logical step in establishing approximately when in their taphonomic history the bones became broken (i.e. fresh from the animal, after a little drying or post-depositionally with loss of some or all organic content).

Bone fracture has been relatively well studied and there are several good descriptions of bone fracture characteristics (see Morlan, 1984; Johnson, 1985; Outram, 2002). These studies identify three main criteria for the identification of long bone shafts that were fractured whilst in a fresh state. Firstly, the gross morphology of the fracture line will be helical (spiraling out from the point of impact). Secondly, the angle of the fracture surface to the outside cortical surface will be sharp (either acute or obtuse). This angle tends to change along

the spiral outline. Finally, the fracture surface tends to be smooth. When exposed to the air for any length of time, bone dries and micro-cracks form that tend to produce straight fracture lines and steps within the fracture outline. Over longer periods of time, the organic fraction is lost, leading to rougher, more right-angled, straight breaks. Once fully mineralized, all features of fresh bone fracture are lost. It is also important to note that dynamically-impacted, fresh bones also display scars at the point of percussion where cones of bone were removed upon impact. These can be used by archaeologists in a similar way to the bulbs of percussion found upon flaked stones.

Outram (2002) developed a simply-applied system for characterizing fracture patterns on shaft bone fragments. For each of the three criteria, a score of 0 was given if entirely consistent with fresh bone fracture, 1 for mixed features and 2 for predominantly non-fresh features. These scores could then be added to produce an index of fracture type running from 0 – 6. This method was tested experimentally (see Outram, 2002 for more details). In applying such a method to assemblages, no claim is made that the type of fracture identified on every single fragment will be spot on. The method is designed to characterize the general levels of peri-mortem and immediately post-mortem fracture as compared to levels of post-depositional fracture. Such information is crucial to many taphonomic debates.

The above method of indexing fracture types does not rely upon a high level analytical skill. The criteria are straight forward. Another way of carrying out bone fracture analysis is for the analyst

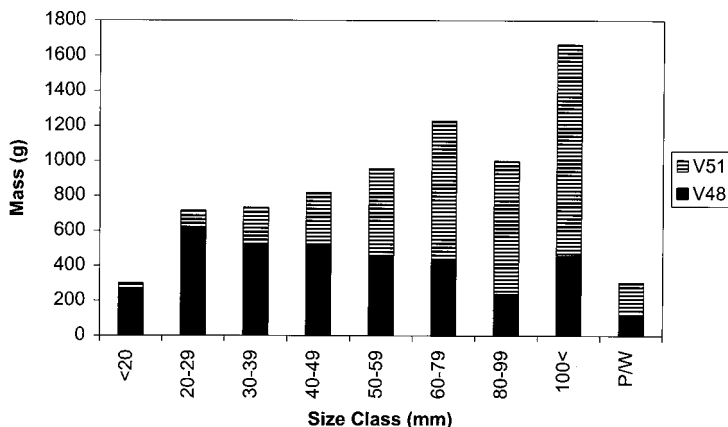


Figure 2: Masses of bone fragments in different size classes at two Greenlandic Norse farmsteads, Sandnes (V51) and Niaquussat (V48) (P/W = part/whole bone class).

to simply identify the presence or absence of ‘fresh bone’, ‘dry bone’ and ‘mineralized’ fractures on each specimen. This requires the analyst to have experience of how bones fracture and to take account of the three criteria. Whilst this seems more subjective and less scientific (perhaps it is), it is little different from other aspects of zooarchaeological analysis. For instance, speciation and the identification of surface modifications both require skill and subjective decisions to be made by analysts. This author has employed both methods, but the case study below makes use of the six point index.

Case Study

This example application of fracture and fragmentation analysis comes from a study of medieval Norse assemblages from Greenland (for details see Outram, 1999, 2003). The aim of this study was to assess

levels of bone marrow and grease extraction, but it has considerable implications for both the understanding of taphonomic histories and the differential destruction of anatomical parts (see also Munro & Bar-Oz, 2005). There are numerous good ethnographic and ethnoarchaeological accounts of bone grease rendering (e.g. Binford, 1978; Leechman, 1951, 1954; Wilson, 1924). To summarize, bone marrow is the most easily extracted bone fat, requiring only the fracture of long bone shafts (and a few other elements like mandibles) to access medullary cavities. Bone grease, however, is what results from the arduous rendering of fat from spongy, cancellous tissues found in the epiphyses of long bones and in the axial skeleton. The rendering process involves the fragmentation of cancellous bone tissues into quite small pieces before boiling them in water to melt out the fat, which then rises to the top where it can be solidified and skimmed off. Before the

advent of metal cauldrons this process involved the heating of water with hot rocks. This is very arduous indeed with relatively modest yields, as shown by Binford (1978) and this author's own experience of rendering bison bones in this fashion.

This practice will clearly leave very particular patterns in the archaeological record. Some elements, or portions of elements, will be destroyed beyond recognition. Which bones are targeted for bone grease will depend of two factors. These are the types of fat desired by the people in question and their level of need for fat. Both Binford (1978: 32) and Wilson (1924) report that the bone fat extracted from appendicular and axial bone is different in nature and tends to be kept separate for different purposes. It is also clear that some bones have more grease

utility than others and that people will tend to have a cut-off point in what they will bother to process, depending upon their needs (see Binford, 1978: 32). The sequence of processing can be understood within a framework of Diet Breadth and Optimal Foraging Theory (Outram, 2004).

A very clear pattern emerges from the subsistence-stressed, Norse sites on Greenland. Very heavy grease processing has been carried out. Figure 2 shows the combined results from two sites regarding the categorization by fragment size classes. Very few whole elements or epiphyses (P/W) survive on these sites. Figure 3 shows the numbers of different types of bone fragments within the size classes at one of these sites. Larger size classes are dominated by shaft bone fragments and ribs. The vast majority of cancellous bone material from vertebrae and epiphyses has

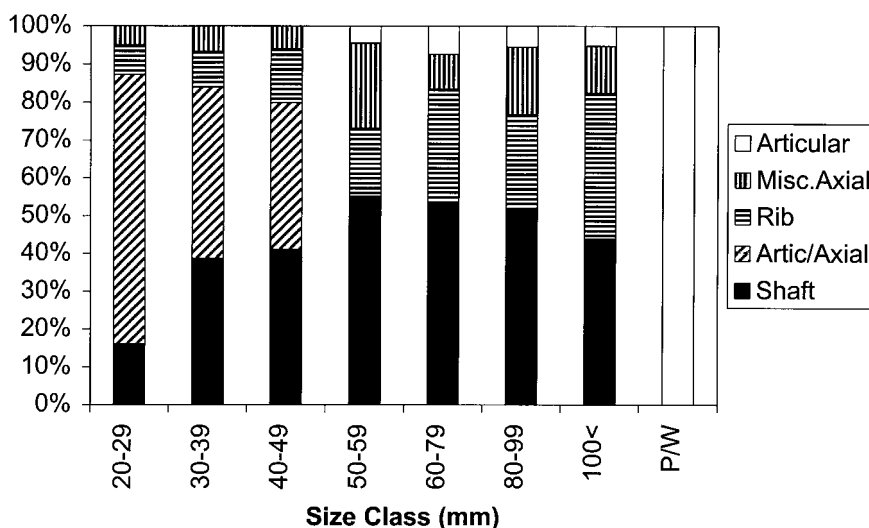


Figure 3: Types of bone fragments in different size classes at Sandnes (V51).

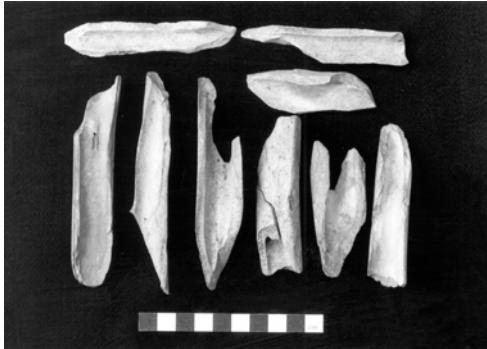


Figure 4: Helically-fractured shaft splinters from Sandnes resulting from marrow extraction (scale in 1cm divisions).

been heavily comminuted. Figures 4, 5 and 6 show what this assemblage looks like photographically. Figure 7 shows the use of the six point scale to characterize fracture types. It shows that bones were predominantly broken whilst in a fresh state, ruling out large amounts of later, post-deposition fracturing (as does the survival of large amounts of fragile, yet relatively undamaged ribs). Instances of dynamic impact scars were high. Levels of carnivore gnawing were very low.

The interpretation of these sites (Outram, 1999, 2003) is that almost all elements were rendered for fat. The only exceptions are the ribs which provide poor quality fat due to high levels of blood content (Rixson, 2000, 11). This interpretation could only be reached, and problems of equifinality bypassed, because a highly detailed taphonomic picture was built up through the laborious assessment of many variables. It is clear what has and has not been fragmented, it is clear to what extent fracture occurred before or after deposition, evidence for deliberate, dynamic fracture has been assessed and the

role of carnivores has been studied. Our understanding of density-mediated attrition from bone mineral density studies also helps to rule out that interpretation due to the plentiful survival of fragile ribs. Our knowledge of the fat utility of different elements helps us put the bone processing decisions of past people within a palaeoeconomic framework, possibly through the application of optimal foraging theory.

Discussion and Conclusion

It is clear that bone grease rendering could have a drastic effect upon skeletal part abundance patterns. The prevalence of such practices within ethnographies suggests that it was widespread amongst peoples of the recent past (and many still today) and, therefore, was probably a significant feature in the formation of many archaeological bone assemblages. Detailed analysis of fracture types and fragmentation



Figure 5: Heavily comminuted cancellous bone from Sandnes resulting from bone grease rendering (scale in 1cm divisions).

patterns using the methods outlined above, or ones like them, can identify such patterns and avoid problems of equifinality due to the level of detail in the data and the number of taphonomic variables considered.

Such a methodology has wide reaching application beyond the identification of one mechanism that affects skeletal part abundances. This general approach would, in many cases, allow analysts to assess the differential contributions of the pre- and post-depositional forms of attrition on bone assemblages. When this information is considered alongside our knowledge of element utility and bone density it will be far more possible to establish which



Figure 6: Large, unprocessed rib fragments from Sandnes (scale in 1cm divisions).

mechanisms led to a given end pattern.

This paper calls for a shift in emphasis towards higher-resolution, multi-variable taphonomic analysis of

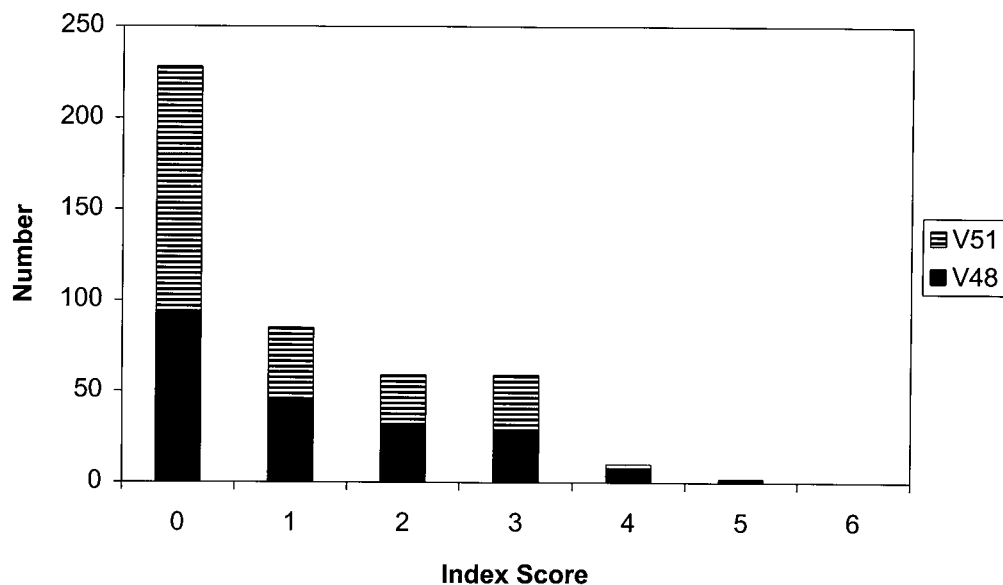


Figure 7: A bar chart showing the number of shaft fragments assigned to different fracture type scores at Sandnes (V51) and Niaquussat (V48).

archaeological faunal assemblages. Whilst more labour intensive, such an approach stands a much better chance of resolving problems of equifinality than the post-analysis application of interpretative indices. The more widespread application of fracture and fragmentation studies is recommended.

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References

- Bar-Oz, G. and Dayan, T. (2002). "After 20 years": a taphonomic re-evaluation of Nahal Hadera V, an Epipalaeolithic site on the Israeli coastal plain. *Journal of Archaeological Science*, 29: 145-156.
- Bartram, L.E. and Marean, C.W. (1999). Explaining the 'Klasies Pattern': Kua Ethnoarchaeology, the Die Kelders Middle Stone Age archaeofauna, long bone fragmentation and carnivore ravaging. *Journal of Archaeological Science*, 26: 9-29.
- Binford, L.R. (1978) *Nunamuit ethnoarchaeology*. Academic Press, New York.
- Blumenshine, R.J. & Madrigal, T.C. (1993). Variability in long bone marrow yields of East African ungulates and its zooarchaeological implications. *Journal of Archaeological Science*, 5: 555-587.
- Boyle, K.V. (1990). *Upper Palaeolithic faunas from South-West France: A zooarchaeological perspective*. BAR International Series 557. British Archaeological Reports, Oxford.
- Brain, C.K. (1967). Hottentot food remains and their bearing on the interpretation of fossil assemblages. *Scientific Papers of the Namib Desert Research Station*, 32: 1-7.
- Brain, C.K. (1969). The contribution of Namib Desert Hottentots to an understanding of australopithecine bone accumulations. *Scientific Papers of the Namib Desert Research Station*, 39: 13-22.
- Brink, J. and Dawe, B. (1989). *Final Report of the 1985 and 1986 field season at Head- Smashed-In Buffalo Jump, Alberta*. Archaeological Survey of Edmonton Manuscript Series 16, Edmonton.
- Dobney, K.M. and Rielly, K. (1988). A method for recording archaeological animal bones: the use of diagnostic zones. *Circaea*, 5: 79-96.
- Gifford-Gonzalez, D. (1989). Ethnographic analogues for interpreting modified bones: some cases from East Africa. In (Bonnischen, R. and Sorg, M.H., eds.) *Bone modification*. Orono: University of Maine Center for the Study of the First Americans. pp.431-471
- Harland, J., Barrett, J. Carrott, J., Dobney, K. and Jacques, D. (2003). An integrated zooarchaeological database for research and teaching. *Internet Archaeology*, 13.
- Johnson, E. (1985). Current developments in bone technology. In (Schiffer, M.B., ed.) *Advances in archaeological method and theory Vol. 8*. New York: Academic Press, pp.157-235.
- Jones, K.T. and Metcalfe, D. (1988). Bare bones archaeology: bone marrow indices and efficiency. *Journal of Archaeological Science*, 15: 415-423.
- Klein, R.G. (1976). The mammalian fauna of the Klasies River Mouth sites, Southern Cape Province, South Africa. *South African Archaeological Bulletin*, 31: 75-98.
- Klein, R.G. (1989). Why does the skeletal part representation differ between smaller and larger bovids at Klasies River Mouth and other archaeological sites? *Journal of Archaeological Science*, 16: 363-381.
- Klein, R.G., Cruz-Uribe, K. and Milo, R.G. (1999). Skeletal part representations in archaeofaunas: comments on "Explaining the 'Klasies Pattern': Kua Ethnoarchaeology, the Die Kelders Middle Stone Age archaeofauna, long bone fragmentation and carnivore ravaging" by Bartram & Marean. *Journal of Archaeological Science*, 26: 1225-1234.
- Knüsel, C.J. and Outram, A.K. (2004). Fragmentation: the zonation method applied to fragmented human remains. *Environmental Archaeology*, 9: 85-98.
- Lam, Y.M., Chen, X. and Pearson, O.M. (1999).

- Intertaxonomic variability in patterns of bone density and differential representation of bovid, cervid, and equid elements in the archaeological record. *American Antiquity*, 64: 343-362.
- Lam, Y.M., Pearson, O.M., Marean, C.W. and Chen, X. (2003). Bone density studies in zooarchaeology. *Journal of Archaeological Science*, 30: 1701-1708.
- Leechman, D. (1951). Bone Grease. *American Antiquity*, 16: 355-356.
- Leechman, D. (1954). The Vanta Kutchin. *National Museum of Canada Bulletin*, 130: 1-17.
- Lyman, R.L. (1985). Bone frequencies: differential transport, *in situ* destruction, and the MGUI. *Journal of Archaeological Science*, 12: 221-236.
- Lyman, R.L. (1994a). Quantitative Units and Terminology in Zooarchaeology. *American Antiquity*, 59: 36-71.
- Lyman, R.L. (1994b). *Vertebrate Taphonomy*. Cambridge University Press, Cambridge.
- Lyman, R.L. and O'Brien, M.J. (1987). Plow -zone zooarchaeology: fragmentation and identifiability. *Journal of Field Archaeology*, 14: 493-498.
- Lyman, R.L., Savelle, J.M. & Whitridge, P. (1992). Derivation and application of a meat utility index for phocid seals. *Journal of Archaeological Science*, 19: 531-555.
- Marean, C.W. and Frey, C.J. (1997). Animal bones from caves to cities: reverse utility curves as methodological artifacts. *American Antiquity*, 62: 698-711.
- Marean, C.W. and Spencer, L.M. (1991). Impact of carnivore ravaging on zooarchaeological measures of element abundance. *American Antiquity*, 56: 645-658.
- Marshall, F. and Pilgram, T. (1991). Meat versus within bone nutrients: another look at the meaning of body part representation in archaeological sites. *Journal of Archaeological Science*, 18: 149-163.
- Metcalfe, D. and Jones, K.T. (1988). A reconsideration of animal body-part indices. *American Antiquity*, 53: 486-504.
- Morlan, R.E. (1984). Toward the definition of criteria for the recognition of artificial bone alterations. *Quaternary Research*, 22: 160-171.
- Morlan, R.E. (1994). Bison bone fragmentation and survivorship: a comparative method. *Journal of Archaeological Science*, 21: 797-807.
- Munro, N.D. and Bar-Oz, G. (2005). Gazelle bone fat processing in the Levantine Epipalaeolithic. *Journal of Archaeological Science* 32:223-239.
- O'Connell, J.F., Hawkes, K. and Blurton-Jones, N. (1988). Hadza hunting, butchering, and bone transport and their archaeological implications. *Journal of Anthropological Research*, 44: 113-161.
- 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: 301-316.
- Outram, A.K. (1999). A Comparison of Palaeoeskimo and Medieval Norse Bone Fat Exploitation in Western Greenland. *Arctic Anthropology*, 36: 103-117.
- Outram, A.K. (2000). Hunting meat and scavenging marrow? A seasonal explanation for Middle Stone Age subsistence strategies at Klasies River Mouth. In (Rowley-Conwy, P.A., ed.) *Animal bones, human societies*. Oxford: Oxbow. pp.20-27.
- Outram, A.K. (2001a). Economic Anatomy, Element Abundance and Optimality: A New Way of Examining Hunters' Bone Transportation Choices. In (Millard, A., ed.) *Proceedings of archaeological sciences '97*. BAR International Series 939. Oxford: British Archaeological Reports. pp.117 – 126.
- Outram, A.K. (2001b). The scapula representation could be the key: A further contribution to the 'Klasies Pattern' debate. *Journal of Archaeological Science*, 28: 1259-1263.
- Outram, A.K. (2001c). A new approach to identifying bone marrow and grease exploitation: why the "indeterminate" fragments should not be ignored. *Journal of Archaeological Science*, 28: 401-410.
- Outram, A.K. (2002). Bone fracture and within-bone nutrients: an experimentally based method for investigating levels of marrow extraction. In (Miracle, P. and Milner, N., eds.) *Consuming passions and patterns of consumption*. Cambridge: McDonald Institute for Archaeological Research. pp.51-64.
- Outram, A.K. (2003). Comparing levels of subsistence stress amongst Norse settlers in Iceland and Greenland using levels of bone fat exploitation as an indicator. *Environmental Archaeology*, 8: 119-128.
- Outram, A.K. (2004). Identifying dietary stress in marginal environments: bone fats, optimal foraging theory and the seasonal round. In (Mondini, M., Muñoz, S. and Wickler, S., eds.) *Colonization, migration and marginal areas: A zooarchaeological approach*. Oxford: Oxbow. pp.74-85.
- Outram, A.K. (in press). Juggling with indices: A

Fracture and fragmentation

- review of the evidence and interpretations regarding Upper Palaeolithic horse skeletal part abundance. In (Olsen S., ed.) *Proceedings of horses and humans symposium*. Pittsburgh: Carnegie Museum of Natural History.
- Outram, A. and Rowley-Conwy, P. (1998). Meat and marrow indices for horse (*Equus*). *Journal of Archaeological Science*, 25: 839-849.
- Pickering, T.R. and Carlson, K.J. (2002). Baboon bone mineral densities: implications for the taphonomy of primate skeletons in South African cave sites. *Journal of Archaeological Science*, 29: 883-896.
- Ringrose, T.J. (1993). Bone Counts and Statistics: A Critique. *Journal of Archaeological Science*, 20: 121-157.
- Rixson, D. (2000). *The History of meat trading*. Nottingham University Press, Nottingham.
- Rowley-Conwy, P., Halstead, P. and Collins, P. (2002). Derivation and application of a food utility index (FUI) for European wild boar (*Sus scrofa* L.). *Environmental Archaeology*, 7: 77-87
- Savelle, J.M. and Friesen, T.M. (1996). An Odontocete (Cetacea) meat utility index. *Journal of Archaeological Science*, 23: 713-721.
- Savelle, J.M., Friesen, T.M. and Lyman, R.L. (1996). Derivation and application of an Otariid utility index. *Journal of Archaeological Science*, 23, 705-712.
- Stiner, M.C. (2002). On *in situ* attrition and vertebrate body part profiles. *Journal of Archaeological Science*, 29: 979-991.
- Symmons, R. (2004). Digital photodensitometry: a reliable and accessible method for measuring bone density. *Journal of Archaeological Science*, 31: 711-720.
- Villa, P. and Mahieu, E. (1991). Breakage patterns of human long bones. *Journal of Human Evolution*, 21: 27-48.
- White, T.E. (1952). Animal bone and plains archaeology. *Plains Archaeological Conference Newsletter*, 4: 46-48.
- White, T.E. (1953). Observations on the butchering technique of some aboriginal peoples: no. 2. *American Antiquity*, 19: 160-164.
- Wilson, G.L. (1924). *The horse and dog in Hidatsa Culture*. New York: Anthropological Papers of the American Museum of Natural History 15, 2.