Chapter 20
Calibrating Nutritionally Driven Selective Transport

Chapter 19 contextualized human decisions about which parts of larger animal bodies to carry to secondary locations and which to discard where they were initially processed, stressing that zooarchaeological inferences about transport primarily rest upon element frequencies. Zooarchaeologists' ability to assess nutritional values of different skeletal elements may elucidate these decisions. This chapter reviews zooarchaeologists' attempts to calibrate the nutritional yields of different body segments, which may motivate selective discard and transport of them. Chapter 21 discusses the other determinant of element frequencies in archaeofaunas: the differing durabilities of various skeletal elements in the face of destructive processes. In both cases, archaeologists have striven to find measures of bone's intrinsic properties, so that these can be applied in reasoning about element frequency patterning in archaeofaunas.

20.1 Making Sense of Element Frequencies: Nutritional Utility Analyses

As noted in Chap. 5, in the late 1970s and early 1980s, several publications brought a nutritional focus to archaeofaunal analysis. Speth and Spielmann (1983) introduced consideration of the uniform physiological needs of mammals living in strongly seasonal climates, especially the effects of seasonal variations in prey species' fat content, on human hunters prey and processing choices. Binford (e.g. 1977, 1978, 1980, 1981) wished to define "uniformitarian principles" to aid in exploring the evolution of modern human behavior, defining three lines of evidence likely to been uniform through hominin history, and to have affected the structure of archaeological sites: prey animal anatomy, regional ecology, and spatial consequences of the human body's size and organization on site structure. He accordingly advocated actualistic research with modern analogues and pursued research on all three lines among the Nunamiut people of the Anaktuvuk Pass area of the Brooks Range, Alaska.

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20.1.1 Constructing Relative Nutritional Values for Archaeofaunal Materials

In *Nunamiut Ethnoarchaeology* (Binford 1978), presented data on variable decisions regarding prey body segment transport according to specified situational factors. Binford presented a method for assessing the "economic anatomy" of prey animal bodies. The method was intended to be tool for reading the logic of butchery, transport, and discard behavior by hunters, and beyond that, for diagnosing activity and site type from archaeofaunal assemblages. The basics may be condensed as follows:

1. Skeletal element frequencies in archaeofaunas can be quantified.
2. Every element can be analyzed for its associated nutritional values.
3. Element frequencies in archaeofaunas reflect nutritionally motivated body segment selection or abandonment by butchers.
4. This in turn can suggest the function of the site yielding the archaeofauna – kill-butchery versus residential, for example.

Such understandings could permit insights into the planning depths with which hunters made decisions about using animals as food. Grayson (1989:643) succinctly described this approach: "people optimally forage across the body of an animal, as some believe people optimally forage across larger landscapes."

To provide key data for this analysis Binford (1978) devised a set of relative measures of associated nutritional values of caribou and sheep skeletal elements, which he named "utility indices." These numerically express the relative nutritional value of all tissues associated with a bone unit, 100.00 being assigned to the element with the highest nutrient yield and proportionate values for other units calibrated against this value. Binford commissioned nutritional analyses of two domestic sheep and a caribou body segments, to note meat, marrow, and bone-grease yields for each segment. These nutritional values served as the basis of indices for meat (Meat Utility Index), marrow (Marrow Index), and bone grease (White Grease Index) for the two species (Table 20.1).

Utility indices were based on individual bones, bone segments (e.g. proximal versus distal humerus), or to groups of bones (e.g. ribs, lumbar vertebrae). Binford's definition of carcass units stemmed from functional units observed in Nunamiut carcass processing (Binford 1978). He (1978:50, 62) assigned different MGUI values to proximal and distal ends of long bones, probably because Nunamiut often smash through the shafts of these elements when removing frozen limbs from meat caches. This type of carcass handling is not used regularly in other latitudes and led to later utility index modifications, discussed below. Binford combined all three values for each element or portion into the General Utility Index (GUI), a calculation found in Binford (1978:18–38). He noted that Nunamiut butchers often carried low-utility carpals, patellae, and tarsals from a butchery site as part of larger body segments. Reasoning that these low utility "riders" were transported because it would have cost butchers more time and energy to remove them in the field than it

Table 20.1. Binford's (1978, b:74, Table 2.7). MGUI values for caribou and sheep and Metcalfe and Jones's standardized (S)FUI values, and FUI values from Metcalfe and Jones (1988:492, Table 2). Radius and ulna values duplicate Binford's single set of values for both elements, listed as "radiocubitus"

Element	Caribou MGUI Base 100	Sheep MGUI Base 100	Caribou (S)FUI Base 100	Caribou FUI
Antler/horn	1.02	1.03	1.0	1
Cranium (CRA)	17.49	12.87	18.2	469 (235)
Mandible				
With tongue	30.26	43.60	31.1	1600
Without tongue	13.89	11.65	11.5	590
Atlas (ATL)	9.79	18.68	10.2	524
Axis (AXI)	9.79	18.68	10.2	524
Cervical (CER)	35.71	55.33	37.1	1905
Thoracic (THO)	45.53	46.49	43.3	2433
Lumbar (LUM)	32.05	38.90	33.2	1706
Sacrum (SAC)[a]	39.97	60.20	41.3	–
Innominate (PEL)	47.89	81.50	49.3	2531
rib (RIB)	49.77	100.00	51.6	2650
Sternum (STE)	64.13	90.52	66.6	3422
Scapula (SCP)	43.47	45.06	44.7	2295
p humerus (P HUM)	43.47	37.28	44.7	2295
d humerus (D HUM)	36.52	32.79	36.8	1891
p radius (P RAD)	26.64	24.30	25.8	1323
d radius (D RAD)	22.23	20.06	20.2	1039
p ulna (P ULN)	26.64	24.30	25.8	1323
d ulna (D ULN)	22.23	20.06	20.2	1039
Carpals (average)	15.53	13.43	12.7	653
p metacarpal (P MC)	12.18	10.11	9.0	461
d metacarpal (D MC)	10.50	8.45	7.1	364
p femur (P FEM)	100.00	80.58	100.00	5139
d femur (D FEM)	100.00	80.58	100.00	5139
Patella (PAT)[a]	82.37	66.29	81.4	–
p tibia (P TIB)	64.73	51.99	62.8	3225
d tibia (D TIB)	47.09	37.70	44.1	2267
Astragalus (AST)	31.66	23.08	27.7	1424
Calcaneus (CAL)	31.66	23.08	27.7	1424
Tarsals (TAR)	31.66	23.08	27.7	1424
p metatarsal (P MT)	29.93	15.77	19.5	1003
d metatarsal (D MT)	23.93	12.11	15.4	792
Phalanx 1(PHA1)	13.72	8.22	8.6	443
Phalanx 2 (PHA2)	13.72	8.22	8.6	443
Phalanx 3 (PHA3)	13.72	8.22	8.6	443

[a] Not listed by Binford, but MGUI value calculated by averaging distal femur and proximal tibia MGUI values, per Binford's treatment of "riders." See discussion in Metcalfe and Jones (1988:490–491). Values in parentheses in Metcalf and Jones's FUI are considered more realistic estimates, due to the high proportion of cartilage in the cranium originally weighed as usable meat

did to carry them, Binford modified the GUI to take this into account. He adjusted the GUI of "riders" by averaging their actual GUI with that of their adjacent, higher-value elements, producing the Modified General Utility Index (MGUI) for each unit (Table 20.1).

20.1.2 "Utility Curves"

Binford expected patterning in archaeofaunal assemblages to reflect choices based on such economic anatomy as indexed by MGUI, with highest-ranking body segments transported away from carcass acquisition locales at differentially higher rates than lower ranked ones. Based upon his experience with the Nunamiut, he argued that carcass processing in different seasons and with varied numbers of animals acquired should be expected to produce strategic variability in element frequencies and associated processing marks. He stipulated that, within each seasonal situation, strong regularities should exist in the carcass segments transported to residential sites and those left behind at kill/butchery sites, the results of reiterated, rational decisions by hunters and their households.

Binford constructed hypothetical models, or "utility curves," for with relative element frequencies in assemblages at different site types, usually expressed as %MAU (Chap. 10) plotted against MGUI values in an x-y plot. He argued that mass kill-butchery sites, where low utility elements would systematically be discarded, would display an "inverse bulk utility curve," with high frequencies of low MGUI elements, and low frequencies of high utility elements (Fig. 20.1). More selective butchery and transport tactics, Binford argued, would produce an "inverse gourmet utility curve," with the same high frequencies of low MGUI elements but in addition higher frequencies of elements with middling MGUI values, reflecting a focus on the very highest-utility elements (Fig. 20.1). He predicted that residential bases would display the inverse of element frequency patterns from kill-butchery sites: "bulk utility curves" (Fig. 20.1), essentially the mirror image of inverse bulk utility curve, or "gourmet utility curves" (Fig. 20.1).

To assess these predictions, Binford tabulated element frequencies from documented Nunamiut kill-butchery sites, hunting stands, and residential encampments. He sometimes hand-drew curves to his x-y point plots of %MAU to MGUI (Fig. 20.2), but he never calculated correlation coefficients nor fit curves via regression analyses. This would have been problematic, given the ordinal nature of the utility index variables. Binford demonstrated that element representation at Nunamiut mass kill-butchery sites generally matched the "Inverse Utility" curve (Fig. 20.2), which supported his predictions. On that basis, he asserted that a utility-curve approach was a useful tool for exploring transport choices, and hence site function, in archaeological cases. However, residential sites did not produce a mirror image of the "Inverse Utility" pattern, nor have they in other ethnoarchaeologically documented cases, as will be discussed later in this chapter.

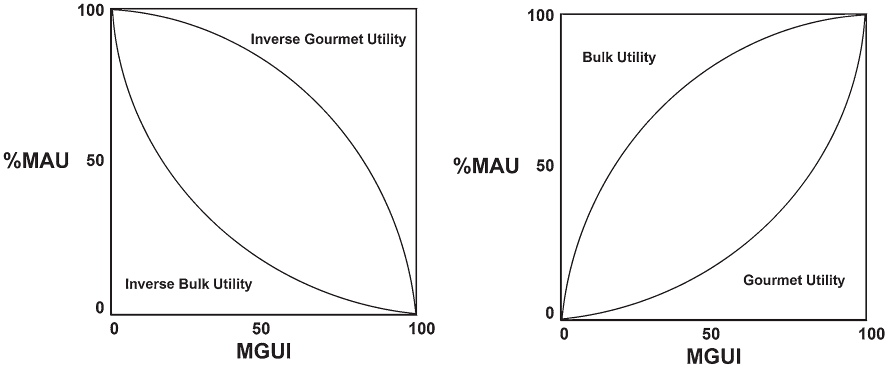

Fig. 20.1 *Left***:** schematic representation of Binford's "inverse bulk utility curve" and inverse gourmet utility curve, with element frequencies indexed by %MAU against MGUI. *Right***:** schematic representation of Binford's bulk utility and gourmet utility curves, the mirror-images of the inverse utility curves in the previous figure (Redrawn from Binford (1978: :81, Fig. 2.18). Used with permission of the Lewis R. Binford Estate and Elsevier/Academic Press)

20.2 Early Applications of the Utility Index Approach

In *Bones: Ancient Men and Modern Myths,* Binford (1981) used utility curves to analyze archaeological materials from Olduvai Gorge, Bed I. From the relative infrequency of high-utility elements of large mammals in these sites, he inferred that early hominins did not transport choicer carcass parts to consumption locales, but rather took the leavings from carnivore kills and other animal deaths. Analyzing the Klasies River Mouth Cave (1984) archaeofauna, Binford used %MAU:MGUI as one line of evidence to argue that archaic *Homo sapiens*, then the presumed creators of Klasies' Middle Stone Age deposits could only successfully hunt game their own body size or smaller, that they scavenged larger mammal species, which displayed a strong inverse bulk utility curve. Binford's interpretations of the Klasies pattern were later undermined by the association of MSA deposits with modern *Homo sapiens* (Jacobs et al. 2008) and critiques based on collection bias in specimen selection (Turner 1989).

Thomas and Mayer (1983) analyzed a thick deposit of bighorn sheep (*Ovis canadensis*) bones in Gatecliff Shelter in Nevada, using MGUI. They determined that the assemblage displayed an inverse bulk utility curve and inferred that this layer represents a butchery event from which high utility elements had been deleted. Speth (1983) used MGUI values in analyzing the Garnsey bison kill site and found a general inverse bulk utility pattern of representation. He noted that relatively high-utility elements of male bison were taken from the kill, whereas the same elements of female bison were abandoned in place. He proposed that this spring season kill was exploited for marrow by fat-depleted human hunters, with the male bison being in better condition than reproducing females, and thus more attractive to human consumers.

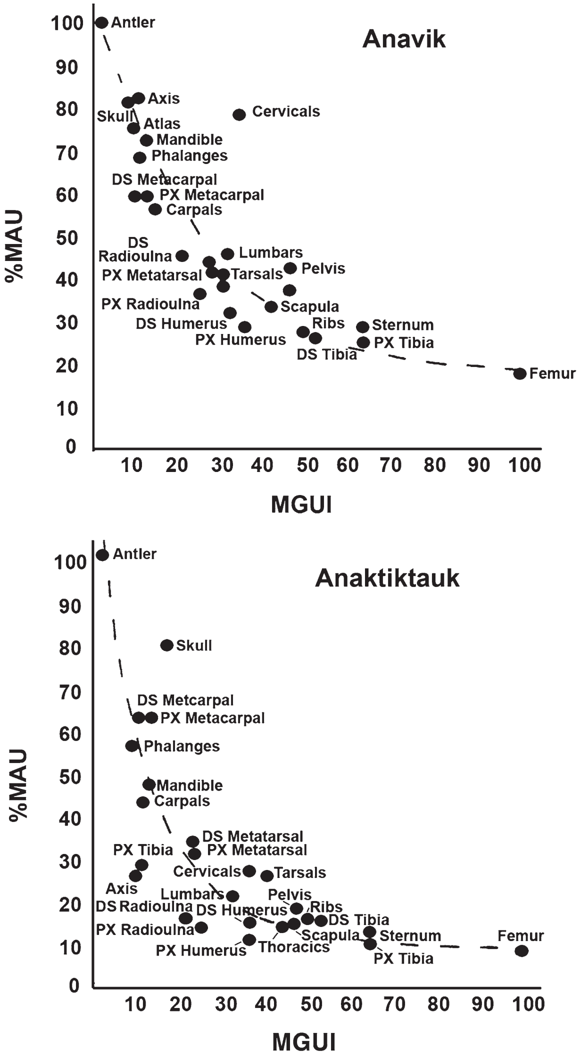

Fig. 20.2 Two examples of inverse utility curves from actual Nunamiut caribou kill-butchery sites, plotted as %MAU against MGUI, with hand-fit curves. Note: Binford originally used the term "MNI" for MAU in his graphics, but later renamed this MAU when it was clear that his mode of calculating this statistic deviated considerably from those for reckoning MNI (Redrawn by the author from Binford (1978: 80, Figs. 2.14, 2.15). Used with permission of the Lewis R. Binford Estate and Elsevier/Academic Press)

20.3 Problems with Calculating and Using Utility Indices and Curves

As zooarchaeologists tried to replicate and apply Binford's utility indices, three problems emerged. The first related to calculating the values, the second pertained to appropriate methods for comparing element frequency patterning statistically, and the third involved the broader question of whether human choice was the main determinant of element frequencies in archaeofaunas. This section addresses the first two issues, and Chap. 21 reviews the third.

20.3.1 Alternate Approaches to Calculating Utilities

Metcalfe and Jones (1988) reported that they could not readily replicate Binford‘s original GUI calculations using his published data and suggested a simpler method of reckoning the index. Noting that Binford‘s original calculations for the Meat Utility Index (MUI) were quite complicated, they proposed that a similar result could be produced by the following calculation:

$$\text{MUI} = \text{gross weight of part} - \text{dry bone weight of part}$$

The “gross weight of a part” is that of a fully fleshed element or body segment, including all marrow, grease, fat, and meat, so MUI lumps total meat, fat, marrow, and grease weights in the calculation. Metcalfe and Jones noted that it is probably not worthwhile to separate the MUI from the grease utility index (GUI) since, in their analysis, the correlation coefficient of MUI to GUI is 1.00. They argued that this simplified approach permits a more straightforward calculation of nutritional value than Binford’s approach, which may in turn encourage researchers to construct indices for taxa with substantially different anatomy from the two that Binford analyzed. Metcalfe and Jones went on to propose the “food utility index” (FUI), in which low-utility “riders” are handled with the same averaging approach applied by Binford in creating the MGUI (Table 20.1). Metcalfe and Jones (1988:496) noted that some of Binford‘s original analytic units for MGUI were not realistic in many situations, asserting that whole-long bone values, rather than Binford’s proximal and distal values, are more broadly useful, for cases in which butchers dismember carcasses by cutting through joints, as do Nunamiut people with warm-weather kills. Food utility indices have been derived for other economically important species. (e.g. O'Brien and Liebert 2014; Rowley-Conwy et al. 2002)

Metcalfe and Jones also challenged Speth‘s assertion that relative fat level is the only utility-related variable that could account for the Garnsey assemblage. They argued that the sex-biased selectivity reflected in the archaeofauna could simply stem from the considerable sexual dimorphism between male and female bison: any body segment of a male, they argue, would yield more of all nutrients than would the same part of females. “We suspect that much, if not all, of the variation noted by Speth in the selection of body parts would be accounted for simply as a function of their different FUI values” (Metcalfe and Jones 1988:500).

In their 1988 article, Metcalfe and Jones did not discuss whether marrow utilities could sometimes usefully be treated as a separate variable rather than as a component of the FUI. By definition, seasonal variations between sexes in FUI values for a given element would incorporate fluctuating fat (and white marrow) levels. However, in another article the same year (Jones & Metcalfe 1988), they outlined their difficulties in replicating Binford’s (1978) marrow utility index, which was based upon a calculation from three variables: an element’s actual marrow cavity volume; fat quality, with a positive weighting for the proportion of oleic acid, and processing time. Working with Binford's own data (1978:24, 30) on Nunamiut selection of skeletal elements to prepare *akutuk*, a marrow-based delicacy, they reported the strongest correlation (*r* = 0.97) with a single variable, marrow cavity volume. They reported a much weaker, negative relationship (*r* = −0.53) between oleic acid content and Nunamiut selectivity of skeletal elements as reported by Binford and therefore dismiss fatty acid content as a predictor of selectivity. They recommended empirically deriving and using this value for species studied, as a proxy for the volume of marrow available in any given element, for any assessments of relative marrow value. Foreshadowing the approach taken by Lupo (2006; Chap. 19), Jones and Metcalfe recommended taking a return rate approach to marrow indices, assessing each elements' marrow yields in light of the processing times involved in retrieving the marrow from it. Using Binford's data, they offered such return rates for caribou elements (Jones & Metcalfe 1988: 421, Table 3, Fig. 3).

Morin (2007) reviewed ethnographic, zooarchaeological, and physiological research and offered new insights on the underlying aspects of marrow bone selectivity discussed by Binford and Jones and Metcalf. Returning to the relationship of specific fatty acid content to human selectivity, Morin reported that marrow of ungulates' limb extremities is proportionately higher in unsaturated fatty acids, including oleic and palmitoleic acids (Fig. 20.3). This marrow is softer and considered more palatable by an array of ethnographic informants in various studies. In reviewing Binford's *akutuk* study and Metcalfe and Jones's critique of it, Morin noted that the respective researchers were not assessing the same variables. Binford was assessing Nunamiut *selectivity* for *akutuk* preparation, relative to a specific set of previously stockpiled marrowbones. By contrast, because their aim was to develop a method widely applicable to archaeological cases, in which the original pool from which elements were selected is unknown, Metcalfe and Jones were assessing the *rank order* (expressed as %MAU) of elements selected, without reference to the original stock. Morin found that upper leg elements of fore and hind legs, with lower proportions of unsaturated fatty acids, were less frequently selected for *akutuk* (Fig. 20.3). He states, "Although the proportions of skeletal parts selected for marrow procurement are strongly correlated with marrow quantity, a stronger correlation was found with quantity of unsaturated fatty acids" (Morin 2007: 69). This contradicts Metcalfe and Jones's inference that specific fatty acid content bears little relation to human choice of elements.

Based on his analyses, Morin proposed a new scale of marrow utility, the Unsaturated Marrow Index, to more accurately calibrate the relative nutritional values of different marrow-bearing long bones. Given the importance of EFA's in supporting brain and neural development during pre-and post-natal human development (Chap. 5), this later research supports application of some form of a marrow utility assessment in assemblage analysis.

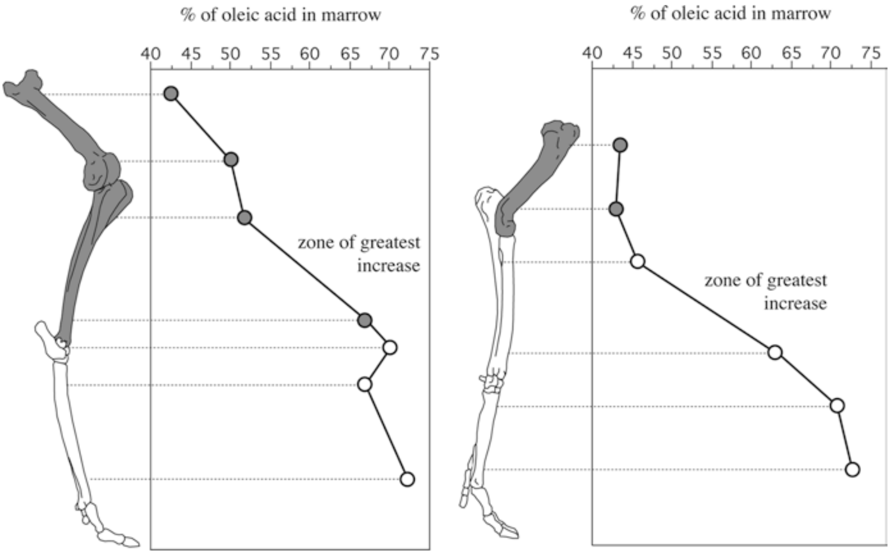

Fig. 20.3 Diagrammatic representation of increases in oleic acid in hind leg (left) and foreleg (right) of caribou, showing higher incidence in distal long bones and zones of greatest gain in oleic acid for each limb set (From Morin 2007:75, Fig. 7, used with permission of E. Morin and Elsevier)

20.3.2 Other Studies Calibrating Nutritional Utility

The phylogenetic history and functional anatomy of large land and marine mammals is diverse, and zooarchaeologists have undertaken economic anatomy studies of a number of species to better understand the constitution of archaeofaunas on several continents. While not using precisely the methods of Binford or Jones and Metcalfe, Blumenschine and Madrigal (1993) reported on variations in marrow yields in eight species of African antelope, wild pig, and equid. Blumenschine and Caro described flesh yields of Thomson's (*Eudorcas thomsonii*) and Grant's (*Nanger granti*) gazelles, impala, and wildebeest (1986). Bar-Oz and Munro (2007) assessed marrow yields in mountain gazelle (*Gazella gazella*) in the Levant. Emerson (1990) derived utility indices for bison. Madrigal (2004) calculated utility indices for North American white-tailed deer (*Odocoileus virginianus*), while Belardi and Gómez Otero (1998) did so for the huemúl (*Hippocamelus bisulcus*), a South American deer. Argentinean archaeologists have derived meat utility indices for the wild South American camelid, the guanaco, *Lama guanicoe* (Borrero 1990), and for its marrow (Mengoni Goñalons 1996). Outram and Rowley-Conwy (1998) derived meat and marrow indices for equids. Two studies have specified the meat utility of phocid, or earless, seals (Diab 1998; Lyman et al. 1992), and one has described utility indices for otariid, or eared seals (Savelle et al. 1996). Savelle and Friesen (1996) derived a meat utility index for small- to medium-sizes toothed cetaceans such as dolphins (Delphinidae) and porpoises (Phocoenidae).

Savelle (1997) presented a thoughtful consideration on the architectural utility of cetacean skeletal elements in northern areas with a dearth of wood construction materials. He argued that bones of architectural potential, the cranium, mandible, maxilla/premaxilla, and cervical vertebrae, all have relatively low meat utilities but display high "architectural utility" at prehistoric Thule sites in the Arctic.

20.3.3 Drying Utility: Another Significant Index in Mass-Kill or Distant Transport Situations

Many foragers, whether engaging in mass-kill acquisition of large prey or serial predation on individual animals, dry meat to extend its "shelf-life" and to reduce its weight for transport, as do food-producing people in other situations. Friesen (2001), like Binford, analyzed sites reflecting Inuit caribou butchery and caching, and he revived a discussion of selectivity and transport and/or caching based upon various body segments' potential to produce dried meat for long-term storage. Binford (1978) had introduced the Drying Utility Index, using a rather complex formula that took into account the associated amount of meat of a skeletal element, as well as the potential of brain and marrow to cause meat spoilage. The derivation of the index incorporated the finite amount of meat associated with an element, the ratio of bone weight to gross weight, and the presence of brain or marrow in the associated element. Friesen (2001:319) rephrased the ideal body portion for drying as having, "a great quantity of meat attached, a high bone-to-gross-weight ratio, and no brain or marrow."

Much as Jones and Metcalfe simplified the MGUI to the FUI, Friesen (2001:319) rewrote the derivation of meat drying utility using simpler terms than those of Binford to derive a Meat Drying Index (MDI):

$$\frac{(\text{meat wt})(\text{bone wt})}{(\text{gross wt})(\%\text{brain marrow wt})}$$

Friesen's tabulation of MDI for caribou, based upon Binford's data, shows that the skeletal elements of the thorax (thoracic vertebrae, ribs, sternum), adjacent axial regions (cervicals, lumbars), and pelvic bones have the highest values, with ribs having more than two times the MDI of thoracic vertebrae (Table 20.2). Reworking Binford's data and that from three Barren Ground Inuit caches he excavated, Friesen argued that assessing element frequencies using the MDI has significant relevance for revealing preservational decisions in the field and in specific caches. However, he cautions that, especially at long-term encampments, the aggregate situational considerations and decisions involved in animal processing may obscure the "pure" patterns emerging from meat-drying choices.

De Nigris and Mengoni Goñalons (2005) applied Friesen's drying utility indices to central-west Patagonian sites spanning much of the Holocene, using actualisti-

Table 20.2 Friesen's (2001: 320, Table 2) adaptation of Binford's (1978) Meat Drying index (MDI). Shaded area shows highest-ranking elements for meat drying

Element	Gross Weight	Bone Weight	Brain or Marrow Weight	% Brain or Marrow Weight	Meat Weight	Meat Drying Index
Skull	1397.1	460.1	361.8	100.0	575.2	1.9
Mandible w/ tongue	1778.1	178.1	8.7	2.4	1591.3	66.4
Mandible w/out tongue	768.1	178.1	8.7	2.4	581.3	56.2
Atlas-axis	630.2	106.0	0	1.0	524.2	88.2
Cervical 2-7	2112.2	207.0	0	1.0	1905.2	186.7
Thoracic	2789.6	357.0	0	1.0	2432.6	311.3
Lumbar	1940.0	234.0	0	1.0	1706.0	205.8
Pelvis	3175.2	644.2	9.5	2.6	2521.5	196.8
Rib	3687.4	1037.0	0	1.0	2650.4	745.4
Sternum	3628.8	207.0	0	1.0	3421.8	195.2
Scapula	2398.4	103.0	4.0	1.1	2291.4	89.5
Humerus	1661.3	174.9	30.0	8.3	1456.4	18.5
Radius	918.5	164.0	28.4	7.9	726.1	16.4
Metacarpal	374.2	106.2	16.6	4.6	251.4	15.5
Femur	5342.3	202.9	41.1	11.4	5098.3	17.0
Tibia	1532.0	222.1	50.6	14.0	1259.3	13.0
Metatarsal	754.1	173.1	40.3	11.1	540.7	11.2
Phalanx	294.8	108.0	3.2	1.0	183.6	67.3

cally derived utility indices for the guanaco (Mengoni Goñalons 1996), the main mammal prey in the region. They derived a MDI for guanaco using Friesen's formula. Their use of these indices was aimed at better accounting for a pattern observed in cave and shelter assemblages in their study region, which displayed either no selective transport of body segments or a predominance of long bones and a lack of axial elements. In the study area, it is likely that animals were taken one-by-one, or in small numbers, rather than as mass kills, in a cold and dry landscape. One better-preserved archaeofauna had moderate to strong correlations of element frequencies to meat and marrow utilities, respectively. De Nigris and Mengoni Goñalons (2005) infer that this sample represents a locale for preferential processing and consumption of bones rich in meat and marrow and with low bone-to-meat proportions. They further proposed that this assemblage structure represents the starting point of a sequential chain of selective processing, transport, and consumption, with marrow-bearing long bones being processed and discarded first. De Nigris and Mengoni Goñalons do not explicitly state why these elements were processed earliest, but harking to discussions by Lupo (2006) and Emerson (1993) in Chap. 19 and Binford and Morin in this chapter, marrow must be consumed before it turns rancid – and discard of meat-stripped log bones reduces transport costs.

De Nigris and Mengoni Goñalons (2005:163) report that all assemblages displayed a significant *negative* correlation of element frequencies with MDI, implying that those bone units more suitable for drying were preferentially removed from acquisition locales to other places where they were processed for jerky. They infer, "Bones that are rich in meat only, and have a high bone to meat proportion were preferentially consumed later due to their suitability for drying" (2005:164). Thus, the authors are, without graphically depicting it as such, describing much the same spatiotemporal segregation of handling and consumption events as described in the *chaîne opératoire* approach advocated in Chap. 15. De Nigris and Mengoni Goñalons stress that the signature of selective transport for drying does not necessarily imply long-term storage. Rather, immediate consumption of marrow and meat, and short-term preservation of some meat from the same animal, "might have allowed inland Patagonian hunter-gatherers to cope with irregularities in the intake of energy such as nutritional stress related to the seasonal depletion of animal fat, and other temporal incongruencies" (2005:164).

20.4 Statistical Problems with Utility Curves

The x-y axis plots of %MAU to utility indices – especially Binford's curves fitted to the distribution of data points – suggest that parametric statistical analysis, e.g. Pearson's correlation coefficient or regression analyses (Siegel and Castellan 1988) might be appropriate (Chap. 18). Despite being expressed as ratios of 100, utility indices are not ratio scale variables that can be multiplied or divided into one another, and the intervals between them are irregular. They ordinal scale variables, which can be arranged from highest to lowest and vice-versa. Hence, they so they are not amenable to parametric statistical tests. Working with these values, Lyman (1985) and Grayson (1989) instead applied nonparametric rank-order tests appropriate to such ranked data, namely Spearman's rho or Kendall's tau. Fundamentally, these tests ask how well one variable, in this case a utility index (MGUI or FUI), predicts the frequency rankings of skeletal elements in a sample.

20.4.1 Are Utility Curves Actually Useful?

Binford hand-fit curves into distributions of %MAU in his Nunamiut data (Fig. 20.2), and others, such as Thomas and Mayer, also attributed the Inverse Bulk Utility strategy to a curve by inspection rather than through a statistical process. The Inverse (sometimes called Reverse) Utility Curve has been the focus of debate about its causes, as will be seen later in this chapter. Though critical of Binford's inference of human selectivity from this curve and advocating consideration of the bone mineral determinants of element, Lyman (1985, 1992) displayed data in the same manner. But, given that they cannot be subject to regression analyses, are such curves actually analytically useful?

I have found it helpful to start thinking through such published utility distributions by visualizing the natural distribution of skeletal MGUI or FUI values in the species under study. Each carcass offers an array of utility values upon which human decisions act, one carcass at a time, whether the handlers are processing a single animal or multiple animals acquired in a mass-kill. Iterative choices, acting on multiple carcasses with this array, create the curves discussed in the zooarchaeological literature, whether abstract or based on concrete archaeofaunal and ethnographic data.

Figure 20.4 shows this pattern for caribou (Binford 1978:74, Table 2.7) using "% of Skeleton" rather than %MGUI on the y-axis; base data for the graphic are in Table 20.1. A few points are apparent. First, most high-utility elements occur at frequencies of two per carcass, e.g. the femora, patellae as riders, and tibiae. Second, to create a high-utility array such as that modeled by Binford for the Gourmet Utility Curve (Fig. 20.1), with the majority of elements of MGUI greater than 50, many reiterated selections of such relatively rare elements must be made from multiple carcasses, all in the same high-utility mode. This level of selectivity is unlikely to be a realistic assemblage outcome. From Binford's account (1978: 60–61) of specific incidents in Johnny Rulland's acquisition of caribou and moose, it is possible that a single hunter can situationally adopt a gourmet strategy when encountering a large prey animal at a distance from a camp or longer-term residential base. The hunter butchered the animal competently but carried back to the base only the highest-ranked limbs, plus internal organs requiring immediate consumption. There, after a meal, the hunter could expect to recruit a carrying party to retrieve the rest of the kill, whereupon a bulk utility pattern transport is established. One such moose recovery was frustrated by an unexpected, nine-day snowfall, in which case the gourmet strategy held but would not have, had the carrying party not been stranded at camp by the blizzard, while the moose was buried under several feet of snow.

The classic Bulk Utility Curve model (Fig. 20.1) requires selecting differentially more elements in the MGUI 50–100 range. Of these, the 26 ribs, at MGUI 50 and constituting 19% of entire skeleton, would be the preponderant element (Table 20.2) but higher-ranked elements, constituting only 6% of the individual skeleton, would offer far fewer selection options on a carcass-by-carcass basis than predicted by the model. It may be unrealistic, even with mass kill processing, to expect that people would be so selective as to build such an assemblage at the end-point of transport, even mass kill situations.

However, one ethnographic case, so specific and localized that similar sites are unlikely to be found in most regions, shows such a curve. Caribou body units were introduced in 1971 and 1972 into Nunamiut ice cellars, large pits cut into a permanent, subterranean ice dome for frozen meat storage (Binford 1978: 127–129, Figs. 3.21, 3.22). Compared with kill-butchery sites from the same years, the utility distributions are not mirror images of those localities: they were biased differently each year by decisions by women of Anaktuvuk village made to include or exclude specific cuts of meat in the ice cellar, according to the overall fortunes of the spring hunting season. This process included discard outside the ice cellar of parts deemed to be from animals of poor condition, situationally broader inclusion of moderate utility parts in a year of poor hunting yields, and preferential transport from the

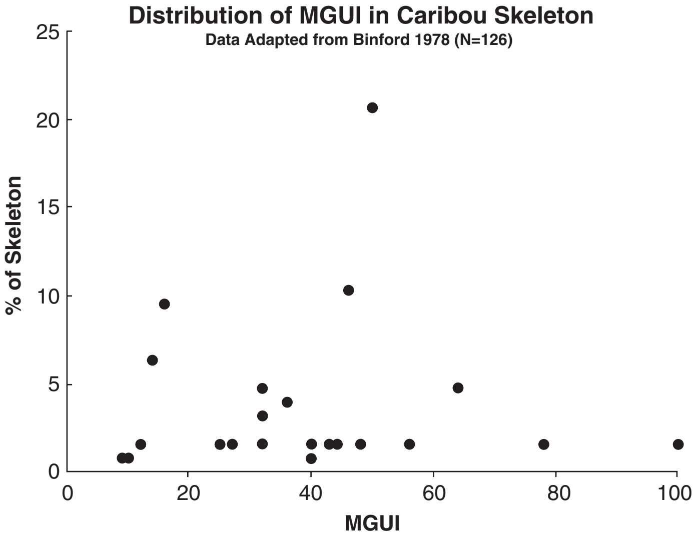

Fig. 20.4 Distribution of Modified General Utility Index values in a caribou skeleton. To convey the rates of occurrence of various elements with different MGUI values, the y-axis shows percent frequency of an element and its associated value in the caribou skeleton, rather than %MGUI, which also norms for these same element counts. Note: Binford used proximal and distal values for long bones, which inflates the contribution of long bones. To coincide more with ethnoarchaeological observations that butchers most often handle whole long bones, Binford's proximal and distal values are averaged and only one value per long bone is presented (Figure by the author, using Binford's 1978 MGUI data, see Table 19.1)

processing site to the main village of high-ranked skeletal segments. Such special storage facilities, at a distance from a village, simply due to the accident of nature that produced an ice deposit in the permafrost, thus reflect a double winnowing of mass kills, driven by considerations both of spoilage and of assessment of potential nutritional need in the season ahead. The example also points out the importance of "home base" management decisions on the constitution of specific deposits of skeletal elements.

The two inverse utility curves merit consideration, but perhaps for somewhat different reasons. The Inverse Gourmet Utility curve is unlikely to be realistic for reasons outlined above regarding the Gourmet Utility curve itself. The Inverse Bulk Utility curve has been the subject of much discussion about the influence of differential durability of different skeletal elements, to be taken up in detail in Chap. 21.

As noted by (Lupo 2001), residential assemblages as a whole reflect an average of varied situational decisions taken over the duration of use of site, in which even the same species are handled differently, due to the circumstances of acquisition and the varying needs of personnel at the home base. Binford (1978: 114–115) discussed the variations in causal factors that produced very different additions over three observed years of selective transport to the same locale, the winter village of Anaktuvuk. He never summarized the totality of utility signatures from the site.

However, if one were to sample skeletal elements across dog yard, meat rack, household, and bone grease assemblages mentioned in Binford, one receives the impression that this long-term, seasonal residential camp is not the simple inverse of kill-primary butchery localities.

Before leaving the role of nutritional utility in structuring assemblage composition, it is worth reiterating that modern caribou hunters such as the Nunamiut, from which many recent discussions of transport factors stemmed, are not typical of most hunters documented by ethnographic and historic records. In mass kills, an efficiency-driven system of body segment triage emerges: some are definitely marked for discard, others for transport, and yet others are transported or discarded according to situational factors. However, most large prey acquisition is one animal at a time, discussed by Emerson (1993) who analyzed transport under mass versus single acquisition, and others mentioned in Chap. 19. Analysts should certainly know enough about the habits of prey species encountered in archaeofaunas to grasp the range of encounter situations hunters might face with them – whether they are come upon singly or in groups –and reflect on how this will affect transport decisions.

20.4.2 Nutritional Utility or Return Rate?

As foreshadowed in Chap. 19's discussion of Hadza transport decisions and in citations in this chapter, a related measure of relative nutritional value of vertebrate body segments is available: the return rate. Return rates are widely used in behavioral ecological analysis in zoology because they provide a more realistic assessment of the trade-offs that specific resources offer foraging animals (Krebs and Davies 1993). Return rate refers to the net income, rather than the gross value, of a resource, in which the average costs of locating and processing the resource are deducted from the resource's absolute value. In behavioral ecology, the income is normally calibrated in kilocalories, while for reasons of practical expediency, the costs are usually calibrated in time as a proxy for energy expended (Chap. 24). The base assumption is that, the greater the time expended, the more calories are spent as well. Two classic classifications of time invested in obtaining a resource are deducted from the net energy yield of the resource: search time and handling time.

In most applications of return rates to species other than humans, species or taxonomic groups are ranked as food resources in terms of net caloric returns (Barlow and Metcalfe 1996; Bettinger et al. 1997). This is a logical outgrowth of patch choice theory, which will be described in more detail in Chap. 24. For human foragers using animal prey, the matter is more complicated because costs of search and handling often involve effort invested in developing infrastructure and gear that obtain, dispatch, and process prey, as again will be discussed in Chap. 24.

20.4.3 Questions about the Primacy of Human Selectivity in Structuring Archaeofaunas

Almost simultaneously with publication of utility index approaches, other researchers questioned inferences from them. Foremost among the reservations expressed was whether other taphonomic processes could produce skeletal element representation attributed by Binford and others to human selectivity. This question is a variant of the longstanding paleontological question of whether fossil vertebrate element frequencies that depart from those typical of the skeleton were produced by fluvial transport or in-place destruction by taphonomic processes. Chapter 21 takes up this topic in detail.

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