

What Explains the Carcass Field Processing and Transport Decisions of Contemporary Hunter-Gatherers? Measures of Economic Anatomy and Zooarchaeological Skeletal Part Representation

Karen D. Lupo¹

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This paper uses rationale derived from central place foraging models to explore the factors that guide the carcass processing and transport decisions of modern hunters. Using data derived from butchering experiments, I test different economic indices that purportedly reflect the field processing and transport decisions of contemporary African Hadza hunter-gatherers. The results show that no single index predicts part processing and transport for the species examined in this analysis. Processing and transport decisions are, however, patterned in ways that are consistent with theoretical predictions. While similar processes likely guide carcass treatment and transport decisions among all hunter-gatherers, different ecological, social, and historical constraints define the range of solutions to problems involving carcass treatment. In this specific example, intertaxonomic differences in carcass size and bone properties constrain how the trade-offs between field processing and transport costs are resolved. I conclude by suggesting ways in which analysts might make use of central place foraging rationale and models to explain variation in skeletal representation and abundances across time and space.

KEY WORDS: skeletal part representation; foraging models; field processing costs; transport costs; economic anatomy; Hadza hunter-gatherers.

The ability to transport resources from the place of acquisition to consumption and/or use locations is often assigned an important role in human evolution (e.g., Isaac, 1978; Kaplan *et al.*, 2000; Lancaster, 1978; Lee, 1979; Potts, 1988, 1994; Potts *et al.*, 1999). Archaeological evidence of hominid transport

¹Department of Anthropology, Washington State University, Pullman, Washington 99161; e-mail: klupo@mail.wsu.edu.

capabilities in the form of transported raw lithic materials predates 2 mya and is associated with *Homo* sp. (Potts, 1991). Analysis of the limb proportions of *Homo ergaster* (1.9–1.5 mya) implicates load carriage as an important selective factor influencing modern body proportions (Wang *et al.*, 2003; Wang and Compton, 2004). Many nominate the ability to transport resources as an important preadaptation that gave rise to the use of central places, food sharing, extended and costly juvenile dependency (Isaac, 1978; Kaplan *et al.*, 2000; Lancaster, 1978), and the development of certain cognitive and strategic skills (Jalles-Filho *et al.*, 2001; Potts, 1988). Thus, understanding the factors that shape transport decisions can help explain observed and inferred variability in transported material remains in prehistoric and contemporary contexts and may ultimately shed light on how and why transport capabilities emerged in early hominid populations.

In zooarchaeological assemblages, the selective transport of different body parts of larger sized prey as reflected by biased skeletal part representation and abundances is often central to inferences about prehistoric transport decisions, carcass acquisition, and utilization patterns (Bartram and Marean, 1999; Binford, 1981, 1984; Bunn and Kroll, 1986; Klein *et al.*, 1999; Marean and Assefa, 1999). In the absence of destructive taphonomic processes, archaeologists often assume that the abundances of different skeletal parts represent selective transport and discard by prehistoric hunters. Inferences about skeletal part abundances are often built on fundamental assumptions about what explains human transport decisions and how those decisions are reflected in meaningful and measurable ways in the archaeological record. Important early work by White (1952, 1953, 1954), and later work by Perkins and Daily (1968), helped establish the view that when distances between kill and residential sites were great, prehistoric hunters selectively focused on transporting the body parts of large prey associated with the most meat. Recognizing that human choice is contingency-based, Binford (1978) proposed more sophisticated models for explaining big game part transport by modern Nunamiut Eskimos. Because body parts may be transported for specific products such as meat, marrow, or grease, Binford constructed utility indices that measured different types of animal products to predict skeletal part abundances associated with different carcass exploitation patterns. The most widely used of these indices, the Modified General Utility Index or MGUI, measures utility as the total amount of meat, marrow, and grease associated with different anatomical parts. When used in concert with zooarchaeological measures of skeletal part abundances, the MGUI formed the basis for a family of curves that could potentially define different prehistoric carcass utilization strategies (i.e., bulk, gourmet, unbiased; also see Thomas and Mayer, 1983).

The concept of utility, as measured by the amount of meat, marrow, and grease associated with different skeletal elements, continues to inform zooarchaeological analyses through simplified derivations of utility (Friesen, 2001; Metcalfe and Jones, 1988) and the development utility indices for a variety of different animals

(Belardi and Gómez Otero, 1998; Blumenschine and Caro, 1986; Borrero, 1990; Brink, 1997; Chase, 1985; Diab, 1998; Emerson, 1990, 1993; Friesen, 2001; Lyman *et al.*, 1992; Madrigal and Holt, 2002; Metcalfe and Jones, 1988; O'Connell and Marshall, 1989; Outram and Rowley-Conwy, 1998; Savelle *et al.*, 1996; Savelle and Friesen, 1996). But despite its early promise, a number of scholars recognize significant problems applying utility-based analyses to archaeological skeletal part profiles (Bartram, 1993; Grayson, 1989; Grayson and Cannon, 1999; Lyman, 1985). In archaeological contexts, destructive taphonomic phenomenon (Bunn, 1993; Grayson, 1989; Lupo, 1993, 1995, 2001; Lyman, 1984, 1992, 1994; Oliver, 1993), site formation processes (Lupo, 2001; Metcalfe and Jones, 1988), and methodological biases in collection and identification (Bartram and Marean, 1999; Bunn and Kroll, 1986; Marean and Frey, 1997) can create false profiles and/or obscure original skeletal abundances.

More importantly, theoretical and empirical-based research challenges the universal predictive value of utility. Foraging models derived from Neodarwinian theory show that resource choice is based not only on the benefits (or utility) but also the costs associated with acquiring and processing the resource (Hill *et al.*, 1987; Hawkes and O'Connell, 1981, 1985; Smith, 1983, 1991). Ethnographic and ethnoarchaeological research among hunter-gatherers in different ecological settings suggests that the relationship between human selectivity and part value is more complex than once imagined and is not solely predicted by utility (Bartram, 1993; O'Connell *et al.*, 1988, 1990). Probably the most compelling challenge came from observations of modern East African Hadza big game hunters. Important sources of variation in Hadza transport decisions include some of the situational factors recognized by Binford and others such as the distance between kill and residential camp and carcass size, time of day, wound location, carrying party size, and especially taxonomic identity (Bartram, 1993; Bunn, 1993; Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990). Despite these complex variables, Hadza transport decisions are taxonomically patterned (Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990; Monahan, 1998). For some prey, the Hadza often strip meat from selected high utility parts, such as the vertebrae and upper limb bones, and either transport both meat and stripped bone or only the meat to the residential camp (O'Connell *et al.*, 1988, 1990; see also Bartram, 1993; Bartram and Marean, 1999; Yellen, 1977). These observations imply that the transport potential of a skeletal part is not solely shaped by the amount of meat originally attached to the bone (O'Connell *et al.*, 1988, 1990; also see Metcalfe and Jones, 1988). O'Connell *et al.* (1988, 1990) argue that Hadza transport decisions are based on the trade-offs between the costs and benefits of field processing and transporting different parts with the overall goal of maximizing the amount of animal products returned to camp within a limited time frame. Rationale derived from a central place foraging model developed by Metcalfe in 1989, and later formalized by Metcalfe and Barlow (1992), suggests that two variables influence prey body part transport decisions:

the ratio of edible tissue relative to total part weight and field processing time. Parts with high processing costs and a large amount of edible animal products relative to part weight will have a higher probability of being field processed and discarded than parts with low field processing costs and low ratios of edible tissue to part weight (O'Connell *et al.*, 1990).

Others argue that Hadza transport decisions are complex and cannot be measured by a uniform scale or set of criteria. Bunn (1993) (also see Bunn *et al.*, 1988) argues that the Hadza try to transport entire carcasses to residential camps and intrataxonomic variation in transport is attributable to differences in taste, carcass quality, and attitudes towards sharing. Similarly, Oliver (1993) argues that Hadza carcass processing and transport decisions are generally aimed at maximizing nutritional returns, while minimizing transport, processing, and social costs arising from a concern to share meat. In a reanalysis of the published Hadza data, Monahan (1998) concludes that the Hadza focus on transporting as much food as possible and reduced transport costs by culling high weight and low value parts, but argues that variation in processing costs among skeletal elements is the primary factor determining transport and discard decisions.

In an attempt to incorporate processing costs into measures of part value, several analysts have used data derived from butchering experiments to calculate gross return rates² to evaluate skeletal part representation in archaeological and ethnoarchaeological settings (Egeland and Byerly, 2005; Lupo, 1998; Lupo and Schmitt, 1997; Madrigal and Holt, 2002). Marean and Cleghorn (2003), for example (also see Madrigal and Holt, 2002), argue that part return rate should accurately predict part selection, but their analyses did not show any correlation between Hadza part transport for medium-sized prey and proxy measures of return rate derived butchering experiments involving white-tailed deer. They concluded that the Hadza transport parts with high field processing costs more frequently than those that have low processing cost. However, the poor predictive value of published return rates is at least partially attributable to the fact that these values do not include transport costs, which can be considerable for some medium and larger sized prey (Lupo, 1998). Consequently, the current set of published return rates might predict the order in which skeletal parts are selectively processed at butchery sites, but these data should not be expected to predict the composition of transported assemblages unless transport costs are incorporated into the values (see Egeland and Byerly, 2005; Lupo, 1998).

While there is widespread agreement that the underlying goal of selective transport is to maximize the amount of animal products transported to residential camps (Bartram, 1993; Binford, 1978; Bunn, 1993; Bunn *et al.*, 1988; Jones and

² All the published return rates are gross return rates. Part benefits are measured by the amount of meat, marrow, and sometimes grease associated with the part (either in kcal or by the weight of product). Costs are measured in the amount of time it takes to process different parts.

Metcalfe, 1988; Metcalfe and Jones, 1988; Monahan, 1998; O'Connell, 1993; O'Connell *et al.*, 1988, 1990), there is little consensus regarding the role of field-processing and/or transport costs in human decision-making (also see Bartram, 1993; Emerson, 1993; Monahan, 1998; O'Connell and Marshall, 1989; but see Bunn, 1993). Part of the problem is that it is still unclear what economic measures (if any) actually predict skeletal part transport decisions. More importantly, even if the appropriate predictive measures are identified and explanatory models developed, how do we link this knowledge to the archaeological record in an informative and measurable way (see Grayson and Cannon, 1999)? In order to understand how field processing and transport costs influence human decision-making, we need to know something about how parts are actually processed by hunters in the field. We also need to know something about how field processing influences part utility and subsequent transport costs. This knowledge needs to be cast within a larger theoretical framework to more fully understand and explain how costs influence the decision-making process. Finally, for practical application we need to link the underlying factors that influence human decision-making to tangible measures that correlate to quantitative units in the zooarchaeological record.

In this paper, I use rationale derived from central place foraging models to examine how prey field processing and subsequent transport costs influence the carcass treatment decisions of Hadza hunters. The problem can be simply viewed as one involving how the costs of processing and transporting a resource are partitioned by a forager. A forager can invest more time processing a resource to reduce transport costs or can incur higher transport costs by spending less time processing the resource. In this paper, I consider the factors that influence how those costs are partitioned by contemporary Hadza hunter-gatherers. I begin with a brief review of current applications and rationale for Neodarwinian central place foraging models and then discuss several characteristics of animal carcasses that influence field treatment and transport decisions. Using quantitative data on the economic anatomy of female impala (*Aepyceros melampus*) and zebra (*Equus burchelli*) derived from a series of butchery experiments I then explore how resource characteristics influence field processing, part utility and the transport potential of different skeletal parts. These data are used to develop three different economic indices that purportedly reflect how the Hadza balance field processing and transport costs in animal bone assemblages. The usefulness of these indices is evaluated against actual observations of Hadza field processing and transport for female impala and zebra. Results of these analyses show that part transport for these two species is not consistently predicted by any of the indices evaluated here. Nevertheless, it is likely that similar underlying processes guide carcass treatment and transport decisions. I conclude that Hadza partition field processing and transport costs in such a way as to minimize the amount of animal products discarded in the field and maximize the amount transported to a central location. Important differences among prey in carcass size and bone

properties influence how this trade-off is resolved and manifested in bone assemblages. Species specific differences in how these costs are partitioned may be reflected in archaeological contexts by different economic measures that correlate to the frequencies of different skeletal parts. These results challenge conventional views about how human transport decisions are made and how skeletal part representation is commonly analyzed in zooarchaeological assemblages. I end this paper by discussing how these findings might inform and help modify current approaches to utility-based analysis of skeletal part representation in ethnoarchaeological and prehistoric contexts.

CENTRAL PLACE FORAGING MODELS AND THE ZOOARCHAEOLOGICAL RECORD

Theoretical rationale derived from behavioral ecology in concert with optimality modeling provides strong, quantitative tools for explaining different dimensions of human behavior. The basic premise of behavioral ecology is that organisms are designed by natural selection to optimize lifetime reproductive success and are capable of rapid adaptive shifts in behavior to contemporary environmental conditions, which can be broadly defined to include ecological, social, and political dimensions (e.g., Bliege Bird and Smith, 2005; Borgerhoft Mulder, 1991; Giraldeau and Carcaco, 2000). Optimality models are quantitative tools used to assess the costs and benefits of different foraging strategies that define (1) the range of available choices, (2) the currency used to evaluate those choices, (3) the presumed goal(s) of the organism, and (4) the constraints that limit the payoffs of different choices (Kelly, 1995; Krebs and Davies, 1997; Stephens and Krebs, 1986; Smith, 1983). A reliance on optimality modeling allows for a direct quantitative evaluation of the costs and benefits of pursuing different options. Models derived from behavioral ecology often focus on simple questions about foraging behavior such as what to eat (diet breadth) and when to leave a patch (patch choice and the marginal value theorem), but more complex types of behavior can also be fruitfully addressed with these models (Beck *et al.*, 2002; Bird and Bliege Bird, 2000; Elston, 1992; Elston and Zeanah, 2002; Fitzhugh, 2001; Gremillion, 2002; Kelly, 1995; Madsen *et al.*, 2000; Madsen and Schmitt, 1998; Winterhalder and Smith, 2000; Winterhalder *et al.*, 1999; Zeanah, 2000).

Central place foraging models (hereafter referred to as CPF) were originally designed to examine the behavior of nonhuman foragers who transport resources to a central place to consume and/or provision offspring (Jackson, 2001; Orians and Pearson, 1979; Schoener, 1979; Stephens and Krebs, 1986), store (Elliott, 1988), or engage in other activities (Fryxell and Doucet, 1991; Guerra and Ades, 2002). CPF models consider how the costs of transporting a resource influences resource choice, load size, distances between foraging patches, and the placement

of central places. Recent modifications of classic CPF models highlight how prey preparation, by removing low value and indigestible parts (Kaspari, 1991) or concentrating the nutritional content of the prey by crushing low value parts (Sherry and McDade, 1982), can influence the transport costs and decisions of central place foragers (Cuthill and Kacelnik, 1990; Kaspari, 1990; Rands *et al.*, 2000; Sodhi, 1992; Ydenberg, 1998). After a forager acquires prey it must decide how much energy (or time) is partitioned to processing and transporting that resource. By processing prey at the point of acquisition, the forager reduces the costs of transporting an item, enhances resource digestibility, and reduces the bulk of the item to facilitate consumption or carrying (see Kaspari, 1990; Rands *et al.*, 2000). Cumulatively, applications of the CPF models show that at greater distances from central places, organisms become more selective by transporting loads/prey that are larger-sized (Cuthill and Kacelnik, 1990; Fryxell and Doucet, 1991; Jackson, 2001; Stephens and Krebs, 1986, pp. 187–194), and/or have a higher nutritional value (Sodhi, 1992).

Because human foragers field process some resources and often use central places, a parallel interest in applications of CPF models to archaeological questions has emerged (Barlow and Metcalfe, 1996; Bettinger *et al.*, 1997; Bird and Bliege Bird, 1997; Cannon, 2000, 2003; Jones and Madsen, 1989; Kelly, 1995; Madsen *et al.*, 2000; Metcalfe and Barlow, 1992). Several important models assess the relative maximum distance a resource can be transported given transport costs and the nutritional value of the load (Jones and Madsen, 1989; also see Brannan, 1992; Kelly, 1995; Kramer, 2004; Madsen *et al.*, 2000; Rhode, 1990; Zeanah, 2000). Jones and Madsen (1989), for example, assume that a basket load of a resource will not be transported beyond the maximum transport distance (MTD) or the point where the energetic expenditure for carrying the load exceeds its caloric value (but see Hitchcock and Houston, 1993; Ydenberg, 1998, pp. 348–349, 355). Because transport costs are difficult to accurately measure (see Brannan, 1992; Rhode, 1990), this approach is best used to rank the relative transport distances of resources from their place of procurement, rather than to calculate absolute MTD (Madsen *et al.*, 2000).

Building from classic CPF theory developed by Orians and Pearson (1979), Metcalfe and Barlow (1992; also see Barlow and Metcalfe, 1996) provide a more direct model for understanding how human foragers trade-off the time spent field processing a resource against the costs of transporting an unprocessed load of that resource with the goal of maximizing the rate at which animal products are returned to a central location. They present formulae that can be used to calculate the distance from a central place at which processing a load becomes economically feasible. Key elements in their model include the time it takes to process a load, and increases in load utility and decreases in transport costs resulting from processing. They propose an inverse relationship between improvements in load utility and the minimum distance at which it becomes efficient to process a load.

Processing that realizes a large gain in load utility will decrease the maximum distances from central locations at which field processing becomes efficient and conversely. Metcalfe and Barlow (1992) demonstrate the usefulness of this model for understanding the field processing and transport decisions of simple resources that consist of high and low value components, such as nuts and shellfish (see also Barlow and Metcalfe, 1996; Bettinger *et al.*, 1997; Bird and Bliege Bird, 1997, 2000). For some simple resources, field processing can increase load utility because low value parts with no consumptive value are discarded and more useful product can be transported in fewer trips. Bird and Bliege Bird (1997) further demonstrate the value of this model with shellfish using ethnographic transport data derived from contemporary Meriam Islanders. The Meriam processed shellfish in such a way as to maximize the rate that edible flesh is delivered to a central place. Shellfish species that are difficult to field process and that will not significantly increase the proportion of edible flesh transported if they are processed are transported whole and generally collected from areas in close proximity to camps. Those that are easily field processed, and increase the proportions of transported edible flesh when processed, are taken at greater distances from camps and are field processed (see also Thomas, 2002).

Carcass Characteristics: Constraints Imposed by the Resource

The problem of large mammal selective field processing and transport invites application of CPF rationale (see Cannon, 2000, 2003; Grayson and Cannon, 1999; Jones and Metcalfe, 1988; Metcalfe and Jones, 1988; O'Connell *et al.*, 1988, 1990). But as discussed by Metcalfe and Barlow (1992), the utility function³ of some resources is continuous and not separable into edible and inedible parts. Furthermore, some resources such as animal carcasses are structured (*sensu* Metcalfe and Barlow, 1992, p. 350) in such a way that resource morphology dictates the sequence of processing activities that must occur before some products can be realized. Skin and meat, for example, must be removed from the bone before marrow can be exploited. Unlike renewable resources found in patches, carcasses are nonrenewable and time-limited and must be consumed and/or transported or stored within a relatively short time period. This means that for most carcasses, forager processing and transport decisions are made within the context of each discrete event and are not linked to anticipated future repeated visits to the resource. There are obvious exceptions to this generalization including the acquisition of super-sized carcasses such as whales or elephants or mass kills involving large numbers of animals that cannot be easily depleted without multiple visits

³The concept of utility used by Metcalfe and Barlow (1992) parallels its usage in economic analysis. In economic analyses, utility is a more ordinal measurement that reflects consumer satisfaction. Binford's (1978) use of utility was directly quantifiable and linked to the amount of animal products associated with different skeletal parts.

or large work parties and environmental circumstances where carcasses can be immediately frozen and processed at a later time.

In contrast to simple resources, carcasses comprise different products that have different utilities (*sensu* Metcalfe and Barlow, 1992). The complexity of large-sized mammalian carcasses imposes important constraints and limitations on the potential processing options available to a forager. While there are several different dimensions of carcass composition that influence how processing and transport costs that are balanced, here I specifically examine the relationships among field processing, transport costs, part utility, and the value of remnant animal products.

Relationship Between Field Processing and Utility

Field processing carcasses can involve a range of activities from simple evisceration and/or minimal disarticulation, the filleting of meat from body parts or, at the extreme end, complete processing for immediate consumption and/or storage (see Bartram, 1993; Binford, 1981). The degree to which prey are field processed varies as a function of carcass-size, prey type and density, desired end-product, degree of food-sharing, dependency on storage, transport technology, group-size and composition, immediate needs, proximity to raw materials linked to processing animal carcasses (i.e., fuel and tool stone), features of the local environment and, especially, transport costs. Minimization of the latter is probably one of the most important determinants of large- and medium-sized carcass treatment among central place foragers. In general, the more time spent processing a carcass in the field, the lower the transport costs (Bartram, 1993).

Some of the most common field processing activities that reduce transport costs involve modifying the shape of body segments. Body segments can be modified by simply dismembering specific parts from the carcass, such as the cranium. Part modification can also involve separating meat from skeletal parts and culling or transporting the resulting stripped bone as a complete or segmented part. Part modification reduces transport costs in a variety of ways. Culling stripped bones allows the forager to discard less useful material (i.e., bone) and transport a more valuable load comprising more useful animal products. Filleting meat and segmenting stripped bone creates smaller sized and more easily transported packages that require less energy to carry than do bulky and oversized pieces (e.g., Garg and Saxena, 1980; Smith and Jiang, 1984). Moreover, part modification gives carriers greater flexibility in positioning loads on their body to reduce transport costs. Several well-known studies on carriage physiology demonstrate that loads carried closer to the center of the body mass (i.e., on the torso or head) are energetically less costly to transport than those carried by the small muscle groups such as those found in the arms (Bobet and Norman, 1984; Knapik *et al.*, 1996; Legg and Mahnty, 1985; Lloyd and Cooke, 2000; Maloiy *et al.*, 1986; Spinney, 1995). For example, the Hadza practice of draping stripped meat across their torsos

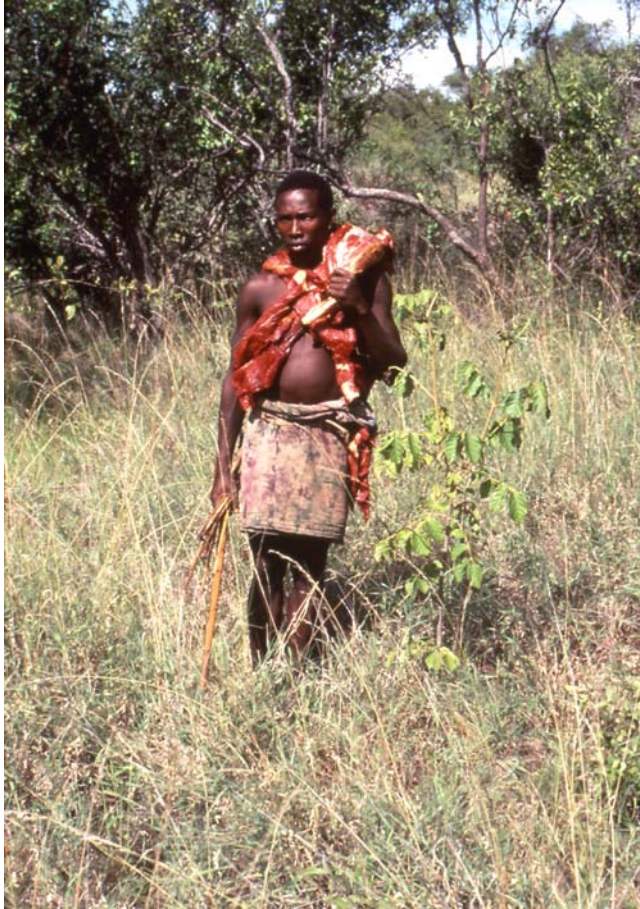


Fig. 1. Hadza man wearing a “meat shirt” to transport meat from a kill site to the residential camp. Note that most of the weight of the meat is positioned over the man’s torso (reprinted with the permission of J. F. O’Connell).

and wearing it as a type of “meat-shirt” to transport it back to a residential camp may actually serve to reduce the energetic costs of transport (Fig. 1). Similarly, modified parts can be repackaged into backpacks or onto other carrying devices such as poles (Fig. 2). By more evenly distributing the load for the carriers, such devices reduce the energy expended carrying the package (e.g., Kram, 1991). Finally, package modification can spread out the cost of transport by allowing more segments of the populations to assist in transporting products back to a central location. Children, for example, can easily carry small-sized packages or loads.



Fig. 2. Hadza men repackage striped meat onto a carrying pole. Poles such as these distribute the weight of the load more evenly between the bearers (reprinted with the permission of J. F. O'Connell).

Because carcass parts comprise many different products, field processing that involves separating meat from bone to reduce transport costs can change the utility of skeletal parts (e.g., O'Connell, 1993). Skeletal parts that are highly valued upon acquisition because of large amounts of attached flesh may become less valuable relative to other carcass parts after they are field processed. By extension, the transport potential of those parts relative to the entire carcass may change after they are field processed. The depression in part value attendant with field processing explains why we should not necessarily expect conventional measures of utility to predict skeletal representation in assemblages processed for transport.

Despite the reduction in utility associated with some types of part modification, culling stripped bone can result in the discard of a substantial amount of unrealized, edible remnant animal products (see Emerson, 1993; Marshall and Pilgrim, 1991). After the meat is stripped from a part, the consumptive utility is restricted to remnant animal products such as grease, marrow, and in some cases, a substantial amount of adhering meat. Foragers can immediately consume some of these remnants, such as bone marrow, and discard the part, but without access to cooking pots (Lupo and Schmitt, 1997), some fat-rich animal products (i.e., marrow and grease) remain unrealized and are discarded with the bone. Foragers can also choose to minimize the amount of animal products discarded or wasted by transporting stripped bones associated with high-value remnant animal products. Alternately, foragers can minimally process and transport intact parts that retain

large amounts of remnant animal products on the bone if those parts are stripped in the field.

The Value of Remnant Animal Products

The choice of how to process specific anatomical elements is mediated, in part, by element shape and other bone properties. These characteristics strongly influence the amounts and types of remnant animal products associated with a part after it is field processed. Some elements, such as vertebrae for example, are oddly shaped and difficult to completely strip (O'Connell *et al.*, 1988, 1990). Taxon-specific differences in bone construction may further limit the exploitation of some animal products without access to thermal processing technology (Lupo, 1998; Lupo and Schmitt, 1997).

The value of remnant animal products adhering to the stripped parts varies as a function of the amounts and types of animal products left attached to the bone, available cooking technology, season of the year, importance of storage and storable products, access to other fat- or carbohydrate-rich resources, degree of importance of the resource in the diet, the number of animals synchronously acquired, prey body size and the needs of the people processing the carcass (see, for example, Binford, 1981; Brink, 1997; Gifford-Gonzalez, 1993; Kelly, 1995; Malainey *et al.*, 2001; Marshall and Pilgrim, 1991; Speth, 1983; Speth and Spielmann, 1983). The enhanced value of fat-rich within bone animal products, such as grease and marrow, relative to lean meat during certain seasons is widely recognized (Malainey *et al.*, 2001; Speth, 1983; Speth and Spielmann, 1983)

Potential changes in part utility resulting from field processing and the value of remnant animal products have particularly profound implications for how foragers partition the costs of field processing and transporting different skeletal parts and the application of CPF models. Whenever field processing results in the discard of significant edible animal products, any potential increase in load utility resulting from culling low value bone must be *discounted* against the value of discarded edible nutrient (see Kaspari, 1990, p. 119, for a similar argument). The degree to which utility gains are discounted depends on the value of the remnant animal products to the forager. This also means that potential gains from reducing transport costs by culling inedible bone can be greatly devalued if large amounts high value remnant edible animal products are discarded.

Thus, foragers attempting to maximize the amount of animal products returned to a central place make processing decisions based on partitioning field processing and transport costs, a key consideration guiding how those costs are partitioned is the minimization of the amount of unrealized animal products discarded in the field (but see Gramly, 1977, for an example of exceptions to this generalization). Importantly, these considerations are most likely to apply in

circumstances where a single carcass is taken at a time and the returns for hunting are unpredictable or associated with a high risk of failure. In the case of the Hadza, for example, big-game hunting is associated with a high risk of failure; the chance of failure on any given day is 97% (Hawkes *et al.*, 1991). Given these circumstances, foragers likely anticipate the amounts and types of remnant animal products that remain attached to the part when it is processed and plan field processing decisions accordingly. In general, foragers should field process skeletal parts in ways that minimize the loss of unrealized remnant animal products. Parts that retain very small amounts of remnant animal products (have a small discount) may be selectively processed and discarded in the field, even if the reduction in transport costs resulting from discarding the bone is quite small (as measured by package weight). Other parts characterized by heavy package weight or bulky dimensions may be selectively processed to reduce transport costs. But because these parts retain large amounts or high-value remnant animal products relative to the weight of the bone (have a large discount), the stripped bone will still be transported. Still, other parts will be minimally disarticulated and transported as intact units because the package size is easily managed and the parts have a high discount value.

ECONOMIC ANATOMY OF IMPALA AND ZEBRA

Specific information on how field processing influences part utility and the transport potential of different skeletal parts is derived from a set of controlled butchering experiments conducted in Kenya in 1992 (see Lupo, 1998; Lupo and Schmitt, 1997). The experiments were designed to collect the weights of different carcass animal products (i.e., skin, meat, internal organs, bone, marrow, and grease) and processing costs for different skeletal parts (see Lupo, 1998, for a description of the experiments). Professional butchers processed 17 different carcasses representing four different taxa commonly hunted by the Hadza. While the sample included adult male and female impala, hartebeest (*Alcelaphus buselaphus*), wildebeest (*Connochaetes taurinus*), and zebra, only detailed economic information on the female impala and zebra are discussed here (see Tables I and II). Whole carcasses were acquired and butchered by professional butchers using small metal knives. In the case of zebra, a large metal machete (or *panga*) was also used to hack and dismember some of the more robust body segments. After the bones were filleted and dismembered, marrow-bearing bones were processed for marrow with a handheld rock hammer and anvil (Lupo, 1998). In the case of the zebra, a machete was used to breach the bones because of the extreme robusticity of the cortical bone. Elements from selected carcasses were subjected to more intense processing to retrieve smaller bits of adhering meat, marrow, and grease (Lupo and Schmitt, 1997). All bones were subsequently dried and weighed.

Table I. Average Weights (g) and Field Processing Time (s) for Carcasses 7 and 8, Young Adult Female Impala^{a,b}

	Weight				Time				Total
	Flesh	Marrow	Wet bone	Total part ^c	Dry bone	Fillet meat	Dismember	Marrow	
Skull ^d	492	4.30	1143	1639	396	78	34	315	427
Cervical	1485	NA	1070	2555	204	87	26	NA	113
Thoracic	2274	NA	840	3114	197	52	41	NA	93
Lumbar	1335	NA	480	1815	157	89	27	NA	116
Ribs	1692	NA	1481	3173	359	111	NA	NA	111
Pelvis	2515	NA	1300	3815	308	92	NA	NA	92
Scapula	935	NA	203	1138	71	65	12	NA	77
Humerus	488	9.00	196	693	110	27	3	63	93
Radio-ulna	280	3.65	191	475	116	22	29	68	119
Metacarpal	NA	3.35	147	150	82	NA	8	75	83
F. Phalanges ^e	NA	1.25	117	118	51	NA	30	55	85
Femur	3045	13.50	287	3345	147	39	42	65	146
Tibia	553	19.90	350	923	189	34	16	81	131
Metatarsal	NA	5.90	172	178	106	NA	11	68	79
H. Phalanges ^e	NA	1.25	104	105	51	NA	48	55	103

^aCarcass 7 weighed 50 kg (live weight) and was lactating. Carcass 8 weighed 49.5 kg (live weight) and was pregnant. Both carcasses were butchered approximately 10 h after death.

^bAll weights (except marrow) are rounded to the nearest gram.

^cWeight of total parts includes weight of all tissues (except the skin) plus the wet bone weight. In all cases the skin was removed and weighed separately (see appendix).

^dSkull flesh weights include all exterior meat from the cranium and mandible, the tongue, and the brain. Dismemberment time is the amount of time it takes to remove the cranium from the torso. Dismemberment time for the mandible from the cranium is not available for these animals (see Lupo, 1998). Marrow time is the amount of time it takes to remove the mandible marrow after the bone is stripped.

^eDoes not include the weight of the digital cushion (but see Lupo, 1998).

Table II. Average Weights (g) and Field Processing Time (s) for Carcasses 13 and 14, Adult Female Zebra^{a,b}

	Weight				Time				Total
	Flesh	Marrow	Wet bone	Total part ^c	Dry bone	Fillet meat	Dismember	Marrow	
Skull ^d	3,241	15.40	6,297	9,553	3,025	399	62	377	838
Cervical	7,525	NA	3,625	11,150	1,036	194	187	NA	381
Thoracic	5,113	NA	4,532	9,645	1,438	134	135	NA	269
Lumbar	8,350	NA	1,588	9,938	600	182	121	NA	303
Ribs	16,500	NA	10,844	27,344	2,412	329	NA	NA	329
Pelvis	19,150	NA	4,750	23,900	1,705	300	NA	NA	300
Scapula	4,350	NA	800	5,150	375	103	20	NA	123
Humerus	2,856	17.20	1,021	3,894	567	80	6	133	219
Radio-ulna	1,306	5.83	832	2,144	513	78	41	136	255
Metacarpal	NA	3.73	465	469	253	NA	32	77	109
F. Phalanges ^e	NA	NA	638	638	342	NA	51	NA	51
Femur	13,438	14.40	1,730	15,182	933	94	125	120	339
Tibia	1,750	19.10	1,075	2,844	558	89	37	163	289
Metatarsal	NA	7.40	880	887	500	NA	68	101	169
H. Phalanges ^e	NA	NA	669	669	342	NA	42	NA	42

^aBoth animals were lactating at the time of death and were butchered within 3–4 h of death.
^bAll weights (except marrow) are rounded to the nearest gram.
^cWeight of total parts includes weight of all tissues (except the skin) plus the wet bone weight. In all cases the skin was removed and weighed separately (see appendix).
^dFor the skull flesh, weights include tissue stripped from the mandible and cranium, the tongue, and the brain. Marrow time includes the amount of time it takes to remove marrow from the mandible and the brain from the cranium. Fillet time includes the time it takes to fillet all exterior flesh from the skull. Dismemberment time is the sum of the time it takes to dismember the cranium from the torso (36.5 s) and the mandible from the cranium after it was filleted (25 s). The total time is the sum of the fillet, dismemberment, and marrow times.
^eDoes not include the weight of the digital cushion (but see Lupo, 1998).

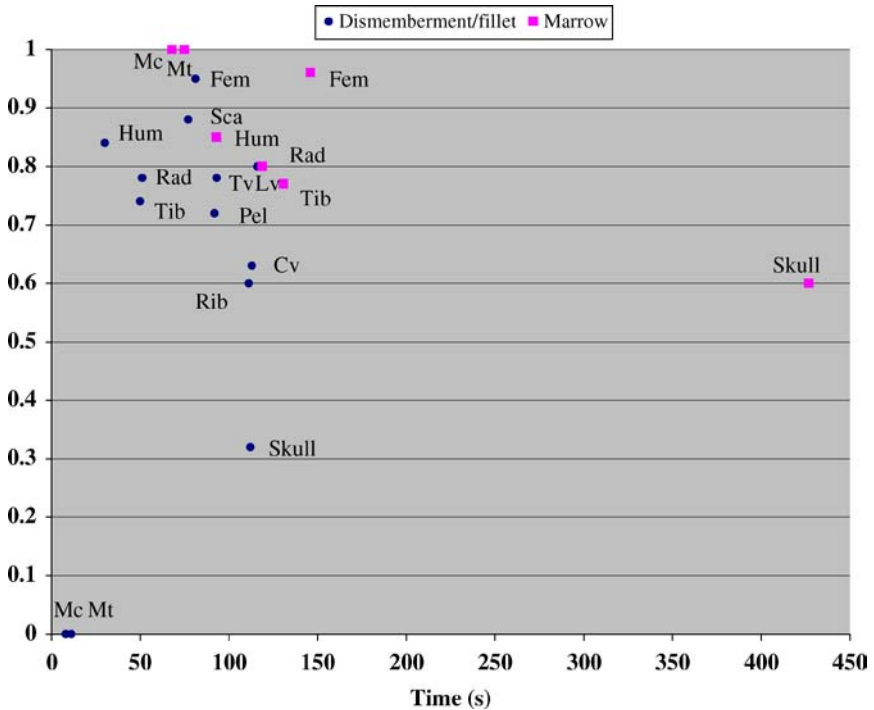


Fig. 3. The proportion of FUI removed over time from different impala parts during different butchering operations (filleting meat and removing marrow).

Impala and Zebra Field Processing Time and Part Utility

As discussed earlier, field processing that involves filleting meat or removing animal products from the bone can depress part utility and, by extension, influence the transport potential of the bone. Figures 3 and 4 show the proportional utility removed from each skeletal part during different processing operations (e.g., fillet/dismemberment and marrow removal). Utility is measured here by the total whole bone values of the Food Utility Index or FUI (as measured by total part weight less dry bone weight; see Tables I and II) after Metcalfe and Jones (1988) and is designated as FUI(t). These values are not adjusted to accommodate riders because observations of Hadza transport show that conjoining elements within body segments can often have independent transport histories.

Most elements of the female impala can be quickly dismembered and filleted, except the skull (Fig. 3). For most elements, especially the limb bones (the femur, scapula, humerus, radioulna, and tibia), a large proportion of FUI(t) can be removed the first time the part is filleted. For example, 95% of all the edible products associated with the femur is removed the first time the element is filleted. Extracting

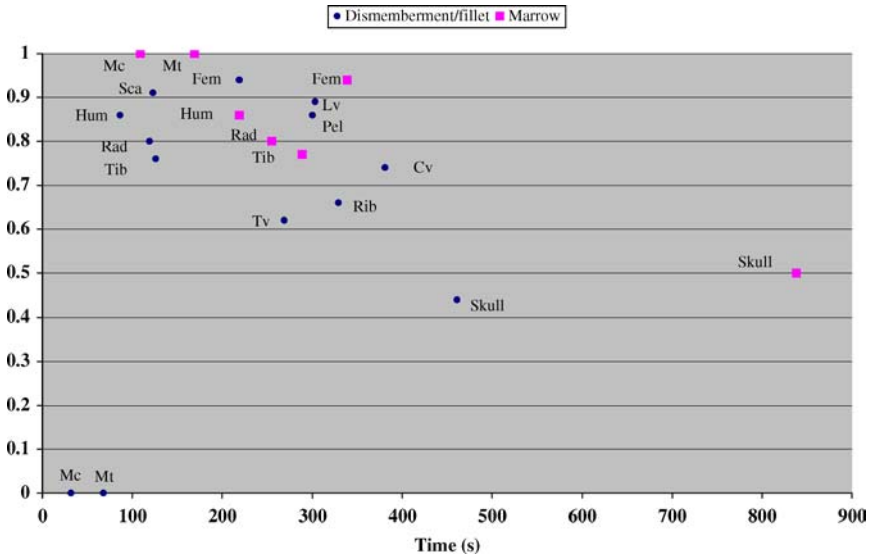


Fig. 4. The proportion of FUI removed over time from different zebra parts during different butchering operations (filleting meat and removing marrow).

marrow almost completely exhausts the remaining animal products associated with the limb bones but note that this nearly doubles the amount of time it takes to field process these bones. In fact, if marrow extraction time is considered part of the costs of field processing, then limb bones are among the most expensive parts (as measured by time) to process. After the marrow is removed from the limb bones, the remaining remnant animal products consist of small bits of flesh and extremely small quantities of within-bone grease (Lupo and Schmitt, 1997).

A smaller proportion of FUI(t) is removed from the impala axial elements the first time the parts are filleted. This is particularly true for the cervical vertebrae, ribs, pelvis, and especially the skull. Of all the skeletal parts, the smallest proportion of FUI(t) is removed from the skull even after the marrow and brain are extracted. Most, but not all, of the axial bones retain large quantities of FUI(t) after being filleted because these elements are oddly shaped and difficult to exhaust in a short period. The exceptions here are the thoracic and lumbar vertebrae.

In general, zebra carcasses take considerably more time to fillet and dismember than impala. This is not unexpected because zebra are larger than impala and have greater quantities of meat, which takes more time to remove. Nevertheless, a large proportion of the meat is removed from the different parts the first time the bones are filleted (Fig. 4). Appendicular elements lose the greatest proportion of FUI(t) and have the shortest processing time of all the skeletal elements, even when marrow extraction times are included. However unlike impala, the marrow

fracturing times for zebra reported here do not reflect the complete effort involved in removing marrow from the bones. As discussed by Lupo (1998; see also Blumenshine and Madrigal, 1993; Lupo and Schmitt, 1997; Outram and Rowley-Conwy, 1998; Sisson and Grossman, 1953; Zietzschmann *et al.*, 1943) architectural characteristics of zebra limb bones (and apparently other equids) limit a forager's ability to extract marrow without excessive amounts of effort and/or cooking technology. Zebra limb bones contain very little free marrow compared to other similarly sized species and the amount of marrow retrieved relative to the total amount available is low (see Lupo, 1998, for comparisons).

All of the zebra axial parts, except the pelvis, lose a smaller proportion of FUI(t) than do the appendicular elements when the bones are filleted for the first time. The skull, in particular, loses a very small proportion of FUI(t) when the bone is first filleted. There is only a small increase in the proportion of FUI(t) removed from the skull after the marrow and brain are extracted.

Transport Costs and Remnant Animal Products

Potential reductions in transport costs associated with field processing are evaluated against the amounts and types of remnant animal products that will be discarded if the bone is processed and culled. Figures 5 and 6 show the cumulative weight of different skeletal parts for impala and zebra after the meat and marrow are removed and the weight of the different components that comprise the part weight (i.e., dry bone weight and remnant animal products). The amount of remnant animal products is designated as FUI(r) for different skeletal parts and is found by

$$\text{FUI}(t) - M1 - M2 = \text{FUI}(r)$$

where M1 is the amount of meat removed during the first fillet (flesh weight in Tables I and II) and M2 is the amount of marrow removed (marrow weight in Tables I and II).

For impala, those parts with the heaviest inedible component (dry bone) such as the ribs, scapula, pelvis, and the cervical vertebrae are the same parts associated with large amounts of FUI(r) that would go unrealized if the bone is stripped and discarded in the field. In all these cases, the weight of FUI(r) greatly exceeds the weight of the dry bone. As expected, appendicular elements only retain small quantities of FUI(r) relative to the total weight of the package after the part is processed. This is especially marked in the upper limb bones such as the femur, humerus, and radioulna. Even though these parts are associated with relatively light weight bone, dry bone weight far exceeds the weight of FUI(r), which represents only minute quantities of animal products.

For zebra, the heaviest bones include the skull, ribs, pelvis, and thoracic vertebrae, but all of these bones also retain large quantities of FUI(r) that exceed

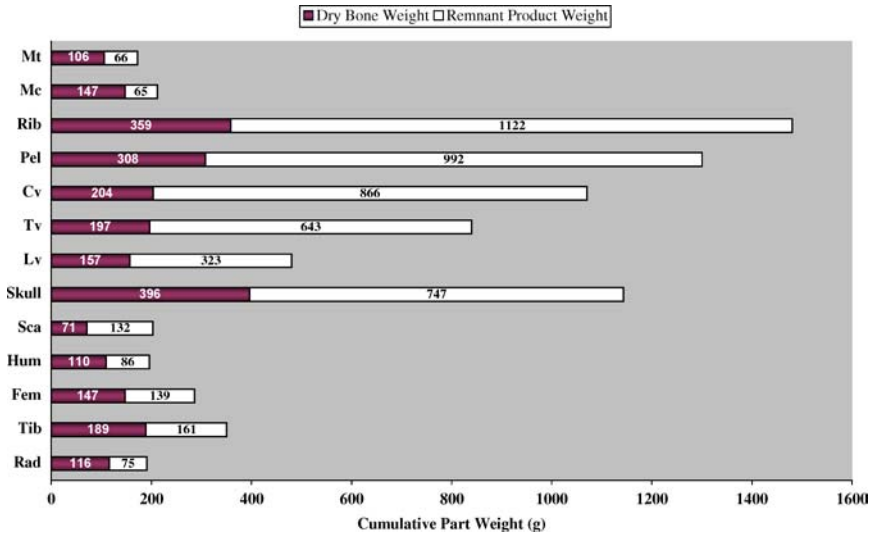


Fig. 5. Cumulative weight of impala parts after being filleted (i.e., bone and remnant edible animal products weight).

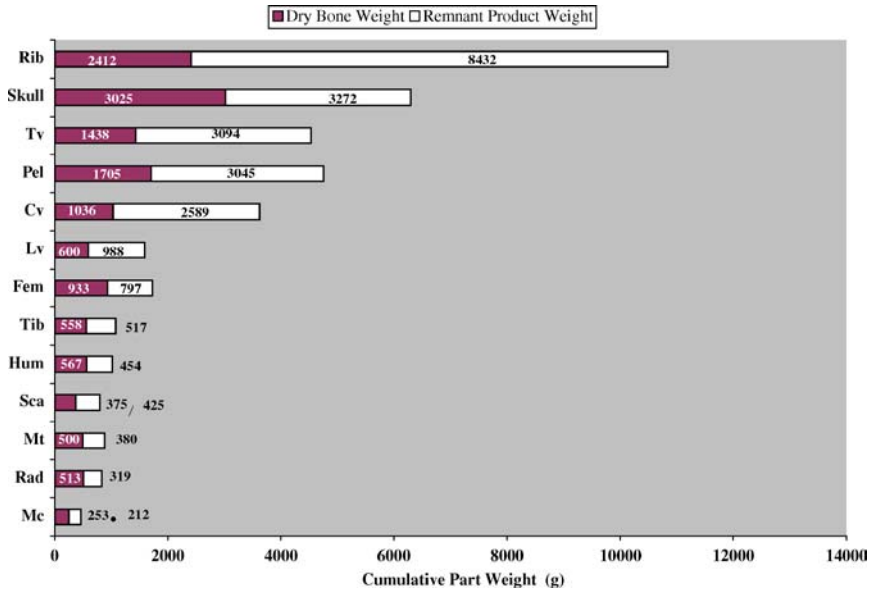


Fig. 6. Cumulative weight of zebra parts after being filleted (i.e., bone and remnant edible animal product weight).

the weight of the bone. As with the impala, FUI(r) associated with the appendicular elements does not exceed the weight of the dry bone. The only exception among the limb bones is the scapula, which retains larger quantities of FUI(r) that exceed the weight of the bone. Since zebra limb bones retain marrow, much of the weight of the FUI(r) associated with the stripped limbs comprises fat-rich marrow.

The results of these analyses show the following:

1. For both taxa considered here, the depression in part FUI(t) attendant with field processing is greater in appendicular than in axial elements. In general, it takes less time to fillet and dismember appendicular elements than axial parts. Even though marrow extraction can increase field processing costs for appendicular parts, limb bones can be relatively quickly depleted of almost all edible animal products in comparison to most axial parts.
2. The heaviest bones that likely have the highest transport costs are also associated with the greatest amounts of meat and largest amounts of FUI(r) and thus have the greatest potential for nutrient waste, or biggest discounts, if the stripped bones are discarded in the field. Although one might expect foragers to strip and cull these heavy weight bones, the loss in remnant animal products may greatly diminish the advantages gained in the reduction of transport costs. While the bones associated with the appendicular skeleton are lighter in weight, discarding these bones may result in greater gains in the reduction of transport costs than of the axial elements because smaller amounts of remnant animal products are discarded. This important counter-intuitive result explains why bone or part weight will not always predict which elements are discarded in the field to reduce transport costs when field processing involves removing meat from the bone.
3. There are important differences between impala and zebra in the amounts (as measured by weight) and types of FUI(r) left attached to the bone after it has been processed. While the relative proportions of FUI(t) removed from the bone when it is first filleted are very similar for impala and zebra, the amounts and types of animal products left adhering to the bone differ for these taxa. Larger quantities of meat and marrow are left adhering to zebra bones after they have been filleted than for impala. This implies that even though zebra have heavier bones that are more costly to transport than impala, the potential for waste or discount resulting from large amounts of discarded animal products is also much higher for zebra than for impala.

HADZA BIG-GAME PROCESSING AND TRANSPORT

The Hadza are central-place, big-game hunters who occupy areas east and south of Lake Eyasi in Tanzania. Different aspects of Hadza ecology are analyzed

and described in detail elsewhere (see Blurton Jones *et al.*, 1996, 2000; Bunn, 2001; Bunn *et al.*, 1988; Hawkes, 1990, 1991, 1993; Hawkes *et al.*, 1991; Marlowe, 2004, 2005; O'Connell *et al.*, 1988, 1990, 1991), and here I generally describe some of the more important circumstances surrounding carcass field treatment and transport. The Hadza hunt a variety of medium and large-sized prey with poison-tipped metal arrows. Common prey animals include impala, wildebeest, hartebeest, zebra, warthog (*Phacochoerus africanus*), buffalo (*Syncerus caffer*), and giraffe (*Giraffa camelopardis*). Animals are procured by encounter and ambush hunting and sometimes by scavenging the kills of other predators (see O'Connell *et al.*, 1988, 1990; Bunn *et al.*, 1988; Marlowe, 2004, for descriptions). When medium and larger sized carcass are found, one or more members of the hunting/tracking party may begin to butcher the animal while others return to camp to enlist the aid of a carrying party. When a very large carcass is acquired, the news of meat quickly spreads and it is not uncommon for members of adjacent villages to travel to the butchery site for meat. On rare occasions, a carcass may be completely or largely consumed in the field by members of the hunting/tracking party and other Hadza foraging nearby (see Carcass 3: Lupo, 1993, for example). Often, some carcass parts (such as small bits of meat and marrow) are consumed as snacks at the butchering site by members of hunting/tracking and carrying party. Men, more often than women, comprise the hunting/tracking party and often consume snacks of meat, and especially marrow, before the carrying party arrives. The carrying party can comprise men, women, and children who may also consume meat and marrow snacks in the field. Carcass parts are widely shared at the butchery site with all members of the carrying party who then transport parts to the residential camp where the meat is further shared with household and camp occupants. The only animal products that are not widely shared are selected meat cuts and internal organs (*epeme*), which are reserved for initiated men and consumed in spatially segregated areas (see O'Connell, n.d.; Marlowe, 2004).

I begin this analysis by describing aspects of selective part processing and transport for a sample of female impala and female zebra derived from published and unpublished sources (Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990; O'Connell, n.d.). This analyses focuses on these two taxa because of all the available published and unpublished data on Hadza processing and transport, these two animals are represented by the largest number of observations. Previous analyses of the Hadza data show that taxonomic identity, as well as seasonal and sexual differences in carcass quality and body proportions, influence how prey are processed and transported (Bunn, 1993; Bunn *et al.*, 1988; Monahan, 1998; O'Connell *et al.*, 1988, 1990). While all of these factors are likely very important, the available sample size is too small to investigate differences in body part treatment as a function of season of acquisition or carcass quality resulting from the condition of animal (i.e., pregnant, lactating, juvenile, injured, etc.).

I expected differences in body part treatment and transport for these two taxa based on body-size and the results of the scalogram analysis originally conducted by O'Connell *et al.* (1988, 1990). With an average live-weight falling between 38 and 50 kg (Anderson, 1982; Sachs, 1967) female impala carcasses are small enough to be carried by one hunter. Yet observations of the Hadza show that entire impala carcasses are very rarely transported by a single hunter (but see O'Connell *et al.*, 1988, case 21) and selective transport by more than one person is far more common. According to Monahan's (1998, Table III) analysis, only 37% of all impala acquired by the Hadza are completely transported. Having a live weight that averages between 175 and 250 kg (Sachs, 1967), female zebra carcasses impose moderate transport constraints on hunters. A carcass in this size range is not normally transported by one person, unless extensively processed or acquired incomplete (but see O'Connell *et al.*, 1988, Case 45). One might expect that larger sized prey, such as zebra, are more extensively field processed and selectively transported than are smaller sized animals such as the impala, especially when transport is constrained. But as Monahan's (1998) analysis shows, 47% of all zebra carcasses are completely (or nearly so) transported. Similar findings are implied by O'Connell *et al.*'s (1990, Table I) analysis, which shows that a greater proportion of zebra bones are transported from kills to residential bases than for impala.

Hadza Field Processing

The Hadza process anatomical parts in the field for immediate consumption at residential base camps.⁴ While the original analyses of the Hadza emphasized the importance of field processing techniques in transport decisions, these are only described in a generalized fashion (Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990). Table III presents unpublished data derived from O'Connell's (n.d.) field notes on specific anatomical field processing techniques for female impala and zebra. Detailed field processing data are only available for a very small sample of cases, but observations show that anatomical parts are generally treated in one of the three different ways:

1. Parts are minimally dismembered from the carcass and transported intact (i.e., as unstripped bone with attached meat);
2. Parts are filleted and dismembered in the field and both the meat and stripped bone are transported as separate packages; and
3. Parts are filleted and dismembered in the field, but the stripped bone is discarded in the field and only the filleted meat is transported to the residential site.

⁴Occasionally, the Hadza dry meat at the residential base for trade. While the actual process of meat drying may take place at the residential camp, this may well influence how parts are treated in the field. However, detailed information on which carcasses were stripped for meat drying is not available. Therefore, I am unable to account for the effects of meat drying in the available data.

Table III. Observed Hadza Field Treatment of Prey Body Parts^a

Body part	Transported part intact ^b	Stripped bone and meat transported ^c	Part processes, meat transported, bone discarded ^d
Female impala (<i>N</i> = 3) ^d			
Skull	2.0	0	1.0
Cervical vertebrae	3.0	0	0
Thoracic vertebrae	3.0	0	0
Lumbar vertebrae	1.5	1.5	0
Ribs	0.3	0.7	2.0
Pelvis	3.0	0	0
Scapula	3.0	0	0
Humerus	2.0	0	1.0
Radioulna	1.0	0.5	1.5
Metacarpal	1.0	0	2.0
Femur	1.0	0	2.0
Tibia	1.0	0	2.0
Metatarsal	1.0	0	2.0
Front phalanx	3.0	0	0
Hind phalanx	3.0	0	0
Female zebra (<i>N</i> = 6)			
Skull	3.0	0	3.0
Cervical vertebrae	0	6.0	0
Thoracic vertebrae	0	6.0	0
Lumbar vertebrae	1.0	5.0	0
Ribs	0	3.55	2.45
Pelvis	5.5	0	0.5
Scapula	4.0	2.0	0
Humerus	4.0	2.0	0
Radioulna	4.0	2.0	0
Metacarpal	4.0	1.0	1.0
Femur	4.5	0.5	1.0
Tibia	4.5	0.5	1.0
Metatarsal	5.0	0.5	0.5
Front phalanx	5.5	0	0.5
Hind phalanx	5.5	0	0.5

^aData derived from O’Connell’s (n.d.) unpublished field notes. Values refer to the number of times the different treatments were observed being used on each part. Female impala field processing derived from observations of cases 3, 16, and 20 (also see O’Connell *et al.*, 1988, 1990). Female zebra field processing derived from observations of cases 14, 22, 23, 28, 46, and 47 (O’Connell *et al.*, 1988, 1990).

^bRefers to body parts that were dismembered and transported intact or as articulated units. Vertebrae were usually transported as articulated units (i.e., all cervical, all thoracic, etc.), limb bones were usually transported as articulated sets (i.e., femur, tibia, tarsals, metatarsals), and ribs as articulated segments.

^cRefers to parts that were stripped in the field and both stripped meat and bone subsequently transported.

^dRefers to parts that were processed in the field. Meat was stripped from the bone, some nutrients were consumed, and the bone was discarded in the field.

The consumption of meat and marrow snacks in the field can also be considered part of carcass processing (Bunn, 1993; Bunn *et al.*, 1988; O’Connell *et al.*, 1988, 1990), but these consumption events tend to be limited to small quantities of animal products (but see Carcass 3, Lupo, 1993, 1994, 1995, for an unusual

exception) and most snacks are derived from parts destined to be discarded in the field, such as limb bone marrow.

A chi-square test of homogeneity comparing the frequency of bones subjected to different treatments for female impala and zebra is significantly different ($\chi^2 = 12.057, p \leq 0.002$). This suggests that while a similar range of processing techniques is used for both animals, these taxa are processed differently. Because the samples reported here are modest (especially for impala), it is not possible to conduct more meaningful statistical analyses of differences between part treatments for these taxa. An examination of Table III shows that for impala, most parts are either transported as intact segments or are stripped and discarded in the field. The limited number of female impala observations actually underestimates the frequency of some field processing activities, especially the treatment of limb bones. Observations of Hadza transport/discard patterns for all impala reported by O'Connell *et al.* (1988, 1990) suggest that limb bones are completely stripped and discarded more frequently than reflected in the sample reported here. Note that more zebra than impala elements are likely to be processed by filleting the part and transporting both meat and stripped bone. This is particularly true for the vertebrae and ribs, which are high bulk packages. Interestingly, many zebra parts are transported as intact body segments (forelimb, hindlimb) involving only dismemberment and minimal processing. Few zebra parts are stripped and the bone discarded in the field. Thus, in contrast to my expectation, impala are more extensively field processed than zebra.

Hadza Selective Part Transport

Previous interpretations of Hadza transport patterns differ considerably in the scale at which various analyses were conducted and hence differ in their conclusions. O'Connell *et al.* (1988, 1990) analyzed transport patterns for each taxon separately, except the alcelaphines which were combined to accommodate the small number of observations for these animals. The results of their scalogram analyses suggest that the Hadza make fine-grained decisions about transport on the basis of taxonomic identity. Subsequent analysis by other researchers combine groups of similarly sized animals into size classes (i.e., Sizes 2, 3, 4, and 5) to more closely approximate the units of zooarchaeological analysis (e.g., Bunn, 1993; Bunn *et al.*, 1988; Marean and Cleghorn, 2003; Monahan, 1998).

To measure transport frequency for different skeletal elements, I calculated the minimal anatomical unit (or MAU) and percentage MAU transported for female impala and zebra using published data (Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990). MAU and percentage MAU are used here because these values are standard zooarchaeological measures of the relative frequencies of different skeletal parts found in archaeological assemblages⁵ (Tables IV and V). Following

⁵O'Connell *et al.* (1988, 1990) report transport and discard decisions as a transport index calculated for each skeletal element. The transport indices are derived by dividing the number of bones transported

Table IV. Observed Hadza Part Transport Decisions for Female Impala^d

Female impala	Case number										Transport ^b MAU	Percent MAU
	3	16	20	49	67	68	69	H8	H13	H14		
Skull	1.0	1.0	1.0	0	1.0	1.0	1.0	1.0	1.0	1.0	9.0	90
Cervical vertebrae	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0	100
Thoracic vertebra	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.7	97
Lumbar vertebrae	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.8	98
Pelvis	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0	100
Ribs	0.8	0.9	1.0	0	0.2	0.5	1.0	0	1.0	1.0	6.4	64
Scapula	1.0	1.0	1.0	1.0	1.0	1.0	0	0.5	0	0	6.5	65
Humerus	0	1.0	1.0	1.0	1.0	0	0	1.0	0	0	5.0	50
Radioulna	0	1.0	1.0	0.5	1.0	0	0	1.0	0	0	4.5	45
Metacarpal	0	1.0	1.0	0	1.0	0	0	0.5	0	0	3.5	35
Front phalanxes	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0	0	8.0	80
Femur	0	1.0	1.0	0	0.5	0	0	1.0	0	0	3.5	35
Tibia	0	1.0	1.0	0.5	0.5	0	0	1.0	0	0	4.0	40
Metatarsal	0	1.0	1.0	0	0.5	0	0	1.0	0	0	3.5	35
Hind phalanxes	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0	0	8.0	80

^aCase numbers 3 through 69 are reported in O’Connell *et al.* (1988, 1990). Case numbers H8, H13, and H14 are reported by Bunn *et al.* (1988).

^bValues under each case number reflect a transport index derived by dividing the number of bones transported to the base camp by the number of times the bone occurs anatomically (O’Connell *et al.*, 1988, 1990). If one humerus was discarded in the field and the other transported back to the base camp it received a transport score of 0.5. If both humeri were transported from the field to the base camp this element received a score of 1. The transport indices are identical to the method used to calculate MAU, or Minimum Animal Unit, a measurement of relative skeletal abundance (Binford, 1978, pp. 478–479). Percent MAU was derived by setting the highest MAU at 100 and scaling all other values relative to it.

Binford (1981), MAU is measured by calculating the number of elements that are transported or represented and dividing it by the number of times the part occurs anatomically. Percent MAU is found by setting the highest MAU value at 100 and scaling all other values accordingly.

The sample of impala and zebra used to calculate transport frequencies includes only those carcasses acquired intact and by hunting (see Lupo, 2001, for a description of methods). Actual transport distances for some (but not all) of the carcasses used in these samples are known and most were taken within a 3 km distance from the residential base. But since the energetic costs of transport can vary as a function of terrain, ambient temperature, walking speed, number of carries, and host of other conditions (e.g., Brannan, 1992; Maloiy *et al.*, 1986; Rhode, 1990), the actual transport costs are not known.

to the base camp by the number of times the bone occurs anatomically. For example, if one humerus was discarded in the field and the other transported to the base camp, it received a score of 0.5. If both humeri were transported the element received a score of 1. Thus, the transport indices reported by O’Connell *et al.* (1988, 1990) are identical to the method used to calculate MAU in archaeological assemblages (also see Lupo, 2001).

Table V. Observed Hadza Part Transport Decisions for Female Zebra^a

Female zebra	Case number								Transport ^b MAU	Percent MAU
	14	22	23	28	46	47	73	H5		
Skull	0	1.0	1.0	1.0	0	0	0	0	3.0	37
Cervical vertebrae	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Thoracic vertebrae	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Lumbar vertebrae	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Pelvis	1.0	1.0	0.5	1.0	1.0	1.0	1.0	0.0	6.5	81
Ribs	0.82	0.8	0.8	0.2	0.33	0.6	0.5	0.6	3.9	48
Scapula	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Humerus	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Radioulna	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100
Metacarpal	1.0	1.0	1.0	1.0	1.0	0	1.0	1.0	7.0	87
Front phalanx	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	7.5	94
Femur	1.0	1.0	1.0	1.0	1.0	0.5	0.5	1.0	7.0	87
Tibia	1.0	1.0	1.0	1.0	0.5	0.5	1.0	1.0	7.0	87
Metatarsal	1.0	1.0	1.0	1.0	0.5	1.0	0.5	1.0	7.0	87
Hind phalanx	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.0	100

^aCases 14–73 reported by O’Connell *et al.* (1988, 1990). Case H5 reported by Bunn *et al.* (1988).

^bValues under each case number reflect a transport index derived by dividing the number of bones transported to the base camp by the number of times the bone occurs anatomically (O’Connell *et al.*, 1988, 1990). If one humerus was discarded in the field and the other transported back to the base camp it received a transport score of 0.5. If both humeri were transported from the field to the base camp this element received a score of 1. The transport indices are identical to the method used to calculate MAU, or Minimum Animal Unit, a measurement of relative skeletal abundance (Binford, 1978, pp. 478–479). Percent MAU was derived by setting the highest MAU at 100 and scaling all other values relative to it.

As shown in Tables IV and V, zebra bones are less selectively transported than those of impala. Note that for both taxa, individual but conjoining skeletal parts within larger anatomical units (i.e., forelimb, hindlimb) can have independent transport histories. For example, the humerus and radioulna can be independently transported. Also note that whole limb bones are either transported or discarded; different limb bone segments (i.e., proximal, distal) do not have independent transport histories, at least from kill sites to residential camps (but see Lupo, 2001).

ANALYSIS OF HADZA PROCESSING AND TRANSPORT

How do the Hadza resolve processing and transport problems involving impala and zebra carcasses? Given the overall goal of maximizing the amount of animal products transported within the contexts described here, how do the Hadza make trade-offs between field processing and transport costs that minimize the amount of animal products discarded? Previous analysts have identified two possible economic measures that could reflect the tradeoffs made by the Hadza in

carcass treatment: field processing costs and the ratio of edible tissue relative to total part weight. In this paper, I argue that minimization of remnant animal products discarded is a key variable influencing how parts are field processed and the subsequent transport potential of the part. Here, I test the value of these measures using data derived from the butchering experiments.

If Hadza carcass part treatment varies largely as a function of field processing costs, there should be positive relationship between part transport and field processing costs. Field processing costs are measured by the amount of the time it takes to fillet, dismember, and remove marrow from different skeletal parts. Field processing also usually includes evisceration and sometimes skin removal, but the time it takes to complete these tasks are not considered here (but see appendix). Since this analysis focuses on the costs and benefits associated with specific skeletal parts, it is not clear to me how costs associated with overall carcass preparation can be accurately partitioned among the different elements.

If transport probability varies as a function of the ratio of edible tissue to part weight, then there should be a positive and significant relationship between part transport and this measure. The ratio of edible tissue to total part weight is measured by the weight of FUI(t) divided by total part weight (including the bone). This ratio essentially reflects the edible fraction associated with each part at acquisition.

If minimization of the amount of edible animal products discarded shapes transport decisions then I expect a positive and significant relationship between some measure of remnant animal products and transport. The amount of remnant animal products relative to the weight of the package is expressed here as a ratio value FUI(r) divided by the dry bone weight. I assume that this ratio measures the discounts in the gains in load utility derived by culling parts in the field relative to the costs of transporting the inedible component of the part. Discounts will be lower and gains higher for parts with a low FUI(r) to dry bone weight than for parts with a high FUI(r) to dry bone weight ratio.

Female Impala

When impala carcasses are selectively processed, the body parts most commonly discarded are the limb bones (Tables I, III, and IV). Limbs are transported as articulated forelimb/hindlimb segments on occasion, but more often the meat is stripped, the marrow removed and consumed, and the stripped bones discarded in the field. The parts most commonly transported include the vertebrae, skull, and pelvis. These heavy boned parts have high field processing costs and are often transported as intact body segments (e.g., cervical and lumbar vertebra as units, thoracic vertebrae attached to the proximal ribs). Parts with moderately high transport frequencies (transported $\sim 50\%$ of the time) include the ribs and scapula. The ribs are field processed in any number of ways. Usually, the bones

Table VI. Correlations Coefficients Calculated Between Observed Transport Frequencies (as Measured by MAU) and Different Measures of Field Processing Time

Processing activities	Female impala ($N=9$)			Female zebra ($N=8$)		
	r	P	r^2	r	P	r^2
Dismemberment/fillet time	0.798	0.001	0.638	-0.524	0.065	0.276
Dismemberment/fillet/marrow time	0.233	0.443	0.054	-0.637	0.019	0.407
Ratio of FUI(t) to part weight	0.261	0.388	0.068	0.164	0.593	0.027
Ratio FUI(r) to dry bone weight	0.855	0.0002	0.730	-0.319	0.287	0.102

Note. Significant values are in bold.

are stripped and segmented and some stripped bone segments are discarded (after bits of the adhering meat are consumed as snacks), while others are transported. If the scapula is not discarded as a stripped part at the kill site, it is transported as an intact portion.

Table VI shows a strong positive correlation between the time it takes to dismember and fillet different skeletal parts and impala transport decisions. But this correlation is weakened and becomes insignificant if marrow extraction time is included as part of field processing. Again, the inclusion of marrow processing time nearly doubles the amount of time it takes to field process the limb bones. There is no correlation between impala part transport and the ratio of FUI(t) and part weight. This result is not unexpected since this measure is based on the total amount of animal products originally attached to the part. As discussed earlier, when field processing involves separating animal products from the bone, any economic measure based on the total animal products originally attached to bone will inaccurately reflect the utility and transport potential of the processed part. A much stronger correlation exists between impala transport and the ratio of FUI(r) and dry bone weight. Those body parts that cannot be exhausted are only minimally processed, and they are transported more often than parts that can be quickly depleted of animal products. In the case of the impala, the nutrient potential of the limb bones is nearly completely exhausted after the meat is removed. Even though additional processing time is required to remove marrow (i.e., marrow extraction time for limbs, except the phalanges), this only adds 14 min to total field time.

The Hadza resolve the trade-offs between field processing and transport costs by selectively processing and discarding those parts that can be completely (or nearly so) depleted of animal products in a short time interval. By selectively discarding processed limb bones, the Hadza are making the choice that effectively reduces transport costs and minimizes nutrient waste. Even though the limbs comprise some of the lightest weight bones in the body, the gains made in reducing transport costs are greater for the limb bones than for other parts because less remnant product is discarded. If the Hadza were to selectively discard heavier weight bones, they would also be discarding larger amounts of remnant animal products. With small-sized carcasses such as impala with limited amounts of

animal products, discarding heavier weight bones (and their associated animal products) would result in a substantial loss of edible animal products.

Female Zebra

For zebra, the two parts with the lowest transport frequencies, the skull, and the ribs, are also the parts with the heaviest dry bone weights and highest processing costs (Tables II, III, and V). The ribs are moderately high ranked for transport (48% of the time), have moderately high processing times, and comprise heavy bones that retain large quantities of FUI(r). Ribs are usually transported as stripped bone or are discarded after the meat is consumed as a snack. The pelvis has a high transport frequency and is usually transported as an intact body portion. Vertebrae are commonly transported and are usually processed by filleting the meat, and segmenting and transporting the stripped meat and bone. Limb bones are also very high ranked for transport and are usually (but not always) transported as complete articulated units.

There is a moderately strong negative correlation between fillet and dismemberment time and zebra part transport ($r = -0.524$, $p = 0.065$, Table VI). This correlation is strengthened when marrow extraction time is included in field processing costs. These results are inconsistent with those derived for the impala and suggest that those parts with the highest processing costs are selectively processed and discarded more often than others. However, since almost all of the zebra carcass is transported, the skull and ribs largely drive these results. If these two parts were removed from the data set, this correlation would disappear. There are no significant correlations between zebra part transport and the ratio of FUI(t) to part weight or the ratio of FUI(r) to dry bone weight.

If the Hadza resolve impala transport problems by selectively discarding the parts that can be quickly depleted of animal products, why does not this same solution work for zebra? It is possible that aspects of zebra anatomy change how the trade-offs between field processing and transport costs are resolved. As with most wild game, zebra carcasses comprise large amounts of lean meat (e.g., Speth, 1987). As already described, architectural features of zebra limb bones make it especially difficult to deplete marrow (and grease) without access to thermal processing equipment. The Hadza could quickly fillet the limbs in the field and discard the bones or attempt to remove the marrow, but both of these options would result in the discard of fat-rich animal products, grease and remnant marrow. Completely processing the zebra limb bones (e.g., filleting, dismembering, and marrow fracturing) adds an additional 46 min to the amount of time spent in the field. But this time investment is not offset by any benefit in the reduction of transport costs because the stripped limb bones still have to be transported to avoid discarding fat-rich products. When fat-rich animal products such as marrow and grease are more highly valued than lean meat then a higher

value might be placed on the parts retaining those products (e.g., Speth, 1983; Speth and Spielmann, 1983). A higher value may be placed on fat-rich products seasonally or interannually when lean meat is abundant and carbohydrates and fats are limited (Speth, 1983, 1987); or when protein comprises a large part of the diet (29.7–40.0% of total energy consumed) and calories are limited (Cordain *et al.*, 2000). If large quantities of lean meat were already available, then the value of remnant bits of meat left adhering to stripped heavy parts, such as the ribs, with high transport costs could be greatly devalued. Similarly, the bits of meat left adhering to the skull, after the brain is removed, may be greatly devalued relative to the costs of transporting the part. In the case of limb bones, the value of specific remnant animal products is greater than the value of reducing transport costs by culling the bone and the costs of field processing.

The overall size of zebra carcasses also likely incurs greater transport costs for some body segments in comparison to the impala. The average size of some parts, as measured in weight, is at the upper end of what most adults can carry for sustained periods (approximately 20 kg; O'Connell *et al.*, 1988, 1990; but also see Osaki, 2005; Tanaka, 1980). Consequently, the gains for reducing transport costs by culling or modifying the heaviest parts may be greater for zebra than it is for impala. While only the heaviest bones are actually discarded, modification to reduce transport costs is evident in the treatment of other zebra body parts (Table III). For example, separating the meat from the bone routinely modifies high bulk parts, such as the vertebrae (and sometimes the ribs). Both the meat and stripped bone are transported as separate, smaller sized, and lighter packages.

In the case of the zebra, bone architecture and size result in a different solution to the problem of processing and transport. Unusual bone architecture that retains fat-rich marrow and grease enhances the value of transporting limbs even though these parts can be easily field processed. Bulky parts are transported, but only after substantial modification. In this case, the gains made by reducing transport costs are greater than any possible gain that could be made by decreasing field processing time. In addition, when large quantities of meat are available the value of some remnant animal products associated with some elements is enhanced. Only the heaviest bones (skull and ribs) with less valuable remnant animal products are discarded after much of remaining animal products consumed at the field site.

SUMMARY AND DISCUSSION

These analyses show that the problems of carcass treatment and transport have different solutions among the Hadza. Of the economic variables examined here, none consistently predict part treatment and transport for both species. Nevertheless, carcass treatment and transport may be guided by a similar set of underlying principles. The Hadza may be maximizing the amounts of animal products transported to central places by making trade-offs between field processing and transport costs that minimize product waste. Again, recall that these decisions

are made within the contexts of available cooking technology, lack of meat storage, a high degree of meat-sharing, unpredictable or high-risk hunting returns, and seasonal or interannual variability in the availability of animal fat relative to lean meat. If Hadza decisions were simply guided by a desire to maximize the amount of animal products transported to central places, then one might expect that complete carcasses of most medium-sized animals would be consistently transported and selective carcass treatment and transport constraints might only be manifest with super-sized carcasses, such as elephants and giraffes. Transport capacity does not appear to be limited; the Hadza can and do enlist the help of carrying parties comprising many people from one or more villages whenever large game is procured (Bunn *et al.*, 1988; O'Connell *et al.*, 1988, 1990). This has led some to speculate that transport costs “do not count” or are insignificant for the Hadza and other group-living foragers. But if transport costs do not influence carcass treatment and transport, one would again expect complete carcass transport or very minimally field processing for most medium-sized carcasses. Yet, at least some of the taxonomic variation in carcass treatment for these taxa seems to be aimed at reducing transport costs (see also Monahan, 1998; O'Connell, 1988, 1990). If variation in part field processing costs alone accounts for carcass treatment and transport, one might expect more consistent significant results in the tests conducted here. The solutions to carcass treatment described here are the results of balancing field processing and transport costs to achieve a primary goal (maximizing animal products returned to central places). Differences between the carcass treatment solutions identified here depend, in part, on resource characteristics such as carcass-size and bone characteristics. Anatomical differences between the two species compared in this analysis changed the costs and benefits of field processing and transporting different skeletal parts and the relative value of remnant animal products.

One might argue that the differences in treatment and transport between the taxa examined here are largely driven by peculiarities of equid anatomy and that the ratio of FUI(r) to dry bone weight (or some other index) might predict part transport for a different bovid with anatomical proportions similar to the impala (i.e., hartebeests and wildebeests). Unfortunately, there are too few cases of alcelaphine processing and transport in the Hadza dataset to actually test this proposition. Future research may, in fact, identify a common economic measure or index that reflects part treatment and transport decisions for a range of similarly sized and proportioned prey animals. But even if such an index is identified, it is unlikely that the same measure will reflect carcass treatment in all contexts. The value of different types and amounts of remnant animal products relative to bone weight varies as a function of the other types and quantities of animal products and other food resources available for immediate consumption. It is not clear, for example, how the copious quantities of marrow (and meat) associated with some super-sized carcasses, such as giraffe, might influence carcass treatment decisions. Given the results of the analyses conducted here, analysts should assume that taxonomic differences in carcass characteristics strongly influence how trade-offs

in carcass treatment and transport are resolved. It is entirely possible that different economic indices will reflect how trade-offs in field processing and transport are resolved for different taxa or groups of prey.

ANTHROPOLOGICAL AND ARCHAEOLOGICAL IMPLICATIONS

Analyses conducted here provide a starting point for exploring how carcass processing and transport decisions are resolved by one group of contemporary hunter-gatherers. The next step for analysts is to document and explain the range of variation displayed by modern foragers in other ecological, social, and historical contexts. Using rationale derived from CPF models, analysts can isolate and focus on those factors that influence the costs of field processing and transport and value of remnant tissue. Explanations should focus on identifying the goals and constraints that influence decision-making. Insights gained by understanding the contemporary range of variation in carcass processing and transport might shed light on how prehistoric hunters resolved similar carcass treatment problems across time and space.

Explaining Variability in Carcass Treatment Patterns

The Hadza are one example of central place big-game specialists living in subtropical conditions that field process and transport prey body parts for immediate consumption. While other foraging populations undoubtedly live under similar conditions, Hadza processing and transport decisions are not necessarily representative of other forager groups with different goals and constrained by different ecological and social conditions. Different goals and constraints define processing options and influence how field processing and transport costs are balanced. Recognition of how different goals and constraints influence carcass treatment decisions should be the primary task of future ethnoarchaeological research.

For example, carcass processing and transport decisions of some San bushmen groups, such as the Kua, G/wi and Ju/'hoansi, occupying parts of the Kalahari Desert in Botswana and Namibia can sometimes involve the production of biltong (dried meat). At the kill site the filleted meat from medium- and larger sized carcasses is cut into thin strips and dried for hours in the sun before being transported to residential camp. Biltong production can reduce transport costs by as much as 29–60% by decreasing the amount of moisture in the tissue, but it is associated with extremely high field processing costs (Bartram, 1993; Lee, 1979; Tanaka, 1980). In the process of biltong production, stripped bones are often discarded in the field and some remnant animal products remain unrealized. This activity is hard to reconcile with the overarching goal of maximization of the amount of animal products transported, since food is discarded. This is further implied by

Bartram's (1993) analysis of Kua produced bone assemblages which shows that conventional measures of utility did not predict skeletal abundances.

There are several important contextual and ecological circumstances that differ between the San and Hadza that may influence how carcass processing and transport decisions are resolved. The excessive field processing costs associated with biltong production and the discard of edible products associated with stripped bones suggest that under some circumstances the San may experience transport costs higher than the value of the remnant animal products associated with discarded bones. Ethnographic accounts show that biltong production is usually associated with larger sized prey animals such as gemsbok (*Oryx gazella*) and giraffe that overlap in size with some of the prey commonly processed by the Hadza. Thus, carcass size is not driving the differences in how prey are processed and transported. But bushmen biltong hunts usually span several days and extend over greater ranges than those covered by Hadza hunters (Draper, 2005; Lee, 1979; Silberbauer, 1981; Tanaka, 1980). Tanaka (1980) reports that game are rarely encountered within 10–15 km of G/Wi campsites and hunters may walk from 15 to 30 km to find prey (but see Bartram, 1993). According to Tanaka (1980, p. 33), "Transporting such a load across the burning Kalahari is no joke. In the case of a giraffe weighing over a ton, the tracking may take three or four days, making the trip home that much longer, not to mention the additional amount of meat to be carried. In such cases, the hunters will discard the bones, then cut the meat into strips and dry it, which reduces the carrying weight considerably. Drying also serves to prevent spoilage." In recent years, a number of bushmen groups have acquired horses and hunt on horseback. Equestrian hunts are undertaken for up to a week and extend over areas some 40–50 km from camp (see Osaki, 2005). Because large numbers of animals may be taken in these hunts, biltong production serves to reduce transport costs and preserve the meat until the hunters return to the camp. In comparison, most prey taken by the Hadza are dispatched and processed within 5 km of the residential camp. Because prey are encountered in close proximity to camp, most hunts rarely last more than 1 day, with the exception of overnight vigils at dry season hunting blinds or circumstances where extremely large-sized animals are hunted and butchered (Bunn *et al.*, 1988; Marlowe, 2004; O'Connell *et al.*, 1988, 1990).

Several studies show that performing physical activities in extremely hot and dry environments, such as the Kalahari, can impose an extra energetic expenditure because of the combined effects of heat stress and muscular work (e.g., Mudambo *et al.*, 1997; Ulijaszek, 2001). Blurton Jones and Sibley (1978) argued that heat strain was a limiting factor in the back loads transported by !Kung women. Ethnographic observations show that some Kalahari populations actively protect themselves from the effects of heat stress and dehydration particularly during the hottest and driest seasons of the year (see Silberbauer, 1981, pp. 276–277; Valiente-Noailles, 1993, p. 16). Some bushmen populations use a diverse array of simple technology designed to carry loads close to the center of the body

thus reducing the energetic expenditure of transporting loads (see, especially, Lee, 1979).

Another important constraint that might influence carcass treatment is the storage and the possible social and political value associated with the delayed sharing of biltong. Meat-sharing is a common practice among many foragers, including the Hadza and San, and seems to help promote social and political alliances and advertise desirable qualities (e.g., Hawkes, 1991; Hawkes *et al.*, 1991; Hawkes and Bliege Bird, 2002; Lupo and Schmitt, 2004, 2005; Marlowe, 2004; Smith, 2004; Smith and Bliege Bird, 2000; Wiessner, 2002). The Hadza and some San populations immediately share fresh meat from large animal carcasses with unrelated conspecifics. Among the Hadza most meat is consumed within 2 days of the kill and only small amounts of meat are smoked and/or dried for trade. Conserving any meat for more than a few days is nearly impossible because others will demand a share (see Marlowe, 2004). Meat preservation with simple techniques is possible in this area, but the shelf-life of the dried meat may be limited because of environmental conditions characterized by constant high humidity (FAO, 1990). In contrast, the hot and dry conditions of the Kalahari provide more favorable conditions for drying and preserving meat using simple methods. According to Lee (1979), most meat (fresh or dried) acquired by the !Kung San is consumed almost immediately and generally not stored. But men undertake hunting expeditions specifically to obtain biltong on several occasions throughout the year (Lee, 1979; Silberbauer, 1981). Unlike fresh meat, biltong can be kept for up to 2 months without spoiling (Lee, 1979, p. 156; Marshall, 1976). Wiessner (2002) reports that after fresh meat is shared most dried meat will be distributed and consumed within 2 weeks of the kill (Hitchcock *et al.*, 2005; Lee, 1979). Since biltong can be widely shared when fresh meat is unavailable, it may have some added value in building good social and political relations. Perhaps, gifts of dried meat have a bigger impact and are more highly valued when fresh meat is temporarily unavailable.

Excessive seasonal transport costs may diminish the value of transporting stripped bones for remnant animal products. The production of biltong, a storable product that can be widely shared over a longer period of time, may have a higher value than transporting bones with remnant animal products. Discounts in load utility resulting from the discard of edible animal products may be inconsequential in comparison to the costs of transporting stripped bones. The trade-offs between field processing and transport costs have different resolutions among some Kalahari populations because the ecological and social constraints are different from those experienced by the Hadza. Clearly, other factors not explored here may also influence part treatment and transport. Different foraging populations with potentially different goals and operating under different ecological and social constraints will likely have different resolutions to carcass treatment. It is not clear, for example, how deferred consumption and a reliance on stored animal products might influence field processing and transport decisions in this particular

ecological contexts. Clearly, more empirical information is needed to identify and explain the range of variation in carcass treatment among contemporary populations.

The Influence of Cooking Technology

As with all modern hunter-gatherers, Hadza carcass treatment decisions are influenced by the use of modern butchery and cooking equipment, such as metal knives and cooking pots, that may improve the efficiency of processing certain elements for specific animal products (e.g., Lupo and Schmitt, 1997). One might rightly question how the use of modern tools, such as metal knives and cooking pots, influences carcass treatment decisions and, by extension, how applicable the results derived here are to the decisions of prehistoric foragers and premodern hominids lacking modern butchering and cooking technology?

Experiments show that metal tools have superior cutting ability compared to those made from stone (e.g., Hurtado and Hill, 1989; Saraydar and Shimada, 1971), so the use of metal knives might increase processing efficiency by reducing the amount of time it takes to butcher different skeletal parts. While the processing times reported here are probably more efficient than those achievable with stone tools, the use of metal knives probably does not change the relative ranking of the processing times for different skeletal parts within the carcass. Similarly durable, metal pots may be more efficient at cooking and extracting some animal products than are vessels made from ceramic, hide, or wood. It is very probable that the ability to cook meat and express and disperse lipids with moist thermal technology (*sensu* Wandsnider, 1997) by simmering and stewing strongly shapes the skeletal transport patterns of modern humans (Bunn, 1993; Lupo and Schmitt, 1997; O'Connell *et al.*, 1990, 2002; Oliver, 1993).

Some argue that the advent of cooking technology may have been pivotal in the emergence of certain hominid morphological features (i.e., modern digestive physiology, tooth reduction, and body size) and inferred changes in life history (see Ragir, 2000; Wrangham *et al.*, 1999, 2003). While the antiquity of boiling technology is unknown, Wrangham *et al.* (1999, 2003) argue for the use of fire to prepare food among early *Homo ergaster* populations by 1.9 mya (but see Brace, 1995, 1999). Direct evidence for the controlled use of fire by early hominids pre-1 mya ago is controversial (Bellomo, 1994; Binford and Stone, 1986; Brain, 1993; Gowlett *et al.*, 1981; James, 1989; Weiner *et al.*, 1998), but recent finds from Geshen Benot Ya'aqov in northern Israel show strong evidence for controlled fire use by 790,000 years BP (Goren-Inbar, 2004).

Even so evidence for fire-use does not necessarily reflect how animal products were cooked by premodern hominids. It is however possible to extract within bone animal products without sophisticated cooking technology, such as ceramic or metal pots. There is ample evidence in the recent ethnographic and historic record that shows that meat and bones can be cooked and bone grease extracted

with very simple, nondurable technology. Water, meat, and bones can be brought to a simmer by adding heated rocks (the so-called hot rock method) to simple containers constructed from hide, basketry, wood, or even in natural rock cavities (Colville, 1892; Kelly, 1932; Smith, 1974; Lupo, 1993; Lupo and Schmitt, 1997; Wheat, 1972, p. 110). Kelly (1932) reports that North American Paiute hunters lacking equipment cooked deer meat in the thorax of the carcass. In this technique, the head and torso below the ribs were removed and the neck tied closed with twine or intestines, the thorax was propped up and water, meat, and heated stones added (see also Stewart, 1941). Even without access to fire, some stripped skeletal parts retain large quantities of adhering meat that would be valuable to prehistoric foragers. As discussed, oddly shaped parts such as vertebrae and innominates retain adhering meat even after the bone has been filleted and this adhering meat can be exploited without access to moist thermal cooking technology (i.e., via roasting).

Evidence suggests that premodern hominids used fire to prepare some types of food but it is not clear how different types of foods were actually cooked (e.g., Gifford-Gonzalez, 1993). Evidence from Kebara Cave a Middle Paleolithic site in Israel, for example, shows that animal parts were burned during the cooking process (Speth, 2005; Speth and Tchernov, 2001). There is, however, no evidence of the hot-rock boiling method in the form of heated rocks in Middle Paleolithic assemblages suggesting that this cooking method appeared later in time (Speth, personal communication, 2005). But even without durable cooking equipment and boiling technology, the amount of remnant meat attached to some bones after they are stripped might have been well worth the transport costs. While the lack of boiling technology would not completely obviate the value of some remnant animal products, it might change how hominids processed carcass parts at acquisition sites and which parts were actually transported to residential sites.

Zooarchaeological Applications of CPF Rationale

The small number of theoretically based ethnoarchaeological studies focused on decision-making limits widespread application of CPF rationale to archaeological datasets. Nevertheless, interpretations of archaeological skeletal part representation can be improved by (1) refocusing the level at which skeletal part analyses is conducted, (2) modifying current approaches to the study of prey utility indices, (3) recognizing the factors that influenced prehistoric processing and transport costs, and (4) identifying how parts were actually processed in the field before being transported.

Direct applications of CPF models to questions about resource acquisition are often hindered by differences between the scale and units of analyses used in

the models and the archaeological record. Theoretical and anthropological applications of CPF models are based on the analysis of single foraging events. With the possible exception of archaeological sites that represent single events, most assemblages are aggregate measures of many separate events that reflect resource acquisition over some period of time (also see Jones and Metcalfe, 1988; Metcalfe and Jones, 1988). Each of those foraging events represents a unique set of circumstances involving different potential trade-offs in field processing and transport costs. In zooarchaeological multiple event assemblages, it might be possible to identify individual carcasses through refit analysis. However, this type of analysis may not be appropriate for all types of assemblages and can be time-consuming. Archaeological applications of CPF rationale (or more conventional utility-based approaches) to the analyses of multiple event assemblages must assume that these situational differences are not significant or their effects are averaged by aggregate counts of material remains. The implications of this nontrivial assumption are not addressed here (but see Lupo, 2001), but should be revisited by future analysts.

In addition to this assemblage-level assumption, zooarchaeologists often make assumptions about how prehistoric hunters made transport and field processing decisions across different taxa. Analysts routinely group the bone counts of similarly sized animals into size-classes for the purposes of part analysis. For example, the skeletal part counts for all the similarly sized artiodactyls might be combined and subsumed under a prey size-class heading (i.e., size-class 3 or 4) to increase the sample size of different identifiable skeletal parts. Furthermore, in areas with many different but similarly sized species, identification of fragmentary remains to any level beyond the most general can be extremely difficult. As demonstrated here the practice of lumping can obscure important taxonomic differences in carcass treatment. Whenever possible, analysts should strive to maintain taxonomic integrity in the level of analyses for interpreting skeletal part representation.

Despite the large number of utility indices that currently exist, zooarchaeologists still know very little about how field butchery influences part utility and subsequent transport costs. Part of the difficulty is that conventional utility indices measure some, but not all, of the relevant variables that would allow zooarchaeologists to access how trade-offs might be made by prehistoric foragers. Future studies need to become more inclusive and collect information on how different processing operations influence utility and the transport potential of different skeletal parts at different stages of the butchering procedure. Specifically studies need to document not only the amounts and types of animal products associated with different skeletal parts but the weight of the bone relative to animal products at different points in the processing operation. Some of this information might be used to estimate the transport costs of different parts. Basic information on processing costs are limited to just a few studies (Egeland and Byerly, 2005; Lupo, 1998; Lupo and Schmitt, 1997; Madrigal and Holt, 2002). Here I focused on activities that can (but need not) be conducted as part of field processing. But data

on the time it takes to conduct other processing activities such as preparing animal products for immediate consumption and long-term storage are limited. Especially relevant here would be information on how different types of cooking technology influence the extraction of different animal products and the costs associated with different cooking methods (Gifford-Gonzalez, 1993).

Skeletal part analysis must proceed by considering material and contextual evidence for those factors that influence the costs of prey treatment. Some of these material classes are obvious and include evidence of butchering, cooking, and storage technology. Evidence for transport technology might include actual carrying devices, sleds, travois, and boats, and less direct evidence in the form of the skeletal remains of transport animals (e.g., dogs, llama's etc). Since transport costs can also be influenced by terrain type, body mass, features of the landscape and overall site location must be considered. Prey acquisition strategies resulting in the synchronous acquisition of large-sized or large numbers of carcasses will also influence field processing and transport decisions. Less obvious impacts on transport costs might include environmental and physiological factors that influence carrying costs for prehistoric populations that lacked transport technology. Differences in the physiological costs bipedal locomotion and the costs of carrying loads without transport technology must also be for considered in analyses of pre-modern hominid assemblages (Kramer, 2004; Kramer and Eck, 2000; McHenry and Berger, 1998a,b; Myers and Streudel, 1985; Streudel, 1996; Wang *et al.*, 2003; Wang and Crompton, 2004).

Finally, skeletal part analysis cannot be conducted without some consideration of how parts were actually processed in the field. This type of information will obviously depend on the type of site under consideration (e.g., kill/butchering station, residential location). As discussed here, part modification can involve several distinct activities. The best known and most widely recognized of these activities, the selective discard of parts in the field has obvious implications for skeletal part frequencies. But other types of modification activities go unrecognized in the archaeological record. Specifically, filleting meat from high bulk parts (such as ribs and vertebrae) in the field to facilitate transport might be reflected by the position of cutmarks on the bone's surface. Future cutmark studies might be aimed at distinguishing fillet marks inflicted before transport from those produced after the part is transported to a residential site for consumption/residential processing.

CONCLUSIONS

While the solutions to carcass treatment and transport likely varied over time and space, the Hadza decisions for impala and zebra reflect specific solutions to universal processes that guide human decision-making. Using CPF rationale the analyses conducted here show how these decisions are based, in part, on trade-offs

among competing costs and not reflected by single economic index. While carcass treatment decisions are more complex than once imagined, that does not mean they cannot be accurately modeled. Additional empirical information collected within the context of a larger theoretical framework such as CPF may provide the tools for modeling carcass processing and transport behavior of prehistoric hunters. By recognizing that a common set of processes underlies human decision-making, zooarchaeologists can build more accurate models that account for variability in prehistoric carcass treatment and transport decisions. In this analysis, I assumed a specific currency, goal, set of options, and constraints influenced Hadza decision-making. But currency, goal, options, and constraints can vary across time and space and have a significant influence on skeletal part treatment (see, for example, Hawkes, 1991; Hawkes *et al.*, 1991; Hawkes and Bliege Bird, 2002; Lupo and Schmitt, 2004, 2005; Marlowe, 2004; McGuire and Hildebrandt, 2005; Smith, 2004; Smith and Bliege Bird, 2000; Sosis, 2000; Wiessner, 2002). In this paper, I have identified how some of these components might vary but this is obviously only a starting point. A clear priority in future research should involve increasing our understanding of how and why large-game parts are processed and transported in different ecological, social, and historical contexts by contemporary hunters. One of the most obvious ways to get this information is through theoretically focused ethnoarchaeological and experimental research on carcass treatment. More generally, theoretically driven data on field processing and transport decisions for a wider variety of resources (such as plants, nuts, honey, etc.) might provide a broader comparative basis for evaluation human decision-making. Comparative data of this sort might ultimately shed light on the circumstances surrounding the evolution of resource transport behavior among ancestral hominid populations.

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APPENDIX: AVERAGE ORGAN WEIGHTS (G), EVISCERATION AND SKINNING TIME (S) FOR FEMALE IMPALA AND ZEBRA

	Carcass	
	Young adult female impala, carcasses 7 and 8 ^a	Adult female zebra, carcasses 13 and 14
Liver	770	5,375
Heart	425	1,425
Spleen	270	1,275
Kidneys	245	825
Lungs	600	2,500
Stomach ^b	1,620	1,325
Intestines ^c	2,785	45,250
Skin ^d	2,900	22,588
Time evisceration	NA	185
Time skin	650	1,431

^aCarcass 8 was also carrying a nearly full-term fetus that weighed 880 g.

^bStomachs were empty when weighed.

^cIntestines were full when weighed.

^dSkin is the wet weight of the hide covering the body and skull.

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