Chapter 19
Skeletal Disarticulation, Dispersal, Dismemberment, Selective Transport

This chapter focuses mainly on one form of aggregate data analysis that has occupied many zooarchaeologists for over four decades: using element frequencies and, to a lesser extent, cut-marks to infer selective transport of larger animals' body segments from where they were acquired to other locales. As with zooarchaeological research on bone fracture, cut, and percussion marks, one line of investigation in this area was driven by debates over early hominin behavior and adaptation. Another line of butchery and transport research centered on of ancient Americans' hunting practices, both Paleoindian and later (Chap. 2). Related actualistic research has focused mainly on butchery by nonagricultural, hunting peoples. Even studies of agricultural peoples' uses of animals have largely focused on hunted prey (Crader 1983). One exception is my own work on butchery by agropastoral Dassanetch people and by poor Dassanetch who lacked livestock and were of necessity farmer-fisher-hunters, foraging for wild animal food to supplement family grain supplies (Gifford 1977, 1978; Gifford-Gonzalez 1989). More attention has been paid to primary butchery at kill sites or other field acquisition sites than to secondary butchery or culinary butchery practices. Research on butchery was so narrowly focused in part because some studies were framed as direct responses to Binford's assertions about early hominin foraging. Others were motivated by a sense of urgency to document foragers' lifeways before rapidly changing political and economic circumstances further altered their hunting and gathering ways of life. The relatively well-funded and active cohort of zooarchaeologists working on human origins set the terms for much methodological debate in the zooarchaeological literature.

This chapter focuses most on skeletal element frequencies rather than cut marks because I am convinced by Lyman's (1995, 2005) case that, of all hominin-inflicted bone surface modifications, cut marks are the least desirable single-variable bases for broader behavioral inferences (Chap. 14). Besides these reservations about the inferential limits of aggregate cut mark data, another emergent question is how best to represent the degree to which an archaeofaunal assemblage is cut marked, given that varying degrees of specimen fragmentation will affect calculation of cut mark rates. Abe et al. (2002) discussed the best method for quantifying cut mark

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frequencies in consideration of the fact that different samples may diverge markedly in their degree of fragmentation. They give the simple example of a complete femur with three cuts (2 proximal, 1 on the shaft), in which the ratio of cut marks to the complete femur would be 3:1 or .30. They then represent the same femur with its shaft broken into 6 diaphyseal fragments, one of which bears the cut mark, plus the proximal (with 2 cut marks) and distal ends. In this case, the ratio of cut marked fragments expressed as NISP (=8) to cuts is 3:2 or .375 (their simple example did not consider the further complication of a break creating several fragments of a single cut mark).

Abe et al. (2002) also posit that taphonomic effects can further affect cut mark frequency estimates, noting that cuts will preferentially be preserved on the more durable sections of elements. They note that fragmentation from these combined sources can be expected to vary across assemblages, according to the intensities of human processing and other taphonomic impacts. For these reasons, they argue, MNE is the more reliable indicator of cut mark intensity, because it norms the count of fragments toward the original "input" of elements. They further suggest using an ArcView® GIS-based analysis to estimate MNE, as discussed in relation to element survival in Chap. 21.

These complications have not stopped some from continuing in pursuit of behavioral inferences from cut marks. James and Thompson (2015) review ongoing controversies over these and other bone surface modifications, offering insights into their root causes and some suggestions for resolving those that stem from the unstandardized and inconsistent definitions of modifications.

Is hunter-centered butchery and transport research done relevant to archaeologists studying remains of domestic animals? Crabtree (1990), O'Connor (2000), and Orton (2012) have all emphasized the value of methods and generalizations drawn from such research for analyzing archaeofaunas from food producing and socially complex societies. The literature details the tactical problems that different-sized animal bodies present to their butchers, and zooarchaeologists studying domestic species must also consider the challenges faced by handling different-sized animals. Sedentary food producers seldom butcher large domestic animals in their homes, and they must make transport decisions based on trade-offs between nutritional gains and the transportability of various carcass segments. In urban food systems, larger animal bodies are subdivided and circulated as commodities (Zeder 1991), but when, where, and how this happened in an archaeological case must be investigated. Social asymmetries may govern individuals' access to different cuts of meat, even in less complex societies, a topic taken up in more detail in Chap. 25. Although embedded in a different web of considerations, transport decisions nonetheless determine the sequence of actions that move a cut of meat from carcass to cook pot. It thus behooves all zooarchaeologists to consider the literature on field butchery and transport.

Three sections of this chapter contextualize the study of carcass subdivision and transport. The first offers some definitions to be used in this and later chapters and again advocates a *chaîne opératoire* approach to butchery, which focuses on the *products* of a temporally – and often spatially – extended process. The second section provides a baseline for studying human butchery by outlining intrinsic anatomical constraints affecting disarticulation, and hence the uniform challenges to dismemberment faced by both tool-using humans and nonhuman carnivores. The last section reviews zooarchaeological research on butchery and transport in Africa and the Americas, focusing on key debates and on actualistic research that have contributed important findings and perspectives over the last half-century. In the interests of brevity, it omits Australia and East Asia. This section sets the stage for Chap. 20, which deals in detail with methods for calibrating the relative nutritional values of different body segments, as this may affect human transport decisions and hence element frequencies in archaeofaunas.

19.1 Initial Definitions and a Conceptual Framework

Chapter 12 discussed reasons why carnivores transport body segments and stressed that both transport *and* consumption sequences reflect a greater than one-to-one size ratio of the consumer and the consumed. This "given" should be kept in mind throughout this chapter and the next. To gain a clearer view of these topics, some definitions are required. I call the natural process of postmortem disaggregation of elements of a skeleton *disarticulation*, which contrasts with the active division of a carcass by human or nonhuman actors, *dismemberment*. As noted in Chap. 15, humans' tool-mediated subdivision of animal carcasses is often called "butchery," which Lyman (1987: 252) defined as, "the human reduction and modification of an animal carcass into consumable parts." Chapters 14 and 15 described distinctive signatures of such handling, which can involve *evisceration*, *skinning*, *dismembering*, *defleshing* (or *filleting*), and other handling (Lyman 1987: Table 5.2). O'Connor (1993) stressed that butchery can also entail stockpiling selected elements for tool manufacture, and I would add, other elements being reserved for fuel (Chap. 15). I prefer "carcasses processing" or "carcass handling" to "butchery," in part because these phrases link to terms used in behavioral ecology for other organisms' costs in handling their prey (24).

19.2 The Baseline: Vertebrate Body Structure and Disarticulation

Natural skeletal disarticulation and dispersal are largely governed by an animal's anatomical organization, which evolved to support the living organism yet also determines much of how body segments disarticulate after death. Human and nonhuman actors' tactics for dismembering vertebrate bodies are structured by these same anatomical constraints (Chap. 5). After a vertebrate's death, soft tissues decompose, facilitated by action of microorganisms and larger invertebrates (Chap. 16) and, as the connective tissues of articulations between skeletal elements degrade, bones of the skeletal unit begin to dissociate (Lyman 1994; Micozzi 1991). Notwithstanding invertebrate activity, this decomposition is largely a passive process because these actors cannot actively move body segments. Vertebrate taxa can be expected to vary in their sequences of disarticulation according to the relative strength of their taxonomically distinctive joint construction, which in turn results from the species' feeding and locomotor adaptations.

Lyman (1994:146) reviewed the role of joint types play in facilitating or impeding the rate at which given articulations come apart. Anatomists distinguish two overall joint types: *synovial joints* and *fibrous joints*. Synovial joints permit movement of body segments in one or more planes. They are composed of a connective tissue joint capsule enclosing synovial fluid, which acts as a lubricant for cartilage plates on the epiphyses of each articulating element, as well as enclosing the joint's ligaments. The range of motion of the joints depends upon the shape of the joint surfaces. Fibrous joints permit little movement between the joined skeletal elements. The strongest of these are cranial sutures, which in adult individuals ossify completely, but which, because of their interlocking sutures, do not readily disarticulate even in their unfused state. Symphyses have a cartilage plate between the two articulated bones, permitting slight joint mobility. The mandibular symphysis begins as such a fibrous joint, and it remains unossified in some mammals, such as ruminants, while ossifying in others, such as primates and equids. The mammalian pubic symphysis is another cartilage-based fibrous joint; in females, the cartilage permits widening of the pelvic outlet during birth. Cartilage-to-cartilage articulations of ribs to the sternum are also classed as fibrous joints.

Some vertebrates' long bones are covered by sheets of heavy fibrous tissue, such as the radius and ulna in birds and in those mammal species having these bones as independently mobile skeletal elements. Bones joined by fibrous articulations remain together long after death. Fibrous joints such as those of the radius and ulna will disarticulate with the decay of the connective tissue, and are more readily opened by consumers than are sutures or symphyses.

19.2.1 Natural Ungulate Disarticulation and Dispersal Patterns

In passive disarticulation of a vertebrate body, skeletal elements slowly disaggregate spatially. In the absence of other influences, gravity contributes to some dispersal of skeletal elements from their original, articulated, anatomical relations. However, animal bodies seldom exist in the absence of other influences. Dismemberment by carnivores, bone collection by rodents, disturbance by ungulate traffic, or transport by flowing water may influence the sequence and degree to which body segments and bones disperse.

Hill and Behrensmeyer (Hill 1979; Hill and Behrensmeyer 1984) documented disarticulation in zebras, three wild antelopes, domestic cattle in East African landscapes. Their aim was to use these "natural sequences" as a baseline for analyzing

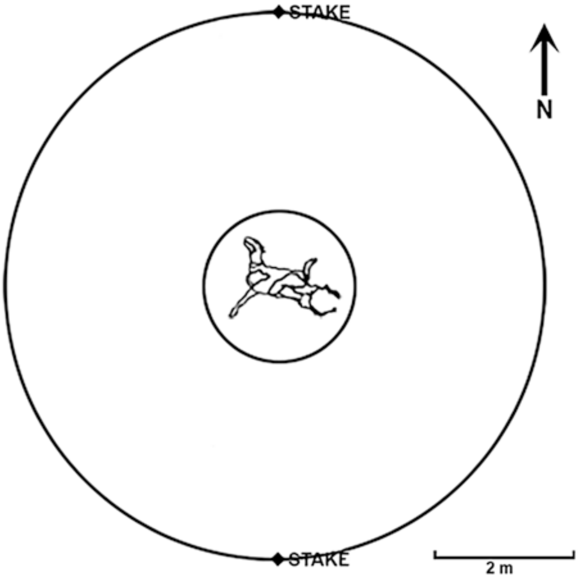

Fig. 19.1 Postmortem disarticulation and dispersal history of a zebra, East Lake Turkana, Kenya. October 1973, body encountered as a recently killed carcass that swiftly mummified, with dried skin and flesh holding it together. See text for details. (Illustration by author)

taphonomic effects in paleontological and archaeofaunal accumulations (Hill and Behrensmeyer 1985). For the taxa surveyed, some consistent patterns of disarticulation occurred, the forelimb detached from the thorax first in all cases, with variable subsequent detachments according to the taxon: the mandible detached from cranium, and the scapula from humerus, in second or third orders, depending on species, and other joints diverged in their order of dissociation in bovid *versus* equid skeletons.

Lyman (1994:144) cautioned that, because the Hill and Behrensmeyer studies were done in natural landscapes, where unobserved biological and meteorological processes could have affected the order of disarticulation, they should not be considered a "pure baseline" for passive disarticulation. Lyman (1994: Table 5.5) analyzed their data and found underlying regularities, with synovial joints tending to disarticulate before fibrous ones.

Figures 19.1, 19.2, 19.3, and 19.4 presents a "time-lapse" view of disarticulation, dispersal, and dismemberment of a common zebra (*Equus quagga burchelli*) carcass that I monitored on a littoral plain on the northeastern shore of Lake Turkana for 10 years after its death in October, 1973. At the time of its death, Taphonomic Specimen 4 (T4) lay about 30 m from the lakeshore. Carnivores had consumed the zebra's hind limb flesh and entrails, but the balance of its skin and flesh swiftly mummified in the hot, dry climate, becoming less appealing to consumers (Fig. 19.1a). It served as a resilient chair for members of a Dassanetch foraging

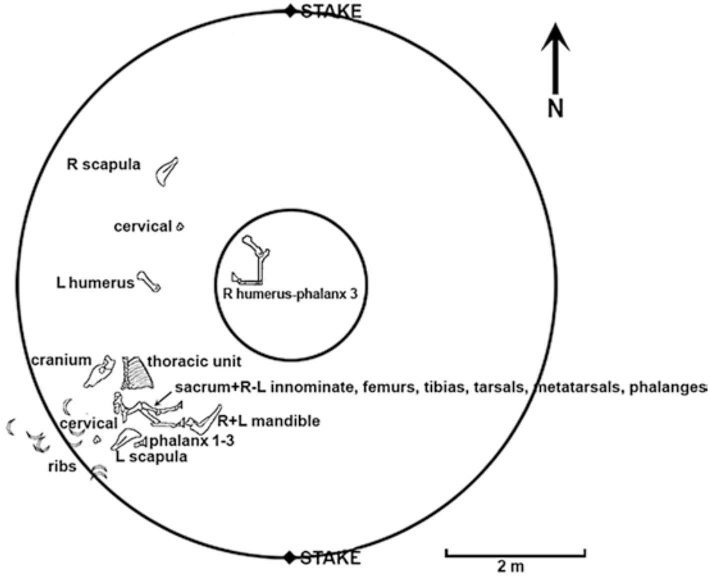

Fig. 19.2 April 1974, mummified skin and flesh were rehydrated by rains and swiftly consumed by invertebrate and mammalian carnivores. Elements were dismembered and scattered by larger mammalian carnivores. See text for details. (Illustration by the author)

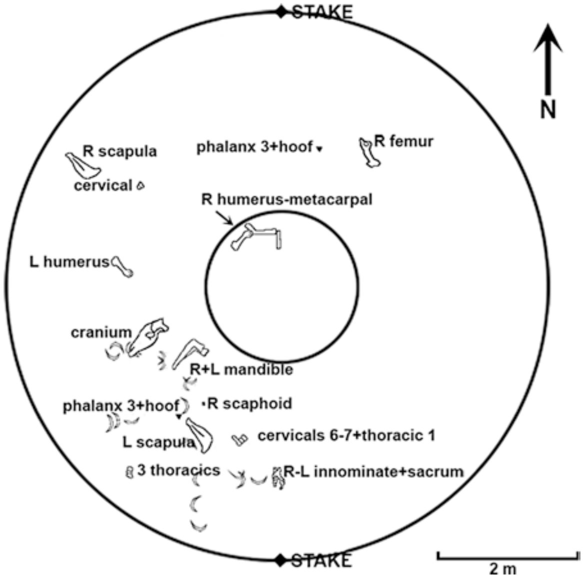

Fig. 19.3 August 1974, skeletal elements continue to disarticulate and be displaced by daily ungulate traffic. See text for details. (Illustration by the author)

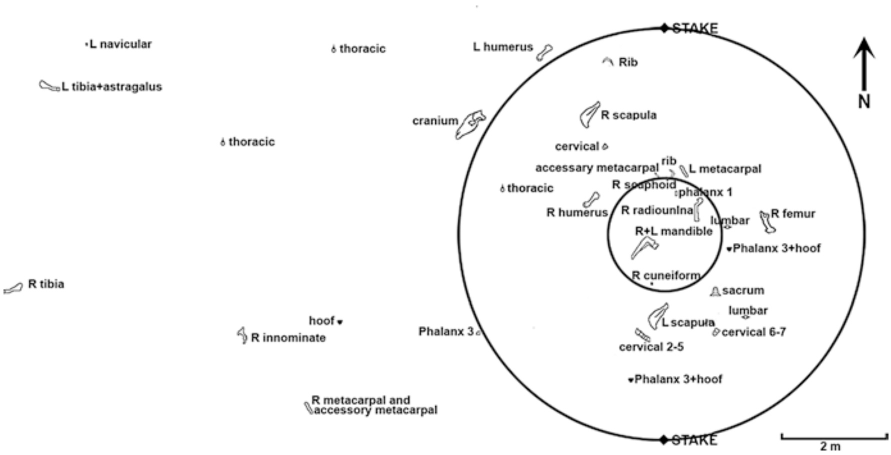

Fig. 19.4 September 1976, skeletal elements continue to disarticulate and be displaced by ungulate traffic. See text for details. (Illustration by the author)

group who camped around it a few months after its death. The carcass remained in its mummified form until April 1974, when heavy rains fell in the area. T4 rehydrated into an odorous but evidently very attractive meal for hyenas and jackals, whose tracks were seen in the mud around the carcass (Fig. 19.1b). Scarab beetles and other insects were active on the carcass. Within the a few days, the still-united axial skeleton was moved about 4 m southwest of its original location, clearly due to the action of larger mammalian consumers, and the mandible, anterior limb bones, and some ribs dissociated from it. Subsequently, passive disarticulation dominated, with more ribs and vertebral segments disarticulated by August 1974 (Fig. 19.2). A well-trodden game trail passed through what was becoming the T4 bone scatter, and herds of zebra and topi antelope coming down to drink at the lakeshore were a dominant engine of modest carcass-part dispersal, as well as trampling damage to skeletal elements. A recheck of this carcass in September 1976 (Fig. 19.3) revealed loss of many of the ribs and some other elements from the scatter, probably by bone-gnawing carnivores such as spotted hyenas, as well as further scattering and dispersal of elements. Thus, an array of biological and meteorological processes interacted with the T4 carcass over 24 months, some leaving traces on its elements and distributions and some not.

The Hill-Behrensmeyer sequence for ungulate disarticulation does not apply to all mammals, much less to other vertebrates. Different taxa possess specialized joints and associated soft tissue anatomy that can speed or slow joint separations. For example, the temporomandibular joint is among the first joints to disarticulate in humans and most herbivores. The structure of these species' jaw joints is relatively open, allowing up-and-down and rotary motion while chewing. When joint capsule tissues and surrounding muscle decompose, the mandible simply falls away from the cranium. By contrast, mustelids such as otters and minks rely on their jaws to seize and kill prey equal to or greater than their own body size. Their mandibular articulations are buttressed by growth of temporal bone around the mandibular condyle; even after all the soft tissues vanish, the cranium and mandible often remain tightly articulated. Mustelids can thus be expected to display a divergent sequence of disarticulation from the ungulates, as well as having more tool marks associated with removal of the jaw, if humans butcher them.

Zooarchaeologists have made taphonomic disarticulation studies on guanacos (Belardi and Rindel 2008; Borrero 1990), pinnipeds (Borella and Muñoz 2006), kangaroos (Reed 2009), and birds of various sizes (Livingston 1989) Weigelt's ([1927] 1989) classic work also offers much useful information on disarticulation across a range of species.

19.3 Carnivores and Carcass Dismemberment, Dispersal, and Transport

Nonhuman carnivores and humans transport vertebrate bodies or body segments from where they encounter them to other locations, with similar motivations: physical safety, shelter from the elements, or provisioning the young or other members of their social groups. Selective removal of body segments from a carcass normally occurs only when that animal's body cannot be transported whole to another place by the consumer, or where the resolution of social tensions within a group of consumers drives subdivision of the carcass. Joint strengths of vertebrate bodies interact with the abilities of consumers to remove and carry body segments away from the death site.

The intentional segmentation of an animal carcass, here called *dismemberment*, results from exertion of force to open joints and break large prey into smaller packets for transport. Both nonhuman carnivores and humans do this, but they approach this task quite differently. Unlike tool-using hominins, carnivores lack the means to sever tightly articulated joints in larger prey. They normally select body segments that readily come off a carcass. For hoofed animals, these are:

1. foreleg (with scapula);
2. mandible;
3. upper hindleg (with or without os coxae);
4. depending on the ungulate taxon, the lower hind leg (metapodials and phalanges) may be disarticulated and left at the death site during initial consumption.

Like human butchery, carnivore dismemberment of larger animal carcasses is an ongoing series of actions that can actually begin during kills, when parts of the prey's body may be dislocated or even wrenched off. It continues during initial feeding at the acquisition locale. As outlined in Chap. 12, carnivores feeding on animals equal to or larger than their own body size display a regular consumption sequence, in a trade-off between the nutritional gains offered by various tissues and their physical abilities to access them. In this process, dismemberment may occur; for example, eating the muscle masses around shoulder and hip joints may cause the limbs to dissociate from the trunk, even if the consumer is not actively wrenching at a leg. Carnivores may break down cartilaginous fibrous joints by gnawing on them. Once a body segment is detached, carnivores may transport it a few meters or several kilometers, depending upon their motivations. Transport of prey body segments over longer distances depends on situational, species-specific nutritional needs such as provisioning of dependent offspring or lactating females in refuges (Chap. 12).

19.4 Butchery: Tool-Mediated Carcass Dismemberment, Dispersal, and Transport

Humans may have been central-place foragers since the emergence of our genus. Foragers taking possession of animal bodies that outweigh them face the challenge of getting the body back to their home base. Human hunters and scavengers use a highly flexible set of tactics to do so, responding to many factors, which Lyman (1987) summarized. These include the weather and time of day when a species was acquired, variations in how many animals are killed or encountered, how many potential carriers are in the hunting party or can be called in to help, how far the hunters are from their ultimate destination, and whether alternate means of transport, such as pack animals, dog sleds, cars, or snowmobiles are available. Other temporal factors include the time of day a carcass is acquired, weather and other physical circumstances, and presence of scavenging animals capable of appropriating a carcass left in the field overnight. Binford (1978:81–83) reported a dramatic instance of Nunamiut butchers racing the breaking ice of the Anaktuvuk River when the mass kills of the northward caribou migration coincided with an very early spring thaw. Hunters were processing the carcasses across the river north of their residential camp and had been intending to transport body segments over the frozen river with their snowmobiles. As butchers worked, the loud cracking of river ice blocks signaled the imminent break-up, and they hurriedly segmented and carried carcass sections across the ice, skipping the fine-grained subdivisions applied in years that allowed a more leisurely approach.

One alternative to the usual pattern of bringing home the prey is simply to move households to the acquisition site for as long as it takes to consume and/or preserve the animal's flesh. This has been documented for mass kills of large animals such as bison (e.g. Denig 1930; Lowie 1922) and for use of very large single animals such as elephants and whales. The more usual practice for hunters acquiring animals in less imposing numbers or sizes is to move the prey, rather than the base of household operations. This entails tool-aided dismemberment of the carcass, which does not necessarily follow the sequence of passive disarticulation outlined earlier but rather conforms to the butchers' aims and the capacities of their tools.

The relative strengths of large prey articulations challenge human as well as nonhuman consumers when they seek to dismember body segments. It is a truism in zooarchaeology that tightly articulated joints are more likely to bear marks of the tool's intervention in the form of cut, chop, or sawing marks (Chap. 13). Human butchers can dismember synovial joints by cutting ligaments and other connective tissues around the joint, opening the joint capsule, and levering the joined elements into a "dislocated" position for final separation. Sutures and symphyseal joints require the heaviest intervention and may not be opened so much as fractured or chopped.

Some central considerations condition butchery decisions. In the parlance of modern postal services, dead animals are "dated materials," demanding processors' timely attention if they are to use them. Ethnographic cases caution against extending Western criteria to other cultures' food preferences; however, at some point, animal body parts become unusable as food. Binford (1978) reported that Nunamiut people consumed red marrow in the ribs of freshly killed caribou, but if the ribs were frozen for several months, they would simply strip and cook the muscle from them because they deemed their marrow was unpalatable after that span. Butchers routinely handle carcasses to isolate the intestinal tract and its contents to avoid contamination of flesh and other edible tissues that accelerate spoilage and pose health risks. Butchers extract and consume parts most likely to degenerate first (blood, brains, viscera) and specially handle tissues of intermediate "shelf life" and risks of transferring bacteria to meat – such as marrow (Friesen 2001) – keeping them away from meat intended for long-term storage, either to extend their palatability or to enhance their transportability. Realities of postmortem decay interact other factors, such as the number of animals acquired in relation to the number of consumers. If 50 people in a hunting group kill 150 bison during one spring day, intending to produce enough jerky for the summer, they are under pressure to speedily strip the carcasses in order to efficiently dry masses of meat. If 50 villagers slaughter and share one ox, subdivision of a single carcass among community members effectively eliminates pressure to extend the use-life of the animal's flesh.

Lyman's (1987) noted that all butchery operations depend upon available technological means for subdividing, transporting, preserving, and preparing carcass parts for consumption. This includes tools used in primary and secondary butchery, as Seetah (2008) explored in detail using the transitions in carcass segmentation enabled by different kinds of metal tools documented during European history. Whether transport of large animals' carcass parts depends on human carriers, pack animals, or vehicles will influence transport decisions, and each entails different strategic social and technological investments. Forms of culinary processing can affect field decisions about what to bring home and how to transport it (Gifford-Gonzalez 1993). In some ethnographically documented cases, the cooks were also the field butchers (see references in Gifford-Gonzalez 1993:189). In other cases, the primary butchers were hunters, but fully knowledgeable about the uses to which carcass parts will be put and process these accordingly.

Pastoralists, farmers, and specialized meat producers in complex societies normally have few "search costs" with domestic animals, but they still must organize the slaughtering of animals in a convenient locale in relation to their settlements, initial tissue extraction and carcass segmentation, and moving transportable units to other places. Traditional Maasai pastoralists in East Africa have habitual slaughtering localities outside their settlements, where they strip flesh from some sections of cattle carcasses and discard bones from those segments, carrying only soft tissues and selected bone-in units to the home camp for further processing (Mbae 1986).

The next section reviews the history of zooarchaeological butchery and transport studies.

19.5 Butchery and Transport Studies in Zooarchaeology

Readers seeking deeper historical context can turn to Lyman's 1987, "Archaeofaunas and butchery studies: A taphonomic perspective," also Domínguez-Rodrigo's 2002 "Hunting and scavenging by early humans: The state of the debate," for details on the earlier Africanist research. Since Dart, White, Wheat, Perkins, and Daly (Chap. 2), most zooarchaeologists have believed that element frequencies can reflect human decision-making during large animal butchery. Except for Binford's (e.g. 1978) investigations of Nunamiut animal use, butchery and transport research has shown a strong inclination toward studying the early stages of carcass acquisition and subdivision, focusing on "kill-site" archaeology. This matter will be taken up further in Chap. 20.

Through the 1970s, Frison and his students (e.g. 1970, 1974, 1978; Todd and Frison 1986) followed Wheat's lead in documenting regular patterns of carcass dismemberment, bone breakage, and selective transport from acquisition sites. They interpreted these cases as reflecting a strategy to maximize swift meat removal from many animals during short, intense butchery episodes, systematically documenting the carcass segmentation and intrasite distributional patterns.

19.5.1 First Wave Ethnoarchaeology of Butchery and Transport

Ethnoarchaeological studies in Africa in the early 1970s and elsewhere reported hunting, butchery, and transport strategies that diverged from those of North American bison hunters and from expectations generated by Perkins and Daly's classic article (1968) on *schlepp* effect (Chap. 2). Yellen's (1977) research on large antelope butchery by !Kung hunters in Botswana, where large animals were taken infrequently and usually one at a time, revealed other patterns of butchery and transport. !Kung hunters removed and discarded horns and digestive organs at the acquisition site during primary butchery and immediately consumed other organs and metapodia. However, they treated the remaining carcass quite differently from the mass kill pattern. Body segments were broken down into readily transportable units and, although some body segments were stripped of flesh to facilitate transport, all skeletal elements as well as flesh were carried home. This handling raised the question of whether differing acquisition circumstances or "cultural" factors governed foragers' approach to carcass subdivision, a discussion elaborated through by ethnoarchaeological research through the 1980s and 1990s.

19.5.2 Binford, Bones, and the Hunting-Scavenging Debate

Butchery and transport research intensified in the 1980s, as the extent to which early hominins were carnivorous and hunted for their meat emerged as a hot topic. In 1981, Binford combined element frequency and bone-surface modification analysis in *Bones: Ancient men and modern myths*, first reporting on his actualistic research among Nunamiut hunter-gatherers of the Brooks Range, Alaska, and then taking many colleagues to task for their interpretations of archaeofaunas. *Bones* articulated Binford's justification for an actualistic approach to elucidating archaeological data. Binford argued that element frequencies, combined with the placement of cut marks on skeletal elements, could testify to the nature of faunal processing activities at a locality, and by extension, to site function. Among Binford's central findings was that Nunamiut people, who engaged in highly efficient mass processing of caribou twice a year, nonetheless displayed considerable variability in their discard vs. transport of caribou carcass parts. He attributed this to their calculated responses to situational variations in the number of animals killed, size of the potential carrying party, availability of means of transport, and weather.

In the most controversial part of the book, Binford applied his methods to analyze other researchers' published zooarchaeological data, from Plio-Pleistocene through Paleoindian periods. His conclusions about site function and the behavior of earlier hominins often departed markedly from those of the primary researchers. In *Bones* and in later publications Binford asserted that all Eurasian and African hominins except anatomically modern humans were inefficient hunters (e.g. Binford 1983, 1984a, 1984b, 1984c, 1985; Binford et al. 1988). He reserved a substantial section for a critique of inferences about hominin hunting from element frequencies of medium to large ungulates at sites in the Olduvai Gorge, Tanzania. At the time he was writing *Bones*, Olduvai was the best-published set of ancient African data, with tables enumerating species and elements (Leakey 1971). In the Olduvai tables, limb bones were overrepresented compared to elements of the axial skeleton, including durable teeth. Binford (1981, 1984b; Binford et al. 1988), contended that the Olduvai element frequency data displayed an "inverse utility curve" (Chap. 20) – in other words, many low-nutrition elements. He argued that the data reflected hominins' scavenging the leavings of carnivore kills.

Even as Binford was framing his critique, some Olduvai collections were being reanalyzed according to contemporary standards. The excellent bone preservation at some sites, especially FLK 22 *Zinjanthropus,* dating to nearly 2 million years of age, permitted study of bone surface modifications, and stone-tool cut marks were first diagnosed in this archaeofauna (Potts and Shipman 1981; Bunn 1981).

Bunn, who along with Shipman and Potts had been reanalyzing the FLK 22 *Zinj* archaeofauna, responded that these accumulations resulted from hominins' transport of meaty limb bones from kill sites as hunters or "active scavengers" who appropriated carcasses from predators while meat remained on the limb bones (Bunn 1986; Bunn and Ezzo 1993; Bunn and Kroll 1986, 1988).

Zooarchaeological debate over whether early genus *Homo* acquired large ungulate body segments by hunting or by scavenging continues to this day. In the late 1980s, it incorporated bone surface modifications, especially cut marks, as well as element frequencies as data, and other research teams joined the fray (e.g. Blumenschine 1988; Blumenschine and Marean 1993; Capaldo 1997; Domínguez-Rodrigo 1997b) with expanded archaeofaunal samples, as evidenced in Egeland et al.'s (2004) comparative study (Chap. 17). A thorough overview of this debate would make – and indeed has made – a book in itself and is beyond the aims of this one: a quick count of relevant, post-*Bones* publications in one decade-old review by Domínguez-Rodrigo (2002) yielded 219 independent citations! This controversy exemplifies the challenges of assigning behavioral meaning to aggregate archaeofaunal data: much of the argument centers on what counts as compelling evidence of primary access to a carcass, and on what grounds.

In sum, Binford's assertions and some of his uses of others' data prompted a wave of research on archaeofaunas associated with early members of the genus *Homo* in Africa and with pre-modern forms of *Homo* in Eurasia. Subsequent fossil hominin research, zooarchaeological analyses, and bone-isotope investigations have disproven many of Binford's assertions regarding hunting capabilities of Middle Stone Age hominins in Africa – now known to actually be *Homo sapiens* in the sites he analyzed – and of Neanderthals in Europe. Nonetheless, many zooarchaeological methods, including use of the %MAU estimate of element abundance, element-specific nutritional utility indices, and cut-mark placement analysis, were spurred by his publications. Binford's provocations also led to considerable experimental and ethnoarchaeological research on bone durability and surface modifications, as well as associated nutritional yields of body segments. While diverse, these studies address the underlying problem of reliably establishing the functional and behavioral meanings of skeletal element frequencies and bone surface modifications in archaeofauna (see also Lyman 2012).

19.5.3 Actualistic Research on Determinants of Butchery, and Transport Decisions

Later publications on hunters' field decisions that determine element frequencies and bone surface modifications in sites included research with San-speaking hunters of southern Africa (Yellen 1991a, 1991b; Bunn 1983; Kent 1993; Bartram et al. 1991; Bartram 1993b); the Hadza of Tanzania (Bunn et al. 1988; Bunn 1993; O'Connell et al. 1988a, 1988b, 1990; Oliver 1993; Lupo 1995, 2006; Lupo and O'Connell 2002); the Okiek of south-central Kenya (Marshall 1993); Efe "Pygmy" foragers in the Democratic Republic of Congo, then Zaïre (Laden 1992); and Bofi and Aka foragers in the Central African Republic (Lupo and Schmitt 1997, 2005). In the Americas, researchers worked with hunters, including the Aché of Paraguay (Jones 1983) and Chipewyan Indians in Canada (Jarvenpa and Brumbach 1983, 1995). O'Connell and Marshall (1989) worked with hunting patterns and site formation among the Alyawara of central Australia. Domínguez-Rodrigo (1997a) undertook experimental observations on processing by expert Maasai and Mwalangulu butchers who were supplied with stone tools and carcasses with differing levels of prior carnivore access. Such studies were complemented by actualistic research on carnivore effects on element frequencies and their distinctive bone surface modifications, discussed in Chap. 12.

19.5.4 Hadza Research on Transport Decisions: Evolution of Methods

Research by two research teams with Hadza foragers of Tanzania merits detailed examination because its internal debates have proved useful in further defining the contexts of field butchery and transport decisions. O'Connell and colleagues (1988b, 1990) worked with Hadza groups near Lake Eyasi, employing a behavioral ecological framework. Their study of butchery and transport initially focused on the contexts of field transport and discard decisions, rather than upon site-focused assemblage formation. Later, Lupo (1994, 1995, 2001) published on bone assemblages collected by this research team from varied site types. O'Connell et al.'s data indicated that Hadza butchers often stripped limb bones of their flesh, cooked and broke long bones open for marrow, and discarded the fragments in the field, only transporting meat stripped from long bones to their residential camps. This contradicted the *schlepp* effect assumptions embedded in much zooarchaeological literature (Perkins and Daly 1968), but accorded with Yellen's earlier observations of !Kung transport practices.

About the same time, Bunn et al. (1988), working with other groups of Hadza foragers in the Lake Eyasi basin, published their research findings on butchery and transport. Members of Bunn's research team supplemented his initial research in the early 1990s, examining bone modifications (Oliver 1993) and comparing the Hadza data to butchery and transport data from Kua San-speaking hunters in Botswana (Bartram et al. 1991; Bartram 1993a, 1993b). These studies tended to support the generalization that groups that acquired one animal at a time transported most large skeletal elements, and that if any skeletal elements were discarded in the field, these would be long bones.

Disagreements emerged between the two groups of Hadza researchers over the meaning of the data. Both teams accepted that transport of nearly entire skeletons to residential camps was facilitated by their possession of boiling technology, which enables efficient retrieval of nutrients from bones of the axial skeleton. Bunn et al. (1988:443) maintained that, before boiling technology emerged, a limb-dominant pattern of transport probably held true. Thus, they argued that element frequencies produced by the Hadza and other contemporary foragers aren't necessarily relevant to analyzing the limb-dominated assemblages apparently created by early hominins.

Bunn's student Monahan (1998) undertook a comparative analysis of all Hadza datasets, demonstrating a "low limb *schlepp*" in all, and arguing that consistent long bone meat-stripping and marrow extraction in the field were part of a "weight-minimization" strategy. He further argued that this outcome might stem less from boiling technology and more from the Hadzas' being the top predators in the modern Eyasi ecosystem, with unlimited time at the butchery locale to dismember, deflesh, and extract nutrients. Monahan proposed that Olduvai hominins were unlikely to have ranked high in relation to other carnivores, with relatively less unhindered time at a carcass. Under such circumstances, he proposed, grabbing a leg and taking it well away to a safe refuge could have been the best "weight minimization" tradeoff.

Lupo (2006) worked through the combined Hadza dataset from a behavioral ecological perspective, specifically assessing transport decisions using central place foraging (CPF) theory (see Chap. 24). She argued that a skeletal element's associated nutritional value or "utility" in Binford's terms (Chap. 20), used by most zooarchaeologists, is not so informative as its return rate, an index now widely used in western North America. The return rate for a skeletal element is its associated nutritional yield *minus* the energy or time it takes a processor to fully realize that value. Lupo posited that, in each carcass acquisition event, "…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" (Lupo 2006:23). She argued that the food value associated with a skeletal element *after* field processing should predict its transport to a central place. She points out that relatively heavy long bones are easily stripped of muscle and broken to extract their marrow in the field, and it is efficient to discard them there. By contrast, irregular bones of the axial skeleton require much more processing effort to retrieve flesh and fat, especially when they are uncooked, thus having relatively higher unrealized nutritional value after field stripping. This provides a strong motivation to transport them to camp, only reinforced by the presence of boiling technology at the central place, which frees nutrients in stews without laborious hand-stripping.

Lupo predicted that outcomes of documented cases of Hadza large-prey processing would situationally involve a trade-offs among field processing effort and costs of transporting the carcass, according to the acquisition site's distance from camp and the benefits realized by doing so. To assess these predictions, Lupo selected two prey species, female impala (*Aepyceros melampus*) and female zebra (*Equus quagga burchelli*), because a good number of acquisitions of each species existed in the combined dataset.

Lupo (1998) had previously experimentally defined return rates for these species and used these in conjunction with each documented instance of acquisition and transport to assess whether element food utility (Chap. 20) or return rates better predicted Hadza transport of prey parts to the central place (base camps). The impala data showed a strong positive correlation between the time taken to retrieve nutrients from a skeletal element and its rate of transport to the central place, with discard of long bones in the field and transport of the axial segments to camp for stewing. By contrast, female zebra butcheries saw a relatively higher rate of long bone transport to camps, as well as higher rates of field discard of skulls and ribs. Lupo assessed these facts in terms of experimental observations on the unique challenges presented to marrow extraction by equid long bone construction, as noted in return rate experiments with the species. She noted that fully processing zebra long bones in the field would add 46 min to field processing episodes. Thermal processing frees marrow and fat from irregular medullary cavities that cannot readily be accessed manually, hence, transport of these relatively heavy elements makes sense. Lupo noted that the zebra skull and ribs are the skeleton's heaviest elements, and their stripped bone weight, when added to that of the long bones, may have dictated the documented decisions to discard them. In both taxa, nutritional utility values alone, without consideration of effort invested in retrieving the nutrients, did not predict transport behavior as well as did return rates. Return rates will be discussed in more detail in assemblages in Chap. 24.

19.5.5 Skeletal Versus Total Fat Values: Further Accounting for Transport Decisions

More than a decade earlier than Lupo's analysis, Emerson (1990, 1993) had advanced data and arguments that supplement and support Lupo's inferences regarding Hadza transport, in her own study of the nutritional benefits of skeletal elements of American bison (*Bison bison*). Emerson compared her findings with those of Binford and Jones and Metcalfe and also used her results to assess patterns of element representation in specific bison archaeofaunas. Emerson commented on the controversies over the Hadza data, as they then stood. Despite her focus on archaeofaunas that would have been products of mass kills, Emerson discussed the differences between processing and transport decisions in one-by-one acquisitions of large animals and those of mass-kills such as Nunamiut caribou harvesting and Plains bison kills. Anticipating later discussions by Lupo, who cites her, Emerson (1993) noted that the Hadza data can be seen as variations on themes of *maximal recovery* of carcass parts from animals encountered one-by-one, instead of the highly selective, nutritionally-driven "winnowing" of carcass segments seen at mass kills such as those of Nunamiut caribou predation or ancient bison kills. She asserted that a mix of four factors should influence large-animal transport decisions: (1) butchers' initial assessment of transportation constraints, (2) processing costs, (3) skeletal fat yield, and (4) snacking prior to return to the residential camp. While she did not specify return rates, Emerson was obviously considering precisely the variables that Lupo worked with in a more explicitly behavioral ecological framework.

Emerson also drew the useful distinction between "total fat," that is, the sum of all fatty tissue that can be recovered from a carcass (comprising subcutaneous, visceral, marrow, and bone grease) on the one hand, and skeletal fat (comprising fats intrinsic to the skeletal elements themselves, namely marrow and bone grease) on the other. She noted that, even when selective transport is required by the circumstances of a kill, axial segments may still be favored because considerable muscle and skeletal fat remain in these elements after muscle stripping, what Lupo (2006) referred to as "remnant animal products." Emerson (1993:142–143) used the bison data to show skeletal elements with relatively greater amounts of marrow have lower amounts of retrievable bone grease. Thus, if elements must be discarded at the primary processing site, it makes sense to snack on marrow there, discard the heavy and relatively unproductive long bone fragments that contained it, and to transport only high bone-grease skeletal parts. Vertebrae lack marrow and are exclusively reservoirs of bone grease. If total fat, including skeletal fat, is assessed, bison thoracic and lumbar vertebrae rank substantially above any elements of the appendicular skeleton, even femur and tibia. Therefore, if bone-grease rendering technology exists, and if fat retrieval is a major goal of animal acquisition, transport should favor those elements with high remnant skeletal fat content: the axial skeleton.

19.5.6 Are Transport Decisions Always Based on Field Conditions?

Chapter 15 noted that the focus on prey acquisition and primary processing alone, and not later processing phases, has pervaded zooarchaeological studies of transport decisions. This may stem from the archaeological cases that motivated some butchery-transport researchers. Plio-Pleistocene archaeofaunas in Africa are thought have been acquired before cooking or other processing strategies developed (Monahan 1999). Perhaps zooarchaeologists working with them assume a very short processing chain from animal acquisition to consumption, but this has seldom been explicitly articulated. Those of us working with archaeofaunas from later times have little excuse to avoid the ultimate aim of all animal-based foraging or keeping: its consumption phase and associated processing. We know that the addition of pyrotechnical food processing and technologically assisted nutrient retrieval, created increasingly complex operational chains involving animal bodies. Each stage involves costs and benefits that must be considered as part of return rates or other measures of effort. A product-focused, *chaîne opératoire* approach must include these stages in consideration of "butchery" (Gifford-Gonzalez 1993; Miracle 2002). Our zooarchaeological studies have yet to fully reflect this fact.

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