Debating Issues of Equifinality in Ungulate Skeletal Part Studies

Natalie D. Munro[*]

Department of Anthropology, Unit 2176, 354 Mansfield Road, University of Connecticut, Storrs, CT 06269, USA

Guy Bar-Oz

Zinman Institute of Archaeology, University of Haifa 31905, Israel

This paper introduces a collection of 11 papers originally presented in a symposium held at the 2004 meeting of the Society for American Archaeology. The papers debate and propose solutions for multiple aspects of equifinality in ungulate skeletal part studies and focus on four primary themes: (1) theoretical issues of equifinality; (2) methods for generating skeletal part frequencies; (3) the tools for analyzing skeletal part frequencies; and (4) attritional biases caused by natural and cultural taphonomic agents. Although debate continues over the methods used to quantify and analyze ungulate skeletal parts, most participants agree on the need for detailed publication of raw bone portion counts and bone portion coding and quantification methods.

Keywords: TAPHONOMY, EQUIFINALITY, SKELETAL PART STUDIES

Introduction

Over the past thirty years ungulate skeletal part studies have grown in popularity and diversified to answer a growing number of archaeological questions. Today, ungulate skeletal part representation constitutes a backbone of zooarchaeological and taphonomic research and is employed to reconstruct a broad spectrum of archaeological processes ranging from human foraging, processing and carcass transport strategies to natural processes such as fluvial transport and carnivore activity. As the application of skeletal part studies and our knowledge of taphonomic processes widens, the potential for equifinality—the property of allowing or having the same effect or result from different events (Webster's Third International Unabridged Dictionary)—has grown. The magnitude of this problem is evidenced by an expanding body of literature that identifies and debates

* E-mail: Natalie.Munro@uconn.edu

potential sources of equifinality in skeletal part studies (Beaver, 2004; Lyman, 1993, 1994; Marean et al., 1992; Pickering et al., 2003; Rogers, 2000a, b; Stiner, 2002; papers in this volume). Recently, these debates have become increasingly methodological and polarized. An impasse over bone counting procedures and skeletal part profiling techniques stimulated the organization of a symposium on equifinality in ungulate skeletal part studies at the 2004 Meetings of the Society for American Archaeology. Participants were asked to address two specific questions: (1) how can we distinguish processes that create identical skeletal part patterns?; and (2) how does equifinality in skeletal part studies impact interpretations of zooarchaeological data? The creative responses of the symposium's participants comprise the 11 papers in this special volume of the *Journal of Taphonomy*. The approaches, solutions and issues raised in these papers address a broader range of concerns than originally anticipated. Furthermore, they include an improved definition of equifinality and its relevance for zooarchaeological studies, a number of practical suggestions for moving forward, agreement on some previously contended issues and continued debate on others. A major goal of this volume is to stimulate further research on resolving issues of equifinality in ungulate faunal analyses.

Brief History of Ungulate Skeletal Part Studies and the Problem of Equifinality

Unlike other archaeological specialists, zooarchaeologists are privileged with a complete skeletal model that provides a natural starting point for zooarchaeological analysis. As they pass from the life to the death and finally the excavated assemblage, the original prey skeletons become increasingly fragmented and depleted. The comparison of the relative frequencies of skeletal elements from archaeological fauna (observed) with a complete skeleton model (expected) pinpoints what parts of the skeleton are under or overrepresented, and provides a springboard to ask why and how specific skeletal parts were deleted from the assemblage.

Skeletal part analyses were introduced into zooarchaeological research as a means to evaluate the transport of prey from kill to consumption sites (Binford, 1978; Brain, 1981; Perkins & Daly, 1968; White, 1952, 1953). The relative abundance of ungulate skeletal parts was used to reconstruct the factors that governed the transport of prey carcass parts away from a kill site. Among others, these factors include prey body size (O'Connell et al., 1988), distance to the residential base (i.e., Schlepp Effect; Perkins & Daly, 1968), the number of hunters (Yellen, 1991), the hunting season, the nutritional value of body parts (Speth, 1987), the method of processing and transporting the carcass (Bartram & Marean, 1999), the practices of meat distribution and sharing (Speth, 1990; Kent, 1993), the foraging strategy of the collector (e.g., hunting versus scavenging), and the function of the site (Lupo, 2001). Reconstructions of human processing and the transport of ungulate skeletal parts are based on cost-benefit principles that assume that body parts with the highest quantities of edible products (high utility) will be preferentially transported (Binford, 1978; Metcalfe & Jones, 1988; Marean &

Cleghorn, 2003; Perkins & Daly, 1968). The construction of utility indices that rank the relative value of skeletal parts in relation to associated quantities of edible animal products such as meat, marrow and grease were innovated specifically to explain patterns of prey transport (e.g., Binford, 1978; Blumenschine & Caro, 1986; Brink & Dawe, 1989; Jones & Metcalfe, 1988; Lyman *et al.,* 1992; Madrigal & Holt, 2002; Madrigal, this volume; Metcalfe & Jones, 1988; Outram & Rowley-Conwy, 1998).

Skeletal part representation has also been employed to discriminate between the actions of taphonomic forces in assemblage formation. The skeletal part patterns produced by experimental research on processes such as fluvial transport, carnivore ravaging and trampling are routinely recorded as referents to distinguish taphonomic forces in the archaeological record. Not surprisingly, as the applications of skeletal part studies diversify, the expectations for different human behaviors and natural processes increasingly overlap. In 1967, Brain recognized that skeletal part survivorship was mediated by bone density—the preferential destruction of low-density bones by taphonomic processes (see also Behrensmeyer, 1975; Brain, 1981; Voorhies, 1967). Lyman (1993) warned that density-mediated bias was widespread in the zooarchaeological record after identifying significant density-mediated attrition in close to half of the 87 published assemblages he surveyed. In the last two decades, actualistic and experimental studies have identified numerous taphonomic agents as sources of density-mediated bias (e.g., carnivore gnawing,

weathering, grease processing, and fluvial transport).

Density-mediated attrition produces faunal assemblages that are overrepresented by dense bone portions. Because many high utility skeletal parts have low bone density (e.g., vertebrae and ribs), while many low-utility elements have high bone densities (e.g., phalanges and metapodials), utility indices and bone density can be negatively correlated (Lyman, 1985, 1992). Density-mediated attrition, is thus easily confounded with human transport behaviors, and produces a classic case of equifinality. Over, the last few decades several solutions have been proposed to overcome this problem. Grayson (1989) suggests that skeletal part frequencies be routinely compared against both utility indices and bone density (see also Klein, 1989). If bone density has a significant relationship with survivorship, but utility does not, bone density would be considered more responsible for bone loss and vice versa. Others (e.g., Blumenschine, 1988, 1995; Capaldo, 1997; Domínguez-Rodrigo, 1997, 2002) argue for the integration of bone surface damage, such as carnivore gnaw marks and cutmarks, into current analyses. These methods are argued to be more reliable than skeletal part patterns because they derive from a strong foundation of actualistic research. Important advances have been made by Beaver (2004) and Rogers (2000a, b) who propose statistical solutions with the resolution to detect the relative influence of multiple taphonomic factors on bone survivorship. These statistical solutions have the potential to revitalize skeletal part representation studies. In the meantime, density-mediated attrition remains a

stubborn source of equifinality and continues to plague zooarchaeological analysis.

The most recently identified source of equifinality in skeletal part studies is zooarchaeological method itself—not only the methods employed to excavate, identify, quantify and analyze bone portions, but the methods used to evaluate the profiles themselves (i.e., utility indices and measures of bone density). At the forefront of the critique Marean and colleagues (Marean & Spencer, 1991; Marean & Kim, 1998; Marean et al., this volume; Pickering et al., 2003) argue that the failure to consider long bone shaft fragments in the calculation of the minimum number of elements (MNE) will result in skeletal profiles that mimic a reverse utility curve (Type II pattern)—a skeletal part profile dominated by heads and feet. Marean et al. argue that Type II patterns are a methodological artifact of incomplete retention—the failure to include long bone shafts in the calculation of long bone MNEs in density-mediated assemblages. They argue that equifinality will result if bone shafts are omitted from skeletal part profiles because the remaining lower density skeletal parts are more subject to destruction by density-mediated processes. In addition, current methods for measuring bone density (Lam & Pearson, this volume) and utility (Outram, this volume) may produce a range of density and utility values for the same bone portion. This may impact the significance of the relationship between skeletal part representation and bone utility or density, and produce different results depending on the chosen indices.

The contributions in this special volume of the *Journal of Taphonomy* are organized around four broad themes of equifinality that occur at different taphonomic stages in the production of skeletal part assemblages. These include (a) theoretical perspective; (b) the methods used to derive and quantify skeletal part frequencies; (c) the tools used to interpret skeletal part profiles—bone density and utility indices; and (d) overlapping signatures of human and non-cultural attritional processes. Most of these aspects of equifinality are raised in more than one of the papers assembled here and constitute the organizing structure for the following discussion.

Presentation of Themes

Theoretical Perspective

Theoretical aspects of equifinality in skeletal part studies center around the definition of equifinality within zooarchaeological and taphonomic contexts. Lyman (this volume) presents the original definition of the term equifinality by system's theorist, von Bertalanffy (1949), as reaching the "same final state from different initial states". When applied to zooarchaeological and taphonomic studies the term has most often been used to refer to the production of similar attritional patterns by different taphonomic processes (Rogers, 2000a; Lyman, this volume). Rogers (2000a) argues that this is a misapplication of von Bertalanffy's original definition, and that von Bertalanffy meant identical rather than merely similar outcomes when he coined the term. He

believes that cases of taphonomic equifinality are for the most part statistically distinguishable—although not using current methods—and thus do not represent true cases of equifinality. Furthermore, he argues that current interpretations are dangerous because perceived equifinality may frustrate zooarchaeologists or drive them into complacency, and thus curb methodological and statistical creativity. In contrast, Lyman (this volume) argues that the term equifinality has been used appropriately in taphonomic research and has stimulated methodological refinement as researchers attempt to better distinguish the processes that produce like results. This volume attests that, as Lyman claims, zooarchaeologists are serious about finding ways to resolve equifinality. Nonetheless, the need for more sophisticated statistical analyses remains, although recent developments in this direction are promising (i.e., Beaver, 2004; Rogers, 2000b).

Methods for Generating Skeletal Part Frequencies

The methods used to identify, quantify, and present skeletal part data can produce tremendous variation in the relative representation of skeletal parts for the same archaeological assemblage. Skeletal part profiling traditionally refers to comparison of the relative frequency of skeletal parts against a complete skeleton model (Stiner, 2002). Although, the term is most often used to refer to graphic representations of the frequency of various body parts (e.g., bar charts), profiling also includes

correlation analyses of bone survivorship against independent indices of bone density or anatomical utility. Graphic representations plot the frequencies of portions of elements, complete elements or anatomical region (e.g., head, upper forelimb, lower hindlimb) for visual inspection. Anatomical regions are most often determined based on affinities in nutritional value and/or the likelihood that elements will be transported together (e.g., Stiner, 1991, 1994).

The frequencies of skeletal parts are traditionally calculated as MNE or MAU (the minimum number of animal units) values. Grayson & Frey (this volume) show that in assemblages unaffected by intensive fragmentation, the use of the number of identifiable specimens (NISP) produces similar results. Whether based on NISP, MNE or MAU, the relative frequency of skeletal parts in a given assemblage is related to the relative identifiability of bone portions. Successful identification of skeletal portions to taxon or element depends on the presence of diagnostic features on bone portions; some fragments such as long bone articular ends and teeth, are more diagnostic than others (e.g., vertebrae, ribs and long bone shafts). Biases introduced by differences in specimen identifiability have been partially circumvented by constructing a single skeletal profile for animals of similar body size (i.e., small mammal, ungulate body size class 4), but this strategy conflates the skeletal profiles of multiple similarly sized species that may have been differentially treated by humans. Researchers have focused on improving the identifiability of traditionally less diagnostic portions by identifying effective anatomical landmarks

for element identification (Marean, et al. 2001; Stiner, 1994, Stiner, this volume: Appendix 1), and refitting fragments from the same bone (Marean et al., 2001).

Tools for Interpreting Skeletal Part Frequencies

The selection of tools such as bone density values and utility indices, to identify the most influential sources of attrition in a given assemblage can also lead to equifinality. Variation in the calculation of density measures may be introduced by numerous factors including the researcher; the sex, age and body size of the animals studied; the computer software; the technique used to calculate measures of bone density (e.g., water immersion, computed tomography [CT] or photon densitometry [PD]), and the use of internal or external shape correction, among other factors (Lam & Pearson, this volume). In many cases these sources of variability will not alter the relative ranking of density values which is important when examining ordinal scale data. However, in some cases ranking is affected, and this can impact the significance of the relationship between skeletal part representation and bone density. Similar problems plague utility indices which also incorporate a variety of factors in their calculation. The relative ranking of skeletal part utility may fluctuate depending on the age, sex, body size, condition and season of death of the study animals, and the decisions made by the researcher on how to rank elements considered "riders" (Madrigal, this volume; Outram, this volume).

Cultural and Natural Taphonomic Agents

Finally, attrition, whether from cultural and natural sources, is a major source of equifinality in studies of skeletal part abundance, particularly if attrition is density-mediated. The first step in resolving equifinality caused by attrition is the identification and characterization of non-cultural processes and their distinction from anthropogenic processes. The identification of specific taphonomic signatures has vastly improved over the past few decades with the tremendous growth of experimental and actualistic studies. Nonetheless, the potential for equifinality increases as the impact of various taphonomic agents become better defined. If equifinality is to be overcome, the identification of density-mediated bias must be a starting rather than an ending point in taphonomic research.

Organization of the Volume

Theoretical Perspective

Lyman aptly opens the volume by establishing that taphonomic systems are open systems (i.e., capable of exchanging materials with their environment), a requirement of equifinality originally stipulated by von Bertalanffy (1949). The term equifinality is thus appropriate for taphonomic research. Lyman argues that in taphonomic studies equifinality is traditionally defined as the production of similar outcomes by different taphonomic processes. Because outcomes are similar and not identical, it is possible to differentiate between sources of equifinality by developing new methodological and statistical tools.

Methods for Generating Skeletal Part Frequencies

Three papers focus on zooarchaeological method as a primary source of equifinality in skeletal part studies. Grayson & Frey touch on a rare advantage of equifinality.They document similarities in relative skeletal part frequencies calculated using NISP and MNE in three zooarchaeological geographically disparate assemblages. These similarities result largely from the dependence of derived quantitative units (MNE, MNI [minimum number of individuals] and MAU) on NISP. Grayson and Frey liken this relationship to a sampling exercise, where the chances that the skeletal portions sampled from a given taxon will match one another is dependent on the number of fragments available for each skeletal portion (NISP) in the first place. Differences in the relative representation of a skeletal part determined using MNE and NISP indicate anomalous cases that when explained, will provide a more robust picture of an assemblage's formation history.

Marean *et al.* and Cleghorn & Marean call for revision of current identification procedures and the methods used to construct skeletal part profiles. Marean *et al.* argue that a major cause of equifinality in skeletal part studies is the failure of excavators and/or zooarchaeologists to collect, identify, and accurately quantify bone shafts in their analyses. Marean *et al.* recommend that researchers pay special attention to the collection, identification and refitting of midshaft areas. Because these tasks are time-consuming, they suggest that actualistic studies be undertaken to

establish the minimal sample size of shaft fragments required to accurately estimate their relative proportion in the assemblage. Marean *et al.* further recommend that researchers standardize and publish bone identification, data collection, and quantitative procedures. Cleghorn & Marean compare skeletal part profiling techniques including Stiner's region-based approach, Rogers' (2000b) analysis of bone counts by maximum likelihood technique and their own high and low survival set model (Marean & Cleghorn, 2003). Like Stiner's method, Cleghorn & Marean's technique is designed to minimize the impact of density-mediated attrition by comparing bone portions with similar densities—Cleghorn & Marean select portions with the highest bone densities (e.g., bone shaft fragments). Both Marean et al. and Cleghorn & Marean argue that equifinality can be averted by improving the accuracy of zooarchaeological method and paying special attention to dense bone shafts.

Tools for Interpreting Skeletal Part Frequencies

The largest block of papers in this volume (Lam & Pearson; Stiner; Enloe; Outram; Madrigal) focus on issues surrounding the construction and application of density and utility values that have been used to interpret skeletal part profiles. First, Lam & Pearson critically evaluate the multitude of factors that can potentially impact and bias the derivation of bone density values. In particular, they emphasize inaccuracies in the construction of density values such as technological variables, mundane errors,

small sample sizes, and cross-sectional heterogeneity among other. If all variables are equal, Lam & Pearson argue that density measures derived using CT and adjusted for both internal and external shape are the most accurate.

Because human foraging behavior is often confounded by density-mediated attrition, Stiner argues that we need reasonably accurate measures of bone density for current density analyses. In response to arguments by Lam and colleagues (Lam & Pearson this volume; Lam et al. 1998, 1999, 2003), Stiner compares the degree of variation between a selection of PD and CT (Lam *et al*'s non-shape adjusted [BMD_1] and shape adjusted measures [BMD_2]). Both PD and BMD_1 values are shown to correspond well to one another and to the range of variation in the density of the bone portions commonly found in Mediterranean Paleolithic archaeofaunas. The shape adjusted BMD_2 values display a much greater range of variation, mainly because bone shaft values are assigned substantially higher densities than other bone portions (except the petrous). These values, Stiner argues, are so much greater than those from other skeletal parts, that they are largely incomparable.

Enloe evaluates the Upper Paleolithic reindeer assemblage from Verberie II_1 (France) for evidence of density-mediated attrition to ensure that potential sources of equifinality are eliminated prior to the interpretation of skeletal part patterns. To do so, he compares the survivorship of reindeer skeletal parts against three sets of density measures obtained using different procedures (PD; and CT with and without shape adjustment). Consistently

insignificant results obtained from this approach firmly establish that the formation of the Verberie II_1 faunal assemblage was not density-mediated. The lack of density-mediated bias is unusual and pinpoints human agency as the primary source of skeletal representation at the site.

Madrigal's study integrates data from recent studies on the meat and marrow yields of white-tailed deer (*Odocoileus virginianus*) to establish improved utility indices and return rates that enable higher resolution skeletal part research in Eastern North America. The construction of a more accurate index will aid in the evaluation of key archaeological questions including transport decisions, provisioning, status differentiation and ritual feasting. The white-tailed deer utility indices provide a welcome replacement of the largely inaccurate low, moderate and high utility groups currently used in the American Northeast.

The section wraps up with Outram's critique of current applications of utility and density measures in skeletal part studies. Outram argues that although utility indices have practical uses, their application must be critically evaluated and occur only in controlled contexts. He urges zooarchaeologists to seek alternative methods to resolve equifinality, in particular the collection of high-resolution data sets. Outram suggests that recording more detailed, albeit time-consuming data will enable differentiation of taphonomic effects that occur before and after burial and at the analytical stage. He proposes detailed bone fragmentation studies that record fragment size, and fracture patterns as one possible strategy.

Cultural and Natural Taphonomic Agents

The final two papers in the volume tackle equifinality resulting from natural and cultural sources of attrition prior to excavation. Bar-Oz & Munro argue that equifinality can be overcome through the use of multivariate approach that distinguishes and measures the relative impacts of different taphonomic agents. In particular, they emphasize comparisons of subgroups of zooarchaeological assemblages that are expected to respond differently to common taphonomic phenomenon (i.e., different taxa, age groups, bone tissue types). Pike-Tay et al. address potential sources of equifinality that may influence the interpretation of seasonality using the skeletal part representation of fish, birds and mammals. After evaluating multiple seasonality indicators from the Early Neolithic site of Ecsegfalva 23 (Hungary), they conclude that the site was likely occupied year-round—more intensively in winter and early spring, and less intensively in other seasons of the year.

Continuing Debates

Although agreement on several issues has been reached, debate continues over how skeletal parts are best identified, quantified, and analyzed. Marean and colleagues (this volume) strongly advocate the inclusion of long bone shafts in the quantification of skeletal parts and recommend the exclusion of assemblages with incomplete retention from skeletal part analysis. In contrast, Stiner (this volume, 2002) emphasizes the importance of identifying diagnostic

compact bone features distributed across the ungulate skeleton, including the long bone shafts. Further actualistic experiments on fragmented bone assemblages with known MNE values are needed to compare Marean *et al.*'s (2001) suggested protocol with Stiner's (2002, this volume) use of diagnostic anatomical landmarks in fragmented material. Results of such an experiment will provide significant insights into the influence of method on equifinality in skeletal part studies.

Although Marean and colleagues (this volume; Cleghorn & Marean, this volume; Marean *et al,* this volume; Pickering *et al.*, 2003) and Stiner (1994, 2002, this volume) fundamentally disagree on several points, Lyman (this volume) notes that the development of both of their approaches was stimulated by observations of equifinality in bone abundance. In addition, they both use bone density as the primary criteria to select bone portions for skeletal part analysis. Part of the failure to resolve their methodological difference is the lack of knowledge about the relative preservation of bone with varying mineral densities. We still do not know the true scale of difference in the preservation of low and high density bone in the archaeological record, or how this difference may change in response to different taphonomic factors. Although, actualistic studies have investigated the effects of bone-eating carnivores on low and high density bone parts (Marean et al., this volume; Pickering et al., 2003), we know little about the impact of most other taphonomic factors.

Toward Resolving Equifinality in Skeletal Part Studies: Directions for Future Research

Important advances toward resolving issues of equifinality in skeletal part studies focus on improving the resolution of our datasets and the quality of our analytical methods, so that currently inseparable sources of skeletal part attrition can be distinguished. In particular, these include: (1) methodological procedures that more accurately identify, present, quantify and analyze skeletal part data (Cleghorn & Marean; Marean et al.; Stiner); (2) the use of actualistic studies to improve the resolution needed to distinguish similar signatures of different taphonomic agents (Cleghorn & Marean; Marean *et al.;* Lam & Pearson); (3) improving the resolution of faunal datasets (Marean *et al.;* Outram); (4) formalizing the analytical approach to the problem (Bar-Oz & Munro); and (5) using multiple analyses to improve the likelihood of distinguishing taphonomic processes.

Marean *et al*. argue that the first step in resolving equifinality in skeletal parts studies lies in the improvement of zooarchaeological method; in particular identification accuracy. They recommend specific methods to measure the completeness of recovery of faunal assemblages. For example, they advocate measuring long bone shaft fragment circumferences, the ratio of long bone ends to shafts, and the publication of raw data from a minimum of five diagnostic zones for each long bone. These suggestions are encouraging, and further actualistic and zooarchaeeological studies with a broad spatiotemporal focus should be implemented to determine if and what generalized criteria for assessing assemblage completeness can be proposed.

Numerous authors recommend eliminating equifinality by increasing the resolution of current zooarchaeological tools and databases. These include refitting shaft fragments (Marean *et al*.); improving accuracy and reducing variation in the derivation and use of density measures (Lam & Pearson); comparing our assemblages against multiple measures of bone density (Enloe); collecting data from the unidentifiable fraction (Outram); and using a multivariate strategy that subjects assemblages to multiple zooarchaeological analyses to reconstruct taphonomic histories (Bar-Oz & Munro). Others (Outram this volume, Stiner this volume) raise issues about how much methodological refinement is truly necessary. Because zooarchaeological data is notoriously biased by myriad factors, analysts often seek general rather than specific patterns in archaeological data. Refinement of some zooarchaeological measures may not improve their interpretive capabilities, and in some cases we may be better off investing in the innovation of new solutions.

Equifinality in skeletal part studies can originate at numerous stages in an assemblage's taphonomic history. Because the impact of one or more of these stages on skeletal part representation will be conflated in the skeletal part profile, strategies that can differentiate attrition originating at different stages are required. In this respect, the symposium made an important advance as contributors tackled equifinality from multiple stages along the taphonomic pathway.

Most researchers agree that the publication of the methods used for the identification, quantification and analysis of skeletal parts is crucial. Coding systems and methods for calculating MNE and MNI and other quantitative measures must be published. Stiner (2002; this volume: Appendix 1) has made important strides in this direction by publishing and illustrating her coding system. Additional steps can be taken by publishing raw data. Marean et al. (this volume) advocate publishing detailed MNE data that includes at minimum five anatomical portions from each long bone (proximal end, proximal shaft, midshaft, distal shaft and distal end). Lyman (1993) previously proposed that the MNE for each density scan site be recorded (see Lyman 1994:240-45 for scan site illustrations). Stiner (this volume), argues that her protocol for quantifying bone portions is more precise as it focuses on morphological features of similar bone density, that are not expected to be differentially affected by density-mediated attrition as are scan sites or whole bone ends and shaft diaphyses.

Nearly all of the studies in this volume identify density-mediated attrition as a primary cause of equifinality in skeletal part studies. However, the combination of agents responsible for density-mediated attrition, its intensity, and the magnitude of differential preservation of high and low density skeletal parts remain poorly understood. Debate also continues over the most effective methods for measuring bone density. Although, improving accuracy is acknowledged as an important goal, how this should be undertaken (i.e., through internal and/or external shape correction) remains contentious. Moreover, density is only one of many factors that determine the resistance of bone portions to destruction—more work needs to be done with other factors such as bone strength, porosity, size and shape (Lam & Pearson, this volume; Stiner, this volume).

Finally, we must extend our analyses to encompass a broader range of times and places. A spatiotemporal bias is revealed in this collection of papers which have been derived primarily by researchers studying prehistoric hunter-gatherers in Eurasia and Africa. These models must be refined by exploring how the issues raised here play out in a broader range of time periods from across the globe.

Acknowledgements

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