Beyond Cautionary Tales: A Multivariate Taphonomic Approach for Resolving Equifinality in Zooarchaeological Studies

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We describe a multivariate approach that reconstructs the taphonomic histories of zooarchaeological assemblages. The approach applies a sequence of zooarchaeological analyses to bone assemblages to determine the most significant agents of assemblage formation. By examining the differential survivorship of bones from subgroups within an assemblage, problems of equifinality in skeletal part studies can be overcome. The multivariate approach follows three primary analytical stages including: a) a descriptive stage that summarizes the representation of key taphonomic variables of each assemblage; b) an analytical stage that investigates the completeness and fragmentation of skeletal parts; and c) a comparative stage that evaluates taphonomic variation amongst subgroups within a zooarchaeological assemblage. In a case study of six Epipaleolithic assemblages from the southern Levant, the multivariate approach reveals that intensive bone processing by humans for marrow and possibly grease was the primary determinant of gazelle bone survivorship, while small game taxa experienced independent taphonomic histories.

Keywords: TAPHONOMY, SKELETAL PART REPRESENTATION, EQUIFINALITY, MULTIVARIATE APPROACH, GAZELLE, EPIPALEOLITHIC, LEVANT, GREASE AND MARROW PROCESSING; DENSITY-MEDIATED ATTRITION

Introduction

Over the past two decades, analyses of ungulate skeletal part representation have become staples of zooarchaeological research. Skeletal part studies address diverse zooarchaeological questions ranging from resource availability, human subsistence strategies, and depositional histories to recovery and methodological biases. Recently, some influential studies have stimulated an ongoing debate
regarding the quantification of prey skeletal parts and the conclusions that can be drawn from their analysis (Pickering et al., 2003; Stiner, 2002; and references therein). At the heart of this debate is the problem of equifinality. Because different analytic procedures and depositional events can lead to the same end result, the use of skeletal part representation as a tool to reconstruct human behavior is becoming increasingly complex. A growing body of literature has established that equifinality is common in zooarchaeological assemblages and can be produced by a wide range of taphonomic agents, in particular those whose effects are mediated by bone density. (see review in Lyman, 1994).

Here, we focus on resolving problems of equifinality created by attritional processes that act before and after bone deposition, but prior to excavation. Because there are many attritional agents and their effects may differ substantially across time and space, taphonomic research aims to discern the most influential processes acting on bone assemblages and to distinguish natural forces from human behavior. We suggest implementing a multivariate approach that subjects a bone assemblage to a series of zooarchaeological analyses to pinpoint the most likely formation agents. By multivariate approach we refer to the application of multiple taphonomic analyses to a bone assemblage in a series of three analytical stages (see below). The analyses focus on differential representation of prey skeletal parts within a single species or between subgroups of an assemblage. We define assemblage following Lyman (1994: 8) as “some analytically defined set of faunal remains usually, but not always from a particular spatio-temporal context.” Many taphonomic analyses take place at the scale of the assemblage, however higher resolution results can be generated through comparisons of groups of bones categorized by different attribute states of a given assemblage variable. Variables of interest include taxon, prey body size, prey age group, bone shape, bone tissue type, and bone density among others. These variables have multiple attribute states (i.e., gazelle, tortoise, and other taxonomic groups are attributes of the variable taxon, while compact and cortical bone are attributes of the variable bone tissue type)—here called subgroups—that may be differentially impacted by taphonomic agents of interest. For example, the variable “age” is characterized by the attribute states juvenile, adult and senescent, and the skeletal parts belonging to these age groups should be differentially affected by taphonomic factors such as diagenesis or human butchering. Dividing a bone assemblage into subgroups allows fine-grained comparisons that can peel away the taphonomic layers and reveal meaningful patterns in zooarchaeological data.

Subgroup comparisons allow us to circumvent equifinality because pre- and post-depositional taphonomic agents, including those that are density-mediated, often do not act equally on all subgroups of an assemblage. If attrition is examined at the assemblage level or in only one subgroup in an assemblage, an average signal of the agent’s impact is obtained. If we divide assemblages into subgroups and evaluate them independently, differences in the impact of the taphonomic agent often correspond to differences in subgroup properties. For example, bone grease
Table 1. Outline of the procedure of the multivariate approach to taphonomic analysis. The list provided here is not inclusive and the selection of taphonomic variables can be altered depending on the research questions. References for various analyses can be found in the text.

PROCEDURE FOR A MULTIVARIATE APPROACH

I. SUMMARY OF TAPHONOMIC VARIABLES
1. Primary quantitative data (e.g., NISP, MNI, diversity indices)
2. Spatial distribution of bones (e.g., orientation, context)
3. Bone surface damage from natural agents (e.g., weathering, root etching, carnivore gnawing, rodent gnawing, abrasion)
4. Bone surface damage by human subsistence behaviors (e.g., cutmarks, hammerstone impact notches, percussion marks, burning)

II. INVESTIGATION OF ASSEMBLAGE COMPLETENESS AND FRAGMENTATION
1. Analyses of in situ attrition
   i. Ratio of cranial bones to teeth
   ii. Analyses of element completeness (e.g., carpal and tarsal bones)
2. Analyses of density-mediated attrition
   i. Relationship between bone survivorship (%MNI) and bone mineral density
   ii. Relative representation of bones of different densities (e.g., proximal to distal humerus and tibia)
3. Analyses of fragmentation
   i. Analyses of body-part completeness (e.g., bone portions, bone elements, anatomical units)
   ii. Mode of bone fragmentation (e.g., fracture angle, fracture outline, shaft circumference)
   iii. Fragmentation index (NISP/MNI)
   iv. Relationship between bone survivorship (%MNI) and fragmentation index (NISP/MNI)
4. Analyses for relationship with utility indices
   i. Relationship between bone survivorship (%MNI) and food utility index
   ii. Relationship between rate of bone shaft fragmentation (NISP/MNI) and marrow index

III. ASSEMBLAGE SUBGROUP COMPARISONS
1. Comparison of bone survivorship (%MNI) and bone mineral density of different prey types (i.e., different taxa; large vs. small; domestic vs. wild)
2. Comparisons of body part representation of taxa of different ages (e.g., completeness of long bone shafts and toes)
3. Comparisons of different bone tissue types (e.g., cortical versus cancellous bone)
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extraction is expected to preferentially destroy the grease-rich cancellous bone of healthy adult ungulates. However, grease processing will not impact low-density bones that contain little or no grease, such as the cancellous bones of juvenile animals or small prey species. Subgroup comparisons thus provide a straightforward method to increase the resolution of the signatures of taphonomic agents and decrease the potential for equifinality.

Previously, we applied a multivariate approach to five assemblages originating in the same general time period (21-11.5 cal. kya) and ecological and geographical setting (Mediterranean region of northern Israel) to assess the role of bone fat processing in the Levantine Epipaleolithic (Munro & Bar-Oz, 2005). The goal of the current paper is to expand on that previous work by providing some new data and a comprehensive outline of the multivariate approach and subgroup analyses, and their ability to resolve issues of equifinality.

A Multivariate Taphonomic Approach

The multivariate approach requires the administration of a series of zooarchaeological analyses that systematically reconstruct the taphonomic history of a faunal assemblage. The analyses should proceed in a roughly hierarchical fashion designed to exclude potential taphonomic agents at each stage. The multivariate approach follows three primary stages (Table 1). First, relevant taphonomic variables are identified, quantified, and summarized in tabular or graphic form. Summarized values most often include frequency or relative abundance data that indicate the magnitude of the expression of a given variable in an assemblage. Variables that are appropriate for the summary table include surface modifications created by natural and cultural agents expressed as the frequency (%) of their occurrence in an assemblage, and zooarchaeological counting units (i.e., NISP, MNE, MNI and MAU). This stage is akin to the multivariate technique proposed by Behrensmeyer (1991). Examples of variables to be considered are listed as specimen attributes by Lyman (1994: Table 13.1). The second stage involves analyses which evaluate the quality of an assemblage’s preservation and identify patterns of attrition and fragmentation by comparing the differential survivorship of various skeletal parts. This stage quantifies the completeness of an assemblage and may compare it to other bone assemblages. The third and final stage refines the conclusions drawn from the first two stages by comparing skeletal completeness, surface damage, and other taphonomic variables amongst subgroups that are expected to be differentially impacted by the taphonomic processes of interest.

Recently, there has been much debate over which zooarchaeological methods are the most accurate for distinguishing human foraging behavior from natural taphonomic processes. In particular, some researchers have argued that the frequency of bone surface damage and its anatomical location is the most accurate indicator of Plio-Pleistocene hominid foraging, due to its strong foundation of actualistic research (i.e., Blumenschine, 1988; Domínguez-Rodrigo, 2002 and references therein). It has been
argued that these methods should be used to the exclusion of other techniques. The strength of the multivariate approach lies in its integration of multiple zooarchaeological analyses and its flexibility to cope with the demands of different research questions. The strength and appropriateness of analogical models and analytical methods will vary with the research question and its placement in time and space. It is important that the researcher weigh the strength of analogical models to explain patterns generated by various zooarchaeological analyses as well as their suitability to address specific research questions before selecting appropriate analyses for each of the three research stages presented below.

Summary of Taphonomic Variables

The first stage of the multivariate taphonomic approach describes the expression of taphonomic variables in a given assemblage using a table or graph for easy reference (see Bar-Oz & Dayan, 2003; Behrensmeyer, 1991; Lyman, 1994; and Stiner, 1992, 1994 for examples). The presentation of data from multiple variables allows easy assessment of the degree of influence of various taphonomic agents. Furthermore, it facilitates comparison of assemblages by standardizing the presentation of selected taphonomic variables. The taphonomic variables can be divided into four primary subsets: (1) basic quantitative information regarding the taxonomic or skeletal part breakdown of the assemblage using measures such as NISP, MNE, or MNI; (2) spatial (contextual and distributional) data; (3) damage caused by natural taphonomic agents such as carnivore gnawing (including gross gnawing, pitting, punctures, scoring and digestion), rodent gnawing, abrasion, root etching, and weathering; and (4) damage inflicted by human subsistence behavior such as cutmarks, impact and percussion fractures, and burning. The interpretation of much of the summary data is facilitated by a strong foundation of actualistic research on the production of bone surface damage by various taphonomic agents (carnivores and human butchery in particular) often under controlled experimental conditions (Blumenschine, 1988, 1995; see Dominguez-Rodrigo, 2002 for additional references). Patterns identified in the summary table can be compared to actualistic data to derive secure interpretations that can be used to direct investigation in the second and third research stages.

Investigations of Assemblage Completeness and Fragmentation

The next stage employs a series of problem-oriented analyses that assess the quality of preservation, the nature of attritional biases, and the fragmentation of the faunal assemblage. Attrition is assessed by comparing the representation of skeletal parts to a complete skeletal model to determine what bones or bone portions are missing from an assemblage. The most common patterns of attrition in bone assemblages are density-mediated—bones with the lowest mineral density are missing because they were destroyed due to their low resistance to mechanical or other processes. Because so many taphonomic
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processes can create density-mediated biases, a fruitful starting point for identifying attritional agents is to compare the survivorship of prey skeletal parts to their bone mineral density. This may involve measuring bone mineral density with photon densitometry (PD; e.g., Lyman, 1984, 1994) or computed tomography (CT; Lam et al., 1999, 2003), evaluating the ratios of proximal and distal long bone ends with differential mineral densities (Binford, 1981), comparing the MNEs of cranial bones to teeth (Stiner, 1994), or examining the completeness of dense bone elements (Lyman, 1994; Marean, 1991) among other methods. If the results of these analyses indicate density-mediated attrition then a detailed taphonomic analysis should be carried out to determine the leading causes of attrition. Productive analyses at this stage also include those that compare skeletal part representation with frequencies of taphonomic damage (i.e., carnivore gnawing, cutmarks, fragmentation; Lyman, 1994; Marshall & Pilgram, 1991), or the nutritional value of individual skeletal elements or anatomical units (i.e., utility indices; Binford, 1978; Metcalfe & Jones, 1988). If a significant relationship exists then influential agents of assemblage attrition can be identified.

Assemblage Subgroup Comparisons

The third stage of analysis allows the investigator to move beyond issues of equifinality to refine and further investigate the role of influential agents identified in previous stages of analysis using independent lines of evidence. This stage compares patterns of attrition, bone fracture, and the frequency of bone surface damage amongst subgroups of an assemblage that are expected to be differentially affected by the taphonomic agent of interest. In fact, any of the taphonomic variables evaluated in stages 1 and 2 can be re-evaluated for different subgroups. The contribution of a taphonomic agent can be confirmed or rejected using subgroup comparisons according to the following procedure: (1) establish what kind of signature an agent will leave on bones (i.e., will it fragment, erode, crush, burn, cut, or differentially destroy bones based on mineral density); (2) specify how different subgroups (e.g., elements of different prey type, age, or bone density) of an assemblage will be affected by the agent; and (3) compare the signatures of the taphonomic agent across subgroups. It is this final analytical stage that allows us to circumvent equifinality and gain high-resolution insight into the taphonomic histories of zooarchaeological assemblages.

An Epipaleolithic Case Study from the Southern Levant

We illustrate the multivariate approach using data collected from six zooarchaeological assemblages from five Epipaleolithic sites in northern Israel (Table 2). The sites are similar in that they are semi-sedentary habitations located within 50 kilometers of one another in the Mediterranean zone. All sites are located within 10 kilometers of the present coastline, but differ in their chronological position within the Epipaleolithic period. Nahal Hadera V dates to the Kebaran (21-
Bar-Oz & Munro

Table 2. The six Epipaleolithic (21-11.5 cal. Kya) assemblages from the southern Levant case study. Sites are arranged in chronological order.

<table>
<thead>
<tr>
<th>Site</th>
<th>Cultural phase</th>
<th>Geographic location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nahal Hadera V</td>
<td>Early Kebaran</td>
<td>Northern coastal Plain</td>
<td>Bar-Oz &amp; Dayan 2002</td>
</tr>
<tr>
<td>Hefzibah 7-18</td>
<td>Geometric Kebaran</td>
<td></td>
<td>Bar-Oz &amp; Dayan, 2003</td>
</tr>
<tr>
<td>Neve-David</td>
<td>Geometric Kebaran</td>
<td>Northern coastal Plain – western slopes of Mt. Carmel</td>
<td>Bar-Oz et al., 1999</td>
</tr>
<tr>
<td>Hayonim Cave</td>
<td>Early Natufian</td>
<td>Lower Galilee – Mediterranean foothills</td>
<td>Munro 2001, 2004</td>
</tr>
<tr>
<td>Hayonim Cave</td>
<td>Late Natufian</td>
<td></td>
<td>Munro 2001, 2004</td>
</tr>
<tr>
<td>el-Wad Terrace</td>
<td>Late Natufian</td>
<td>Northern coastal Plain – western slopes of Mt. Carmel</td>
<td>Bar-Oz et al., 2004</td>
</tr>
</tbody>
</table>

17 cal. kya), Hefzibah and Neve-David to the Geometric Kebaran (17-14.5 cal. kya), Hayonim Cave to the Early (14.5-13 cal. kya) and Late Natufian (13-11.5 cal. kya), and el-Wad Terrace to the Late Natufian period. All assemblages are from open-air sites, except those from Hayonim Cave, and contain high densities of cultural remains including animal bone. Each assemblage was collected using rigorous recovery methods and was sorted and analyzed by the authors using similar protocols (see Munro & Bar-Oz 2005, for details). Although relative abundances vary, mountain gazelle (*Gazella gazella*) is the dominant taxon in all assemblages and is followed by varying proportions of other ungulates including fallow deer (*Dama mesopotamica*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), wild goat (*Capra aegagrus*), and wild cattle (*Bos primigenius*). All assemblages also include variable proportions of small prey taxa, namely Mediterranean spur-thighed tortoise (*Testudo graeca*), hare (*Lepus capensis*), partridge (*Alectoris chukar*), and other birds (mainly waterfowl). Although the types of prey are similar, there are gradual increases in the frequencies of gazelle and small game across the Epipaleolithic sequence. A previous study of five of these assemblages used a multivariate approach to investigate the intensity of gazelle carcass use in the Levantine Epipaleolithic. The research concluded that the survivorship of gazelle skeletal parts in each of the assemblages was determined first and foremost by the extraction of bone fats (grease and marrow; Munro & Bar-Oz, 2005).
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#### Quantitative data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
<th>Value 6</th>
<th>Value 7</th>
<th>Value 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>NISP</td>
<td>19513</td>
<td>8507</td>
<td>2516</td>
<td>7354</td>
<td>8159</td>
<td>2899</td>
<td>385</td>
<td>140</td>
</tr>
<tr>
<td>MNI</td>
<td>385</td>
<td>140</td>
<td>95</td>
<td>118</td>
<td>205</td>
<td>73</td>
<td>109</td>
<td>39</td>
</tr>
<tr>
<td>Ungulate Evenness</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>% Gazelle bone damage of natural taphonomic agents</td>
<td>12.9</td>
<td>11.9</td>
<td>3.0</td>
<td>0.7</td>
<td>0.6</td>
<td>2.8</td>
<td>9.5</td>
<td>3.0</td>
</tr>
<tr>
<td>% Weathered stage 3 or higher</td>
<td>12.9</td>
<td>11.9</td>
<td>3.0</td>
<td>0.7</td>
<td>0.6</td>
<td>2.8</td>
<td>9.5</td>
<td>3.0</td>
</tr>
<tr>
<td>% Carnivore gnawed</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>% Rodent gnawed</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>% Weathered stage 3 or higher</td>
<td>12.9</td>
<td>11.9</td>
<td>3.0</td>
<td>0.7</td>
<td>0.6</td>
<td>2.8</td>
<td>9.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Table 3: Values of key taphonomic variables for Levantine Epipaleolithic assemblages. Unless otherwise noted, % refers to the percentage of gazelle bone fragments (NISP) affected by the variable of interest.
Taphonomic Summary of the Epipaleolithic assemblages

Table 3 summarizes frequency counts of relevant taphonomic variables from the Levantine Epipaleolithic assemblages. Taphonomic variables were selected based on their relevance for Levantine Epipaleolithic site formation, the quality of available actualistic models for comparison, and their general applicability to larger taphonomic issues (Table 3). The selected variables include carnivore gnawing (punctures, scoring, and dragmarks), weathering, rodent gnawing, and root etching, among others. Taphonomic variables were also selected by their potential to address the intensity of gazelle carcass use (i.e., gazelle cutmarks, impact notches, percussion marks, fractures, fragmentation, burning, and completeness indices of small dense elements).

The frequency of most taphonomic surface damage types is similar among sites, although a few informative differences exist (Table 1). First, the relative abundance of small game and the frequency of gazelle relative to other ungulate species are highest in the Natufian assemblages. Similar differences in prey relative abundances exist between Natufian and earlier Epipaleolithic assemblages from across the southern Levant. The shifts have been interpreted as signals of intensified hunting in response to increased human population size, climatic instability and increased sedentism beginning in the Early Natufian (Bar-Oz, 2004; Davis, 1991; Munro, 2004; Tchernov, 1993; Stiner et al., 1999, 2000). Second, at the open air sites of Nahal Hadera V and Hefzibah the frequency of bones weathered to Behrensmeyer’s (1978) stage 3 or higher exceed those from the other sites. This difference is likely attributable to the location of these sites in a sand dune environment (Bar-Oz, 2004). Third, the frequency of burning in the Late Natufian gazelle assemblage from Hayonim Cave is much greater than that of the other assemblages. This pattern extends to all animal taxa from Hayonim Cave which are characterized by higher frequencies of burning in the Late than in the Early Natufian (Munro, 2001). High frequencies of burning in the Late Natufian assemblage were caused by the construction of a Byzantine glass furnace which was dug into the Late Natufian deposits (Bar-Yosef, 1991) and subsequently burned all archaeological bones in its vicinity.

The differences (Table 3) result from long term changes in subsistence behaviors and different depositional settings. Both of these factors have the potential to substantially impact the structure of zooarchaeological assemblages, but the similar expression of most taphonomic variables in our assemblages indicate that this is not the case here. Instead, our assemblages appear to have experienced fairly uniform depositional histories. The multivariate table also facilitates comparison of the relative contribution of the effects of various taphonomic processes. The low frequencies of natural damage types indicate that although non-cultural factors affected our assemblages—in some cases more than others—the bones are in good condition overall. Table 3 does not reveal the effects of a dominant taphonomic agent, although the presence of cutmarks,
hammerstone impact notches, and high frequencies of fresh fractures clearly designate humans as important agents of assemblage formation.

The comparison of taphonomic summaries from multiple assemblages may reveal informative differences that highlight local variation in a site or region’s taphonomic history. For example, carnivore damage has been shown to be common in Middle and Upper Paleolithic assemblages in Africa, Europe and even the southern Levant, but is rare or absent in our assemblages. The low frequency of carnivore modification including gross gnawing, tooth scoring, pitting, puncturing and digestion indicates that Epipaleolithic assemblages were not accumulated or significantly altered by carnivores. This observation is strongly supported by data from other Levantine Epipaleolithic and Neolithic assemblages (L. Horwitz personal communication, 2004; Martin, 1994:330; Rabinovich, 1998a, 1998b; Rabinovich & Hovers, 2004; and references in Rabinovich, 2002). The paucity of carnivore gnawing in Levantine Epipaleolithic assemblages is likely attributable to a combination of several factors. First, if animal bones were cooked, boiled and/or thoroughly processed for marrow prior to disposal (see below), their reduced nutritional value likely made them less attractive to carnivores (Bernabeu et al., 2001; Lupo, 1995; Morey & Klippel, 1991; Speth, 2000). Actualistic experiments using wild carnivores and captive hyenas (Crocuta crocuta) have identified few carnivore tooth marks on human-processed assemblages (Blumenschine, 1986, 1988; Marean & Spencer, 1991; Marean et al., 1992), since bones become undesirable to predators once bone fats have been removed. Intensive fragmentation caused by grease extraction (Outram, 2001; Speth & Spielmann, 1983) may further reduce the attractiveness of bones to carnivores. Second, acceleration of the trend toward sedentism in the early Epipaleolithic likely further discouraged carnivores from scavenging bone from human collected assemblages. By occupying their sites for longer periods, humans may have inadvertently protected their trash from scavengers (Bunn, 1993; Speth, 2000; Yellen, 1991). Furthermore, bones have been shown to lose their attractiveness to scavengers after they have been exposed on the surface for a few days or more (Binford, et al. 1988; Blumenschine, 1986; Yellen, 1991). Ethnographic evidence from long-term occupations indicates low exposure to carnivores (Bunn, 1991, 1993). Finally, it appears that several of the larger carnivores such as the hyenas (Hyaena hyaena, Crocuta crocuta) and other bone-collectors including wolves (Canis lupus) and big cats (Panthera leo, Panthera pardus), are rare or absent in the Levant by the Epipaleolithic (Dayan, 1994; Kurtén, 1965; Rabinovich, 2002). By this time (ca 21 kya), the Mediterranean carnivore guild was dominated by small taxa (e.g., Vulpes vulpes, Felis chaus, Meles meles, Martes foina, Vormela perugusna), few of which scavenge and/or consume bone (Dayan, 1994; Kurtén, 1965). Undoubtedly, a combination of these factors contributed to the lack of carnivore damage in our assemblages. This observation is of great importance given the major role that carnivore gnawing has been attributed in assemblages that have provided evidence for both density-mediated biases and
Table 4. Results of analyses of completeness and fragmentation for the Epipaleolithic Levantine assemblages

<table>
<thead>
<tr>
<th>Analyses of density-mediated attrition</th>
<th>NHV KEB</th>
<th>HEF G-KEB</th>
<th>ND G-KEB</th>
<th>HAYC EN</th>
<th>HAYC LN</th>
<th>EWT LN</th>
</tr>
</thead>
</table>
| Spearman’s r gazelle bone survivorship vs. bone density (n=25) | \(r_s=0.50;\) | \(r_s=0.46;\) | \(r_s=0.52;\) | \(r_s=0.41;\) | \(r_s=0.65;\) | \(r_s=0.40;\)
| p=0.01 | p=0.02 | p<0.01 | p = 0.04 | p <0.001 | p = 0.04 |
| Ratio of proximal to distal gazelle humerus | 0.13 | 0.14 | 0.14 | 0.11 | 0.14 | 0.22 |
| Tooth to cranial bone-based MNI (mammals) | 92 | 98 | 87 | 65 | 100 | 88 |

**Fragmentation analyses (gazelle)**

| % Complete astragalus | 75 | 79 | 77 | 87 | 88 | 79 |
| % Complete central fourth tarsal | 68 | 60 | 65 | 83 | 88 | 70 |
| % Fresh fracture angle on long bone shafts | 64 | 64 | 54 | 60 | 59 | 52 |
| Fragmentation index (NISP/MNI) | 62 | 74 | - | 140 | 98 | 74 |
| Spearman’s r bone survivorship (NISP/MNI) vs. fragmentation index (n=28) | \(r_s=0.63;\) | \(r_s=0.62;\) | - | \(r_s=0.57;\) | \(r_s=0.66;\) | \(r_s=0.44;\)
| p<0.001 | p<0.001 | p<0.001 | p<0.001 | p<0.001 | p=0.02 |

**Analyses of food utility (gazelle)**

| Spearman’s r gazelle bone survivorship vs. food utility index (n=23) | \(r_s=0.24;\) | \(r_s=0.10;\) | \(r_s=0.25;\) | \(r_s=0.29;\) | \(r_s=0.37;\) | \(r_s=-0.17;\)
| p=0.25 | p=0.60 | p=0.24 | p=0.18 | p=0.07 | p=0.38 |
| Spearman’s r gazelle shaft fragmentation (NISP/MNI) vs. marrow index (n=14) | \(r_s=0.63;\) | \(r_s=0.84;\) | - | \(r_s=0.54;\) | \(r_s=0.80;\) | \(r_s=0.80;\)
| p<0.05 | p<0.001 | p<0.001 | p<0.05 | p<0.001 | p<0.001 |
| Spearman’s r gazelle bone survivorship (NISP/MNI) vs. fragmentation index (n=28) | \(r_s=0.63;\) | \(r_s=0.62;\) | - | \(r_s=0.57;\) | \(r_s=0.66;\) | \(r_s=0.44;\)
| p<0.001 | p<0.001 | p<0.001 | p<0.001 | p<0.001 | p=0.02 |
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carnivore damage (e.g., Marean and Kim, 1998; Pickering et al., 2003).

Investigations of Epipaleolithic Assemblage Completeness and Fragmentation

The investigations of skeletal completeness and fragmentation are designed to determine patterns of skeletal part attrition and its most probable cause. Analyses of *in situ* attrition are good starting points because they assess an assemblage’s quality of preservation and determine the effects of processes that occurred after skeletal parts were disposed of by humans. We applied two analyses of attrition to our assemblages; both demonstrate that attritional processes played a minor role in assemblage formation. High representation of cranial bones in relation to teeth (based on MNI; after Stiner, 1994) suggests minor *in situ* loss of bones by decomposition or advanced fragmentation. Similar results for post-burial attrition were obtained using Marean’s (1991) completeness index for the tarsal bones. The percentage of complete astragals and central fourth tarsals ranges from 60-70% at the open-air sites of Hefzibah and Nahal Hadera V to 92% in the Early Natufian assemblage of Hayonim Cave. In combination with the low frequencies of natural damage shown in Table 3, these results suggest that the Epipaleolithic assemblages did not suffer considerably from post-depositional decay.

Next the assemblages were examined for evidence of density-mediated attrition. We found a positive and significant relationship between gazelle bone survivorship (%MNI; Lyman, 1994) and bone structural density (based on BMD, values for *Rangifer tarandus*; Lam et al., 1999; Table 4). In all cases, the representation of gazelle skeletal elements was affected by density-mediated attritional processes. The low ratio of low-density proximal to dense distal gazelle humeri (based on MNE, data from Munro & Bar-Oz, 2005) also points to density-mediated attritional processes that occurred prior to or following deposition as the primary determinant of gazelle bone loss.

Further exploration of bone survivorship was undertaken through detailed inspection of our gazelle skeletal part profiles. Figure 1 shows that the representation of gazelle skeletal elements (%MAU) is similar in five of the studied assemblages. All skeletal part profiles are biased against the vertebral column and ribs, but are rich in heads, limbs including the pelvis and scapula, and toes, except at Hayonim Cave where heads are underrepresented. Compression of individual elements into anatomical units allows consideration of skeletal biases that may have resulted from the transport of prey. We have color coded our elements to distinguish Stiner’s (1994, 2002) nine anatomical regions (horn, head, neck, axial skeleton, upper forelimb, lower forelimb, upper hindlimb, lower hindlimb, and toes). The fairly complete representation of skeletal elements with the exception of vertebrae and ribs suggests that entire skeletons were transported to the sites and that the differential representation does not result from variation in transport decisions. The relationship between gazelle bone survivorship and the food utility index (FUI; Metcalfe & Jones, 1988) provides negative and insignificant results, with a low margin of observed variance (Table 4).
Figure 1. Skeletal part representation of gazelle from five Levantine Epipalaeolithic assemblages. Data is not available from Neve David.
Lack of association between bone abundance and utility coupled with a significant relationship between bone abundance and density indicate that the Epipaleolithic bone assemblages were affected by density-mediated destruction but not by selective transport. It looks, instead, as though most skeletal parts were transported and that survivorship was largely determined by human activities at each site.

The presence of a density-mediated bias in the gazelle assemblages, despite the good quality of preservation and the lack of evidence for human transport biases, pinpoints human processing as the major formation agent. We investigated the influence of human processing in our assemblages by initiating a series of tests on bone fragmentation. Analysis of the breakage patterns of gazelle long bone shafts (following Villa & Mahieu, 1991) revealed a predominance of fresh (green) bone fractures and low proportions of dry bone fractures (Table 4). The high frequencies of green breaks suggest that bones were broken when fresh, possibly for marrow extraction. We found a significant positive relationship between bone shaft fragmentation (NISP/MNE of bone shafts) and marrow values (based on domestic sheep; Binford, 1978). Similarly, we found a strong negative relationship between gazelle bone survivorship and fragmentation (NISP/MNI) in all of the Epipaleolithic assemblages (Munro & Bar-Oz, 2005). This suggests that low-density cancellous bone is underrepresented because it was highly fragmented, perhaps due to grease processing.

The preceding exploration of skeletal part representation enabled us to characterize the attritional patterns in our assemblages and to identify humans as a likely agent of bone fragmentation. This led us to select analyses to evaluate human processing, but the nature of the multivariate approach provides the flexibility to choose from many other analyses if the outcome had been different. For example, if we had discovered that our skeletal part patterns were determined largely by human transport decisions we may have chosen to investigate the relationship between skeletal part representation of taxa with different body size and a variety of utility indices (Binford, 1978; Klein, 1989). Likewise, if there had been strong evidence for carnivore gnawing we may have selected analyses that examined the skeletal distribution of carnivore damage (Blumenschine, 1986), the correspondence between human cutmarks and carnivore gnawing, or the angle of our green fractures to distinguish humans from carnivore agents (Pickering et al., 2004). The investigations of skeletal completeness indicate the human processing of bones for marrow and possibly grease were the leading cause of attrition in our assemblages.

Comparisons of Subgroups of the Natufian Assemblages from Hayonim Cave

We used intrasite comparisons to evaluate if marrow extraction was responsible for the fragmentation and survivorship of gazelle cortical bones. Actualistic data indicate that marrow extraction preferentially fragments bones that contain the most marrow. Results of our earlier
analyses indicate that the degree of fragmentation (NISP/MNE) of gazelle marrow-bearing bones was indeed linked to bone marrow content. However, because attrition in the gazelle assemblages was also density-mediated, we wished to confirm that marrow extraction was a leading cause of fragmentation using additional lines of evidence. We thus compared the gazelle data to subgroups of our assemblage that yielded lower quantities of bone marrow, and had lower bone densities. We specifically chose groups that differed in both bone mineral density and marrow content to distinguish the influence of density-mediated attrition from marrow extraction. It is the inverse relationship between marrow content and bone density that makes this analysis especially informative. First, we compared the fragmentation of gazelle long bone shafts to those of hare and partridge. Gazelle long bone shafts contain more marrow and are composed of thick, dense cortical bone in comparison to hare and partridge. Second, we compared the fragmentation of adult versus juvenile gazelle long bone shafts. Because of their porous nature, juvenile bone is both less dense and more fragile than adult bone, but it contains much lower quantities of fat-rich yellow marrow (Currey, 2002). In both cases we found that the bone shafts that encased the greatest marrow stores (gazelle and adult gazelle) were the most fragmented, despite higher mineral densities (Munro & Bar-Oz, 2005). These results confirm that gazelle long bone shaft breakage is not mediated by

Table 5. Taphonomic data for gazelle, hare and partridge subgroups from the Early and Late Natufian assemblages of Hayonim Cave.

<table>
<thead>
<tr>
<th></th>
<th>HAYC EN</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gazelle</td>
<td>Hare</td>
<td>Partridge</td>
<td>Gazelle</td>
<td>Hare</td>
<td>Partridge</td>
</tr>
<tr>
<td>NISP</td>
<td>2527</td>
<td>1560</td>
<td>1228</td>
<td>1773</td>
<td>417</td>
<td>449</td>
</tr>
<tr>
<td>MNI</td>
<td>18</td>
<td>26</td>
<td>25</td>
<td>18</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>% Assemblage</td>
<td>31</td>
<td>19</td>
<td>15</td>
<td>24</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>% Burned (NISP)</td>
<td>11</td>
<td>29</td>
<td>17</td>
<td>24</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>% Survivorship versus bone mineral density</td>
<td>r_s=0.41; r_s=0.31; n=25</td>
<td>r_s=0.65; p&lt;0.001; n=25</td>
<td>n.a</td>
<td>r_s=0.17; p=0.46; n=21</td>
<td>n.a</td>
<td></td>
</tr>
<tr>
<td>NISP/MNI</td>
<td>140</td>
<td>60</td>
<td>49</td>
<td>99</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>% Complete bones</td>
<td>21</td>
<td>37</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Average fragment length (cm)</td>
<td>2.7+/-1.7</td>
<td>1.8+/-1.2</td>
<td>2.1+/-1.2</td>
<td>2.8+/-2.1</td>
<td>2.1+/-1.4</td>
<td>2.0+/-1.1</td>
</tr>
<tr>
<td>% Complete long bone shafts (MNE)</td>
<td>13 (71)</td>
<td>42 (284)</td>
<td>97 (65)</td>
<td>16 (79)</td>
<td>38 (95)</td>
<td>78 (27)</td>
</tr>
</tbody>
</table>
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Intrasite comparison revealed that the gazelle assemblages at Hayonim Cave are characterized by statistically significant density-mediated biases. The recognition that other subgroups of the assemblages were not affected by this bias enabled us to isolate human processing as the most likely agent of gazelle assemblage formation.

To further demonstrate the utility of the intrasite comparisons we present additional multivariate tables that compare the expression of taphonomic variables in subgroups of the Hayonim Cave assemblage. Table 5 compares the skeletal parts of different prey taxa—gazelle, partridges and hare—which vary in body size, nutritional yields, and cortical bone thickness. Table 6 compares juvenile and adult gazelle skeletal parts which also differ in body size, bone density (Munson & Garniewicz, 2003), and the yield of in-bone nutrients. The taphonomic variables recorded in Tables 5 and 6 include aspects of bone fragmentation and frequencies of surface damage caused by natural and cultural agents. Intertaxonomic comparisons highlight variability in the extent of fragmentation and the frequency of surface damage types that were not apparent in our examinations of a single taxon (gazelle). These comparisons can inform us about differential treatment of prey taxa and animals of different ages. They thus allow us to eliminate agents that are expected to treat all bones equally and to focus on those that are expected to differentially affect bones of different ages or from different taxa.

### Table 6. Taphonomic data for adult and juvenile gazelle subgroups from the Early and Late Natufian assemblages from Hayonim Cave. Unless otherwise noted, % refers to the percentage of juvenile and adult gazelle bone fragments (NISP) affected by the variable of interest.

<table>
<thead>
<tr>
<th>Gazelle</th>
<th>HAYC EN</th>
<th>HAYC LN</th>
</tr>
</thead>
<tbody>
<tr>
<td>NISP</td>
<td>387</td>
<td>804</td>
</tr>
<tr>
<td>MNI</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>NISP/MNI</td>
<td>77.4</td>
<td>53.6</td>
</tr>
<tr>
<td>% of Aged Specimens</td>
<td>33</td>
<td>68</td>
</tr>
<tr>
<td>% Burned</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>% Long bones with cutmarks (NISP)</td>
<td>4 (147)</td>
<td>8 (281)</td>
</tr>
<tr>
<td>% Complete elements</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Average fragment length (cm)</td>
<td>3.0 +/-2.1</td>
<td>2.7 +/-1.4</td>
</tr>
<tr>
<td>% Complete long bone shafts (NISP)</td>
<td>20 (147)</td>
<td>1 (281)</td>
</tr>
<tr>
<td>% Complete phalanx 1 and 2 (MNE)</td>
<td>76 (80)</td>
<td>53 (166)</td>
</tr>
</tbody>
</table>
Differential fragmentation and burning of hare, partridge and gazelle bones suggest that different processing and food preparation strategies were applied to different species, and that this difference was related to more than just prey body size. More detailed comparisons of butchering data (i.e., prey skeletal part representation, cutmarks, hammerstone impact notches, and burning by skeletal part; Munro, 2001) are not reported here, but indicate that hare and partridge bones were less intensively processed than those of gazelle, despite the fact that all three animals display evidence for meat processing. These observations are supported by data in Table 5 which indicate that hare and partridge bones are less fragmented than those of gazelle, despite greater fragility. A similar interpretation can be put forth for juvenile versus adult gazelle, which have similar cut mark patterns, although the adult long bone shafts are more fragmented than the juveniles. This suggests that although only adult skeletons were butchered for bone fats, juvenile animals were still hunted for their meat. This observation has special implications for intensification trends at Hayonim Cave where progressively larger proportions of juvenile gazelles were hunted over time, despite the fact that these animals yielded less meat and could not be exploited for their bone fat. Clearly, the subgroup comparisons play a crucial role in refining the observations drawn at earlier stages of taphonomic research and allow us the detection of patterns in our assemblage’s otherwise complex taphonomic histories.

Discussion and Conclusions

Using the multivariate approach we conclude that human processing for marrow and possibly grease is the primary determinant of gazelle bone survivorship and the key source of density-mediated attrition in the assemblages from our Epipaleolithic case study. Furthermore, our assemblages were only minimally impacted by natural post-depositional processes including carnivore gnawing, and human transport was not a factor in biasing assemblage composition. These results are supported by multiple lines of independent evidence derived from several subgroups in our assemblages.

Our case study focused on assemblages that were formed largely by human processing. Clearly, there is great variability in the influence and combination of taphonomic factors that may affect assemblages originating from different time periods and geographic regions. The multivariate taphonomic approach can be applied to all types of bone assemblages, and will improve knowledge of the range of possible depositional histories that originate from human or natural processes or a combination thereof. Sites that are particularly relevant for the multivariate approach are those with strong representation of multiple subgroups. Good candidates include bone assemblages with large samples of domestic and wild animals (Bernabeu et al., 2001), two or more different prey types (Klein, 1989), or juvenile and adult age groups. These studies allow us to fine-tune our understanding of the depositional history and economic structure of a given assemblage and will lead to meaningful
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conclusions concerning issues of equifinality and skeletal part representation. The wealth of knowledge accumulated over thirty years of taphonomic research has taught us about the limitations and complexities of zooarchaeological data (Gifford-Gonzalez, 1991; Lyman, 1994; and others). At the forefront of these limitations has been the problem of equifinality—since many taphonomic processes have been shown to produce similar attritional biases, in particular those mediated by bone mineral density. The papers in this volume indicate that equifinality in skeletal part representation must be resolved at different stages in the taphonomic pathway, in particular during pre- and post-depositional and analytical stages. We recognize the significance of the methodological issues, but have focused specifically on the attritional sources of equifinality. The leading attritional cause of equifinality in taphonomic studies is the density-mediated bias, which can result from the action of numerous taphonomic factors. The density-mediated agents that have received the most attention in the Paleolithic literature include carnivore ravaging and fluvial transport (e.g., Marean & Cleghorn, 2003; Pickering et al., 2003; Behrensmeyer, 1975). Detailed assessment of our Levantine Epipaleolithic assemblages, however, reveals that neither of these agents played substantial roles in assemblage formation, although we have significant evidence for density-mediated attrition. The multivariate approach established that the source of density-mediated biases were not the result of a single taphonomic agent, but of a combination of human activities, namely marrow and grease processing.

A final benefit of the multivariate approach is its ability to examine zooarchaeological data on multiple scales. The intrasite analyses which compare subgroups within an assemblage allow high-resolution reconstructions of taphonomic processes that acted on subgroups of the assemblage. These enable us to reconstruct local-scale taphonomic histories that are specific to individual sites. The multivariate approach also provides a framework to undertake broad-scale intersite comparisons of taphonomic data. This facilitates the construction of a larger regional picture which can take us beyond cautionary tales and enable us to address substantial questions regarding human behavior.

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