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QUANTITATIVE UNITS AND TERMINOLOGY IN ZOOARCHAEOLOGY

R. Lee Lyman

Fifteen years ago Casteel and Grayson (1977) identified potential ambiguity in the definitions of quantitative terms and units used by zooarchaeologists. As solutions they suggested that analysts use the original definitions of terms and explicitly specify how units are counted. The history of zooarchaeology since then has involved a shift from producing estimates of taxonomic abundances to measuring various taphonomic processes and effects within taxa. As a result, many new quantitative units and terms for those units have been proposed. Some of these new units and terms have been used to measure properties of bone assemblages that are not clearly related to a taphonomic process or effect. Other units and terms have been used inappropriately due to apparent misunderstanding of the property measured by a unit or due to some assumed, implicit meaning of a term. The 112 terms compiled for this study have 122 distinct definitions. Some of the designated quantitative units are synonymous with one another while other units are used in ambiguous manners that seriously compromise their reliability. Explicit definitions of quantitative units and terms along with detailed descriptions of how individual units are measured are mandatory to the efficient communication of research results and the continued prosperity of zooarchaeological research.

Hace quince años Casteel y Grayson (1977) identificaron la potencial ambigüedad en las definiciones de los términos cuantitativos y las unidades utilizados por zoóarqueólogos. Ellos sugirieron como solución que los analistas utilizaran las definiciones originales de los términos y especificaran explícitamente la manera de contar las unidades. Desde aquel entonces la historia de zoarqueología ha cambiado de manera que ya no se producen las estimaciones de la abundancia taxonómica sino que se miden varios procesos tafonómicos y sus efectos dentro de los taxa. Como resultado, se han propuesto muchas unidades cuantitativas nuevas además de los términos para ellas. Algunos de estos términos y unidades nuevas se han utilizado para medir las propiedades de las colecciones de huesos que no están claramente relacionadas con algún proceso o efecto tafonómico. Se han utilizado inapropiadamente otras unidades y términos debido a la aparente mala interpretación de la propiedad medida por la unidad o debido a algún supuesto, implícito significado del término. Los 112 términos compilados para este estudio tienen 122 distintas definiciones. Algunas de las unidades cuantitativas indicadas tienen significados sinónimos, mientras que se utilizan otras unidades de manera tan ambigua que se compromete su veracidad. Las definiciones explícitas de las unidades cuantitativas y sus términos junto con las descripciones detalladas de cómo se miden las unidades individuales son obligatorias para la eficaz comunicación de los resultados de la investigación y la continua prosperidad de las investigaciones zoarqueológicas.

When scientists come up with new ideas, they have to decide whether to coin a new term for this new idea or to borrow and transform an old one [Hull 1988:141].

Fifteen years ago Casteel and Grayson (1977) showed that the terms for quantitative units in use in zooarchaeology at that time were often vague. Terminological ambiguity resided in at least two arenas. First, some terms had multiple meanings. Second, some definitions were assigned to more than one term. For instance, Casteel and Grayson (1977) listed 57 terms, but were able to compile 74 definitions for those terms. These kinds of ambiguity were exacerbated by inconsistent use of some terms. A term with a particular definition might be used during analysis in such a way as to denote a definition different from the original. Casteel and Grayson (1977:239) recommended that (1) new terms must be explicitly defined in such a way as to allow their accurate operationalization by the reader, (2) a literature search should be undertaken to ensure that proposed new terms or definitions are not redundant with existing terms and definitions, (3) use of a previously defined term should include reference to the existing definition, and (4) the analyst should explicitly specify how previously defined terms are applied and used.

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In the years subsequent to the publication of Casteel and Grayson's (1977) paper, the quantitative terminology used by zooarchaeologists has grown. Along with that growth has come not the terminological clarity sought by Casteel and Grayson, but rather, increasing ambiguity. The result has been devastating to efficient communication of the results of zooarchaeological research, and, in some cases, has resulted in misapplications and incomparable results. Here, I present a sequel to Casteel and Grayson's (1977) original treatise. My purposes are to review several of the regularly used new terms, to clarify the quantitative units signified by some of the terms in use as of the early 1990s, to suggest reasons why some of the growth in terminology has occurred and why some of the terminological ambiguity has been perpetuated or exacerbated, and, to point out some cases of incomparable results due to the use of dissimilar quantitative units. My purpose is *not* to argue that new quantitative units and terms for those units should not be developed and proposed. Rather, my hope is that by presenting this review, new quantitative units and terms will enjoy a clear position within the existing set of units and terms.

METHODS AND MATERIALS

In studying the archaeological record, there is no reason to expect that our units of observation are, in their form and distribution, referable to the operation of a single variable in the past. . . . traditional archaeological measures compound variables which probably operated independently in the past. . . . a solution of the problem of measuring along several dimensions simultaneously must be reached in order to determine just what it is we *are* measuring [Binford 1968:24, 26; emphasis in original].

Concepts

It is important at the outset to distinguish among three concepts: measurements, terms, and units. I follow Gibbon (1984:40) and define the process of measurement as "the application of a set of procedural rules for comparing sense impressions with a scale and for assigning symbols to observations." *Measurements* result from comparing observations made on phenomena with a scale according to a set of rules and assigning one or more symbols to each observation per phenomenon. In this paper a *term* is a name or label for a quantitative unit. Quantitative units are of different levels or scales of mathematical power (Shennan 1988:11–12; Stevens 1946), and of different kinds (Gibbon 1984:55). On one hand, the level or scale of a quantitative unit is critical to determining appropriate statistical tests, but this topic is beyond the scope of this paper (see Grayson [1984] for relevant discussion). On the other hand, the kind of quantitative unit is central to my discussion.

Several kinds of quantitative units can be distinguished. *Observational units* are empirical manifestations that are easily observed general properties of phenomena; they are easily experienced with one's senses and can be directly measured. Measuring observational units by tallying the frequency of specimens or determining the length of individual specimens produces *fundamental measurements* of properties of the set of specimens (Fritz 1972; Gibbon 1984; Skibo et al. 1989). *Analytical units* consist of observational units that have been modified, often mathematically, to reflect some complex, indirectly observable property of the phenomena under study (e.g., Skibo et al. 1989:399). The property is indirectly observable because the archaeological record is static, and the property of interest tends to include a dynamic process that is believed to be somehow related to the static archaeological record (Reid et al. 1975; Schiffer 1976:55; Schiffer and House 1977: 251).

Analytical units may take either of two forms: derived, or interpretive. *Derived units* are more complex than observational units because they are defined by some specified mathematical relation between fundamental measurements. Derived units include such things as ratios of fundamental measurements, and require analytical decisions above and beyond the choices of a scale of comparison and a rule set for assigning symbols that characterize fundamental measurements. Measurements of derived units produce what are called *derived measurements* (Gibbon 1984:55). Derived units, in the following, tend to have nonexplicit, unclear, or only weakly established relations to theoretical or interpretive concepts, although they may play a significant role in comparative analyses.

Interpretive units are very complex because they tend to be structured so as to measure some abstract or theoretical concept, and the terms applied to such units often include a name for these concepts. Measurements of interpretive units have been called *fiat* or *proxy measurements* (Gibbon 1984:55).

Derived measurements, in my view, are mathematically generated in the hopes that some hidden pattern within the units measured will be revealed; that pattern may or may not be functionally or causally related to the property we wish to measure. Similarly, proxy measurements are mathematically generated but there tends to be some empirical generalization or theoretically founded reason to suppose the measured interpretive units are causally or functionally related to the property we seek to measure. For example, measures of "socioeconomic status" (a property held, at some level, by all individuals) often include fundamental measures of annual income and occupation, and occasionally other fundamental measures as well, such as level of education attained (e.g., Miller 1983). On one hand, the typically strong correlation between income and status serves as an empirical generalization warranting the conclusion that measures of socioeconomic status can be obtained by mathematically manipulating fundamental measurements of income, occupation, and the like, to produce proxy measures of an interpretive unit we might term a "socioeconomic status index." Derived units, on the other hand, are less closely allied with theoretical concepts, and may simply be used to produce derived measures of different sets of phenomena one wishes to compare (e.g., Todd and Rapson 1988). Derived units and measurements may, however, attain the status of interpretive units as we learn more about their theoretical connotations, and conversely, interpretive units may change status and be used as analytical units if research suggests their suspected functional relation to a dynamic process is less strong than originally believed. While the distinctions of derived units and interpretive units, and their respectively associated derived measurements and proxy measurements are important to recognize, I largely avoid categorizing the units described below as one or the other due to the varying ways analytical units have been used (sometimes as derived units, sometimes as interpretive units). I do, however, distinguish observational units from analytical units.

Basics

The earliest reference Casteel and Grayson (1977) cited dates to 1961 and the latest to 1977. I reviewed much of the English-language zooarchaeological and taphonomic literature with publication dates of 1977 or later to produce the list of 112 terms in Table 1. While there are no doubt references I have overlooked, and thus there are probably terms and quantitative units proposed since 1976 that are not listed in the table, this is irrelevant to the significance of the post-1976 terminology and suite of proposed quantitative units as they are represented in Table 1. What is relevant is that the terminology and number of quantitative units have grown, and what is significant is the reason for that growth. To assess that significance, and to clarify some of the ambiguity found in the list of terms and their attendant quantitative units in Table 1, it is necessary to begin with some basic, well-defined terms.

The terms NISP and MNI are the ones most commonly encountered in the literature, and they tend to have generally agreed upon meanings; that is, the units they seek to measure are clear (e.g., Bobrowsky 1982; Grayson 1984; Klein and Cruz-Uribe 1984; Lyman 1985; Morlan 1983; Plug 1984; Turner 1984). NISP is defined as the number of identified specimens per taxon; it is an observational unit. The taxon can be a subspecies, species, genus, family, or higher taxonomic category. MNI is the term for the minimum number of individual animals necessary to account for some set of identified faunal remains; it is a derived unit because it may or may not take individual variation such as age, sex, or size into account. In the definitions of NISP and MNI, the word "identified" must be clear. Typically, "identified" means "identified to taxon." In her study of Near Eastern archaeological faunal remains Zeder (1991:79), for example, indicates "identifiable bones are those which can be identified on a firm morphological or metrical basis at least to the taxonomic level of subfamily, if not to the level of genus or species." Identified can also mean "identified to skeletal element," such as a humerus, a tibia, a thoracic vertebra, or, a vertebra. Because it is

typically necessary to identify the skeletal element represented by a specimen prior to identifying the taxon represented by a specimen (Lyman 1979a), the meaning of identified as “identified to taxon” usually also entails the meaning “identified to skeletal element.” That is, the latter is necessary to the former, especially when the taxonomic level is a family, genus or species. The former is not, however, necessary to the latter.

Many definitions of the terms in Table 1 refer to “specimens,” “elements,” “skeletal parts,” and the like. Few zooarchaeologists, however, have explicitly defined what is meant by these terms. Grayson (1984:16), following Shotwell (1955, 1958), a paleontologist, defined a *specimen* as “a bone or tooth, or fragment thereof, while an *element* is a single complete bone or tooth in the skeleton of an animal.” A specimen, then, is an archaeologically or paleontologically discrete phenomenological unit, such as a complete humerus, a distal half of a tibia, a mandible with teeth in it, or a set of articulated carpals. A skeletal element is a discrete, natural anatomical unit of a skeleton, such as a humerus, a tibia, a tooth, or a carpal. Specimens can, but need not be skeletal elements and are observational units. Skeletal elements are “anatomical organs” (Francillon-Vieillot et al. 1990:480) that may be represented by fragments or whole bones and are represented, partially or completely, respectively, by archaeological specimens. In other words, a complete femur recovered from a site is a specimen, an observational unit, and a skeletal element. A fragment of a femur such as the distal end is a specimen, an observational unit, and *represents* but is phenomenologically not, technically, a skeletal element.

Given the preceding, Gilbert and Steinfeld's (1977:331) term *bone element*, which they define as “any bone fragment (such as the proximal femur) that has sufficient detail to permit the identification of the whole bone,” is synonymous with specimen. Similarly, Shipman's (1981:200) term *distinctive skeletal element*, or DSE, which she defines as “a skeletal element that is readily recognizable even when fragmentary because of its distinctive texture, markings, or shape,” is also synonymous with specimen (see Salemme et al. [1991] for other examples). Note that in both of these definitions, a “bone element” or a “skeletal element” can be fragmentary, or it can be a complete anatomical unit. This is so simply because zooarchaeologists have a skeletal model to which the observational units (specimens) they study can be related. That model consists of the individual, anatomically discrete, skeletal elements making up the skeleton. For example, it is not unusual these days to find a table listing the frequencies of forelimbs, femora, proximal tibiae, or thoracic sections of the vertebral column in a zooarchaeological report. These anatomical categories are founded on the model of a skeleton consisting of discrete but variously articulated skeletal elements, and the categories are of varying scales of inclusiveness of the skeletal elements. The anatomical category “distal tibia” is less inclusive than the anatomical unit “humerus” which in turn is less inclusive than the anatomical unit “thoracic section of the vertebral column.” Only the second category is directly comparable to, and isomorphic with, an anatomically discrete skeletal element. The first category includes some *analytically* specified portion of an anatomically discrete skeletal element, whereas the last includes several analytically specified articulated but anatomically discrete skeletal elements. These anatomical categories of varying scales of inclusiveness can, and often do, serve as the analytical units within which observational units (specimens) are tallied.

WHY COUNT?

Throughout the history of zooarchaeological research, the major goal of quantifying faunal remains has typically been to measure the relative abundances of different taxa (Grayson 1984). This, of course, accounts for the term *identifiable* most often meaning “identifiable to taxon” rather than, say, “identifiable to skeletal element.” Taxonomic abundance values are often treated as interpretive units because they are typically inferred to measure variation in past environments (e.g., Morlan 1983, 1989), or, variation in the amount of food provided by different taxa (Lyman 1979b; White 1953a). Reviews of counting techniques and quantitative units available for measuring taxonomic abundances abound (e.g., Chase and Hagaman 1986–1987; Gautier 1984; Grayson 1984; Klein and Cruz-Uribe 1984; Rackham 1983). The problems with the quantitative units typically used to

Table 1. Quantitative Terms in Zooarchaeology.

Term	Definition and Reference
adjusted MNE	—MNE per skeletal element based on the minimum number of long-bone ends and the minimum number of [isolated] long-bone shafts [overlapping with shaft parts attached to ends] (Bunn 1986:678) [= comprehensive MNE]
A	—“the actual abundance of a given species in a fossil assemblage; the raw numbers of individuals rather than the proportions; raw specimen counts” (Damuth 1982: 435, 437, 446) [= NISP]
ANI	—“the actual number of individuals in a sample; may be any value between NISP and MNI inclusively” (Lyman 1982:360)
AU	—frequency of anatomical units found intact and in situ (Villa et al. 1986:433)
A/L	—“the ratio of axial bones (A) to all limb elements (L), the minimum number of each skeletal element is used in calculating the ratio” (Potts 1983:53)
bone NISP	—NISP of bones (excluding isolated and articulated teeth and tooth specimens) (Stiner 1992:439)
BONES	—“minimum number of elements” (Hill 1989:172)
BU	—butchering unit: a piece of the animal body that results from the act of butchering (Lyman 1979a, 1979b)
comprehensive MNE	—MNE per skeletal unit or skeletal category based on the minimum number of long-bone ends and the minimum number of [isolated] long-bone shafts [overlapping with shaft parts attached to ends] (Bunn and Kroll 1986:435) [= adjusted MNE]
%Comp.	—percentage of complete elements (Todd and Rapson 1988:309); calculated as $\frac{\text{observed number of complete specimens of skeletal element } e}{\text{minimum number of skeletal element } e \text{ in the assemblage}} \times 100$
CUT	—“percentage of bone with cut marks” (Villa et al. 1986:435, 1988:62) [= CUT(%)]
CUT(%)	—“number of specimens with cut marks” (Villa et al. 1988:51)
D	—“number of bones with cut marks divided by the number of identified specimens” (Villa et al. 1986:433) [= CUT]
DNI	—“documented number of individuals” (Breitburg 1991:153) [historical, written documentation]
DRF	—“distortion of relative frequencies” (Nichol and Wild 1984:37)
%diff.	—percent difference between frequencies of proximal and distal ends of long bones (Richardson 1980: 21); calculated as $\frac{ \text{number of proximal ends of } e - \text{number of distal ends of } e }{(\text{number of proximal ends of } e + \text{number of distal ends of } e)} \times 100$
%Diff.	—percentage difference between proximal and distal articular ends of long bones (Todd and Rapson 1988:310, 314); calculated as $\frac{ (\text{number of complete skeletal element } e + \text{number of proximal } e) - (\text{number of complete } e + \text{number of distal } e) }{2(\text{number of complete } e + \text{number of proximal } e + \text{number of distal } e)} \times 100$
e_i	—“the total element count for the i th species” (Holtzmann 1979:78)
e'_i	—“the count of the most abundantly preserved element of the i th species” (Holtzmann 1979:78)
E*	—**“total number of bone fragments assigned to a species, total fragment count” (Hesse 1982:162, 164)

Table 1. Continued.

Term	Definition and Reference
Element MNI	<ul style="list-style-type: none"> —“the normal number [of skeletal elements] expected anatomically in one individual” (Crader 1983:128) —*“the number of <i>elements</i> of a species identified in a sample of bone” (Nichol and Wild 1984:35) —“number of specimens identified to each taxon” (Potts 1988:157)
EMNI*	<ul style="list-style-type: none"> —recovered element frequencies divided by the number expected in a single individual (Cannon 1991:25) [= MAU]
EMNF/Ind.	<ul style="list-style-type: none"> —*estimated minimum number of individuals (Noe-Nygaard 1977, 1987) —extended minimum number of individuals (During 1986:31) [multiple kinds of skeletal parts are used to determine the minimum number of individuals]
(EMNF/Ind.)MNI	<ul style="list-style-type: none"> —“the expected minimum number of fragments per individual skeleton” (Aaris-Sørensen 1983:244–245; after Noe-Nygaard 1977) —“an estimate on the absolute minimum number of fragments expected to be found per species” (Aaris-Sørensen 1983:245; after Noe-Nygaard 1977)
ENE	<ul style="list-style-type: none"> —“estimated number of elements based on MNI” (Schick et al. 1989:129)
ENI	<ul style="list-style-type: none"> —effective number of individuals (Hesse 1982:165; after Holtzmann 1979) —effective number of individuals: “the average number of bones [necessary to increase the MNI by 1]” (Hesse and Wapnish 1985:115)
f	<ul style="list-style-type: none"> —“standardized joint frequency” (Hill and Behrensmeier 1984:367); calculated as “n ÷ r” as defined by Hill and Behrensmeier (1984)
F	<ul style="list-style-type: none"> —percentage of bones with filleting butchering marks (Villa et al. 1986:435, 1988: 62)
FE	<ul style="list-style-type: none"> —“frequency of elements whose number in a live animal can be determined” (Chase and Hagaman 1986–1987:79)
f.n.	<ul style="list-style-type: none"> —[not defined, but apparently = NISP] (Villari 1991:117)
F/H	<ul style="list-style-type: none"> —“the ratio of forelimb bones (F) to hindlimb bones (H), the minimum number of each skeletal element is used in calculating the ratio” (Potts 1983:53)
FR	<ul style="list-style-type: none"> —fragmentation ratio (Richardson 1980:111) [for skeletal element ϵ] $FR = (NISP_{\epsilon} \div MNE_{\epsilon})100$
FRI	<ul style="list-style-type: none"> —faunal resemblance index: $FRI = 100(C \div N_1)$, where C is the number of taxa common to two compared faunas, and N_1 is the number of taxa in the smaller sample (Shipman 1981:149, from Simpson 1960); also known as Simpson's coefficient of similarity (see Cheetham and Hazel [1969] for a review of this and similar coefficients)
g	<ul style="list-style-type: none"> —“the number of groups of elements” (Chase and Hagaman 1986–1987:81)
H + H/L	<ul style="list-style-type: none"> —the sum of horn/antler and head parts relative to limb parts above the foot or proximal to the phalanges (Stiner 1991:462–463) $\frac{MNE \text{ of horn/antler} + MNE \text{ of heads}}{MNE \text{ of limb bones}}$
HEAD/L	<ul style="list-style-type: none"> —the proportion of head parts to limb parts above the foot or proximal to the phalanges (Stiner 1991:462–463) $\frac{MNE \text{ of heads}}{MNE \text{ of limb bones}}$
HORN/L	<ul style="list-style-type: none"> —the proportion of horn/antler parts to all limb parts above the foot or proximal to the phalanges (Stiner 1991:462–463) $\frac{MNE \text{ of horn/antler}}{MNE \text{ of limb bones}}$

Table 1. Continued.

Term	Definition and Reference
IFD	—index of fragment disjunction, “measures the relative dispersal of mechanically refitted fragments” (Todd 1987:191, 193); calculated as $(MD_c \div \%_c \text{ with a mate}) \div \text{maximum MD}$
ISD	—index of skeletal disjunction, “created by dividing the mean distance of separation [MD _c] of [left and right pairs] of an element group by the percentage of that element with a recognized [anatomically refit] mate . . . standardized by relating all values to the maximum index value, which is given a value of 100” (Todd 1987:189), calculated as $(MD_c \div \%_c \text{ with a mate}) \div \text{maximum MD}$
k(i)	—number of identifiable parts per skeleton for taxon (i) (Plug and Plug 1990:55) [equivalent to an NISP:MNI ratio]
M	—= MNI (Wapnish and Hesse 1991:77)
m _{i'}	—“effective number of elements per individual” (Holtzmann 1979:78) [see ENI]; calculated as
	$\frac{\text{NISP for taxon}_i}{\text{most abundant skeletal part for } i} = \frac{e_i}{e_{i'}}$
MAU	—minimum animal units (Binford 1984:51) [differences in age, sex, size not taken into account]; calculated as
	$\frac{\text{MNE}_c}{\text{number of times } c \text{ occurs in one complete skeleton}}$
MAU%	—“standardized or ratio MAU values” (Todd 1987:134–137) [= %MAU]
%MAU	—percent MAU (Binford 1984); calculated as
	$\frac{(MAU_c)100}{\text{maximum MAU observed in an assemblage}}$
MCE	—“the <i>most common element</i> present among the bones of a species” (Nichol and Wild 1984:35)
MD	—“mean minimum distance (in meters) separating anatomically [or mechanically] refitted pairs” (Todd 1987:189, 193); calculated as $(\Sigma \text{ distances between refit pairs of } c) \div \text{number of refit pairs of } c$
MENI	—“minimum estimated number of individuals” (Chase and Hagaman 1986–1987:82)
MNB	—“minimum number of bones” (Potts 1982:253) —“minimum number of bones” (Hill 1989:173)
MNBC	—minimum number of beef cuts (Lyman 1987b) [synonymous with BU of Lyman (1979b)]
MNE	—“the minimum number of elements” (Bunn 1982:35) —“minimum number of elements [or] the minimum number of different specimens referable to a given anatomical part” [minimum number of individual elements necessary to account for the whole and fragmentary specimens observed] (Binford 1984:50) —“the minimum number of skeletal elements per taxon” (Badgley 1986:329) —“the minimum number of elements for different skeletal elements” (Bunn 1986:676) —“the minimum number of skeletal units required to account for all of the often fragmentary specimens in an assemblage that are identifiable as each skeletal category [= skeletal portion]; regardless of age, sex, or side, the highest justifiable estimate of the original number of skeletal units in the chosen skeletal category that contributed to the assemblage” (Bunn and Kroll 1986:434–435) [apparently size and taxon not accounted for]

Table 1. Continued.

Term	Definition and Reference
	<ul style="list-style-type: none"> —“the highest justifiable estimate of the minimum number of original skeletal units required to account for all of the fragmentary specimens in an assemblage that are identifiable as each skeletal category” (Bunn 1986:677) —“total number of elements recorded” (Todd 1987:140) —“the minimum number of skeletal elements that have conjoinable fragments” (Todd 1987:193) —“minimum number of elements, an estimate of the number of individual bones represented for each taxon” (Potts 1988:158) —“minimum number of skeletal elements” (Todd and Rapson 1988:308) [can be determined for each of several parts of a skeletal element] —“minimum number of elements [or] whole bones” (Bunn 1989:307) —“minimum number of elements, the minimum estimate of the number of elements represented at the site, derived from the sometimes fragmentary total number of elements or TNE” (Schick et al. 1989:129, 130) —“minimum number of skeletal elements; determined from the most common portion of each skeletal element and summing right and left sides [for paired elements]” (Stiner 1991:459)
MNE/ENE	<ul style="list-style-type: none"> —“percentage survival” (Schick et al. 1989:130)
MNE/MNI	<ul style="list-style-type: none"> —“the average number of bones by which individuals are represented” (Blumenschine 1989:349) —“%survival” (Schick et al. 1989:129)
MNI*	<ul style="list-style-type: none"> —minimum number of individuals: *the number of individual animals necessary to account for all identified specimens (Casteel and Grayson 1977; Grayson 1979, 1984; Klein and Cruz-Uribe 1984; Perkins 1973; Uerpmann 1973; White 1953a) —“the minimum number of individual animals represented by each anatomical part” (Binford and Bertram 1977:79) —calculated by “dividing the observed bone count for a given identification unit by the number of bones in the anatomy of a complete animal for that unit” (Binford 1978:70) [changed to MAU by Binford in 1984; see above] —“the smallest number of individuals of one species from which the most common skeletal element in an assemblage could have been derived” (Shipman 1981:201) —“the smallest number of animals necessary to produce the sample of bones [of a taxon] observed” (Hesse 1982:161) —the number of individual animals necessary to account for a particular category of skeletal part, such as distal humerus or proximal tibia, with ontogenetic age differences taken into account (Klein and Cruz-Uribe 1984) —“the <i>minimum number</i> of separate <i>individuals</i> that can be recognized among the bones of a species” (Nichol and Wild 1984:35) —“a measure of the smallest number of animals whose bones were originally deposited in a site” (Chase and Hagaman 1986–1987:76).
%MNI _e	<ul style="list-style-type: none"> —“an expression of the proportion of total individuals represented by a particular skeletal element [.]” (Blumenschine 1989:354); calculated as $(\text{MNE}_e \div \text{frequency of } e \text{ in one individual}) \div \text{MNI}$
MNI _f	<ul style="list-style-type: none"> —MNI determined from the bones associated with a particular fire hearth (Jones 1983:181) [see RI]
MNI _s	<ul style="list-style-type: none"> —MNI determined from all the bones in a site (Jones 1983:181) [see RI]
MNIs	<ul style="list-style-type: none"> —minimum number of individuals (Cruz-Uribe 1988:180)
MNSU	<ul style="list-style-type: none"> —minimum number of skeletal units (Potts 1982:253; after Lyman's 1979a, 1979b skeletal portions); units are “forelimbs, hindlimbs, axial skeletal units, and skulls” (Potts 1982:253; see also Potts 1988:158)
MNU	<ul style="list-style-type: none"> —“minimum number of bone units” [apparently is equivalent to MAU] (Borrero et al. 1985:274)

Table 1. Continued.

Term	Definition and Reference
modified MNI	—“minimum number of units is the same value that other researchers have labeled MNI (minimum number of individuals by skeletal part) or MAU (minimum animal units)” (Bunn 1993:167)
MTWT	—variation in age, sex, size, etc. is accounted for (Hesse and Wapnish 1985:114)
n	—“weight of usable meat (Lyman 1979a, 1979b; after White 1953a)
ñ	—“the observed number of recognized bone fragments of a species” (Lasota-Moskalewska and Sulgostowska 1977:154) [= NISP] —“total number of a particular skeletal joint in the assemblage or collection” (Hill 1979a:740, 1979b:264) —“the minimum number of specimens based on major elements” (Dodson and Wexlar 1979:276) [= MNI] —“sample size” (Richardson 1980:115) [= NISP] —“number of the type of skeletal joint in the whole assemblage” (Hill and Behrensmeyer 1984:367) —number of identified specimens (During 1986) [= NISP] —“the number of individuals whose bones were originally deposited in a given location” (Chase and Hagaman 1986–1987:75)
N	—“the theoretically expected number of bone fragments of a species” (Lasota-Moskalewska and Sulgostowska 1977:154) [calculated as a χ^2 value]
n(i)	—“total number of all intact joints in the whole assemblage or collection” (Hill 1979a:740, 1979b:264)
Ns	—“the number of specimens represented by an identifiable shaft (diaphysis)” (Dodson and Wexlar 1979:279)
Ncm	—“the original number of individuals of a species deposited at a site” (Nichol and Wild 1984:35)
NI	—number of specimens identified [= NISP] or unidentified (Crader 1984, 1990) [apparently, sample size or NISP by taxonomic category including taxonomically unidentified specimens] —number of individuals (During 1986) —“number of specimens after refitting” (Villa et al. 1986:435, 1988:62) —number of specimens (Russell 1987:384) [= NISP]
n_{ij}	—sample size for taxon (i) (Plug and Plug 1990:55) [= NISP(i)]
n''_{ij}	—“number [of bone specimens] with striations” (Russell 1987:384) —“number [of bone specimens] with cutmarks” (Russell 1987:384)
NISP*	—initial number of animals, number of animals in the thanatocoenoses or death assemblage (Gautier 1984:242; from Poplin 1976) —number of individuals (Plug and Plug 1990:54); same as MNI, but written “NI >(some whole number)” to denote MNI is a minimum estimate rather than an absolute —“number of identified specimens” (Payne 1975) —“number of identifiable fragments of bones of each species” (Davis 1987:35; Klein and Cruz-Uribe 1984:24–25) —“minimum number of identified specimens” (Todd and Rapson 1988:307)
NISP _i	—number of identified specimens for skeletal part, (Lyman 1984)
NISPs	—number of identified specimens (Cruz-Uribe 1988:180) [= NISP]
NISP/MNI	—“an estimate of skeletal completeness or degree of fragmentation of a faunal assemblage” (Schick et al. 1989:126)
NMI	—minimum number of individuals (Altuna et al. 1991:99–100)
NR	—“numbers of identifiable specimens” (Altuna et al. 1991:98)

Table 1. Continued.

Term	Definition and Reference
NRI	—real number of individuals present in an assemblage, the number of animals in the excavated taphocoenosis or fossil assemblage (Gautier 1984:242; from Poplin 1976)
NSI	—number of specimens per individual: “the number of bones attributed to a taxon divided by the MNI of that taxon” (Shipman 1981:202)
NSpecies	—number of species (Cruz-Uribe 1988:181)
NSP	—number of specimens [includes unidentifiable and identifiable] (Grayson 1991: 487)
p(A)	—“the probability of association of skeletal elements in a bone assemblage . . . the probability that non-redundant skeletal elements present [in a bone assemblage] are derived from one individual” (Badgley 1986:320)
PNI	—probable number of individuals (Coy 1977); the minimum number of individuals per taxon calculated from an assemblage of bones defined as an assemblage on the basis of a spatially (horizontally and vertically) identified deposit (Hesse and Wapnish 1985:114)
PP	—“percentage-present is the proportion of elements present relative to the expected number, given MNI” (Kusmer 1990:630); calculated as $\frac{\text{NISP}_e \text{ observed} \div \text{NISP}_e \text{ expected}}{\text{NISP}_e \text{ observed} \div \text{MNI} (c)}$ where c is the constant represented by the number of skeletal element e in one skeleton [actually calculated as $\text{MNE}_e \text{ observed} \div \text{MNI} (c_e)$]
%preservation	—“the percent preserved of the number expected if all had been preserved, based on minimum numbers of individuals for each taxon” (Wolff 1973:94) [= % survival]
r	—“number [frequency] of a type of skeletal joint in a single skeleton” (Hill and Behrensmeyer 1984:367) [= R] —“the recovery rate of the bones—the probability that any given skeletal part will be recovered by the paleontologist or archaeologist” (Chase and Hagaman 1986–1987:76)
R	—“the number [frequency] of a particular skeletal joint in a single skeleton” (Hill 1979a:740, 1979b:264) [= r] —= RF (Wapnish and Hesse 1991:77)
RAI	—relative abundance index: “an indication of the similarity of two faunas, based on the number of species in common and the number of individuals in each fauna” (Shipman 1981:203); $\text{RAI} = [\text{I}_c \div (\text{I}_1 + \text{I}_2)]100$, where I_c = total number of individuals of the common taxa; I_1 = total MNI in fauna 1; I_2 = total MNI in fauna 2 (Shipman 1981:149; from Simpson 1960)
RatioMAU	= [%MAU] (Todd 1987:135)
RF*	—relative frequency (Chase and Hagaman 1986–1987; Gilbert and Singer 1982; see also Gilbert et al. 1981); if e is a bone type, RF is calculated as $\frac{[\Sigma(\text{TNF}_e \div \text{frequency of } e \text{ in one skeleton})]}{\text{number of bone types recovered}}$
	—*relative frequency: “a sort of average MNI” (Hesse and Wapnish 1985:115–116) [apparently per taxon]; calculated as $\frac{\Sigma \text{TNF per skeletal part}}{\text{number of kinds of skeletal parts}}$
R _i	—“the relative abundance of element i” (Andrews 1990:45), calculated as $(N_i \div \text{MNI})E_i$ in which N_i = the number of element i in the sample [actually = NISP of i],

Table 1. Continued.

Term	Definition and Reference
RI	MNI = the minimum number of individuals in the sample, and E_i = the number of element i in one skeleton —index of redistribution (as meat sharing decreases, the summed MNI associated with individual fire hearths will more closely approximate the MNI for the entire site) (Jones 1983:181); if n = the number of fire hearths in a site, RI is calculated as $\frac{\sum MNI_f}{(MNI_f)n}$
s	—“the number of skeletal parts used in calculating MNI . . . the sum of all the skeletal parts in a single living individual, that (1) can be identified to taxon, (2) can be recovered independently of all other such parts, and (3) are distinguishable by definition from all other parts” (Chase and Hagaman 1986–1987:76)
S	—“the number of identifiable elements in a <i>skeleton</i> of a species” (Nichol and Wild 1984:35)
Sk	—percentage of bones with skinning butchering marks (Villa et al. 1986:435, 1988:62)
SP	—skeletal portion: some arbitrarily defined part of the body (Lyman 1979b; after Read 1971); operationalized as forelimbs, hindlimbs, feet, vertebral column, rib cage, and skull and mandible (Lyman 1979a) —survival percentage: the percentage of the original number of a bone part expected to survive density-mediated attrition (Binford 1981:218) [see %survival]; also called “survival probabilities” (Binford 1981:217); calculated as $-352.778 + 1050.4(D^2) - 1008.69(D^2) + 332.882(D^3)$ where D = structural density of the skeletal part
%survival	—observed proportion of each anatomical part that survived attritional processes (Brain 1969; see also Brain 1976); [= % preservation]; calculated as $\frac{100(MNE_c)}{MNI \text{ (number of times } c \text{ occurs in one skeleton)}}$ —expected proportion of each anatomical part that will survive density-mediated attrition (Binford and Bertram 1977:138); if D = the structural density of a skeletal part, the expected % survival of that skeletal part is calculated as $-352.778 + 1050.4(D) - 1008.695(D^2) + 332.822(D^3)$
tMNE/MNI	—“anatomical completeness index, representing the quantity of substantial bony parts transported relative to the average number of carcass sources” (Stiner 1991: 462–463) [tMNE = 106 per carcass as modeled by Stiner; standardized MNI is the greatest MNI per skeletal element observed, or, 1 per carcass] $\frac{\text{total MNE}}{\text{standardized MNI}}$
tooth NISP	—NISP of isolated and articulated (still set in bone) teeth and tooth specimens (Stiner 1992:439)
total NISP	—tooth NISP + bone NISP (Stiner 1992:439)
T	—= TNF (Wapnish and Hesse 1991:77)
TMAU	—“total minimum animal units” (Chase and Hagaman 1986–1987:81) [summed MAU values (<i>sensu</i> Binford) for a taxon] —“total minimum animal units . . . calculated by first dividing the frequencies of elements [MNE] by the number of them in a complete skeleton, then summing these modified frequencies” (Ringrose 1993:131; after Chase and Hagaman 1986–1987)
TNE	—“number of identifiable elements; number of specimens identifiable as to element and taxon” (Schick et al. 1989:127, 128) [= NISP]

Table 1. Continued.

Term	Definition and Reference
TNE/MNI	— same as NISP/MNI (Schick et al. 1989:133)
TNF	— total number of fragments (Gilbert and Singer 1982) — total number of fragments (Crader 1983:111) — total number of fragments: the number of identified fragments (Hesse and Wapnish 1985:112) [apparently per species]
TNFcl	— total number of fragments comparable lists; the number of identified fragments of a taxon such that the kinds of skeletal elements that are represented in the counts are the same ("comparable") across all taxa (Hesse and Wapnish 1985:113)
T/V	— "teeth to vertebrae ratio; the number of teeth in an assemblage divided by the number of vertebrae; a measure of the degree of sorting of an assemblage" (Shipman 1981:204)
Ubiquity	— "a measure of bone distribution across the site . . . the proportion of features in which a taxon was present" (Purdue et al. 1989:149)
Ubiquity Index	— "plots the number of units containing a species against the median number of bones per unit for that species" (Styles 1981:43)
W	— weight of bone (Altuna et al. 1991:99)
WAE	— weighted abundance of elements: $NISP \div$ "maximum number of skeletal elements that can be preserved for one individual" (Holtzmann 1979:80) — "the weighted abundance of elements of a species in a sample; E [<i>sensu</i> Nichol and Wild 1984] standardized for differing values of S [<i>sensu</i> Nichol and Wild 1984]" (Nichol and Wild 1984:35)
#	— "number of specimens" (Wapnish and Hesse 1991:77)

Note: Multiple definitions for a term are listed chronologically, and denoted by a "—". Terms and definitions listed by Casteel and Grayson (1977) are signified with an asterisk. Lyman's comments are in brackets. "e" denotes particular skeletal elements or skeletal portions for those formulas that in their originally published form had no such designation.

measure taxonomic abundances are varied, but many of them result from the potential that the counting units are heavily influenced by taphonomic processes (e.g., Ringrose 1993), and those processes may be differentially distributed across taxa thereby producing inaccurate measures of the relative abundances of taxa. That is, as our knowledge of taphonomic processes has increased, the status of the analytical units typically used to measure taxonomic abundances has shifted from interpretive to derived (see Ringrose [1993] for extended treatment of this issue).

For example, NISP (number of identified specimens) is often criticized as a potentially inaccurate measure of the relative abundances of taxa because it does not account for intertaxonomic variation in the fragmentation of skeletal elements (e.g., Gilbert and Singer 1982; Holtzman 1979; Klein and Cruz-Uribe 1984). That accurate yet simple fact has prompted some researchers to seek analytical controls for the potentially biasing effects of taphonomic processes on this traditionally used quantitative unit (e.g., Aaris-Sørensen 1983; Gilbert and Singer 1982; Holtzman 1979). Such concerns have resulted in the development of techniques for making estimates of taxonomic abundances the accuracy of which can be assessed probabilistically (Allen and Guy 1984; Fieller and Turner 1982; Horton 1984; Lie 1980, 1983; Nichol and Creak 1979; Nichol and Wild 1984; Turner 1981, 1983; Turner and Fieller 1985; Wild and Nichol 1983a, 1983b). In fact, these techniques for estimating taxonomic abundances were built with explicit acknowledgment of the differential effects of preservation, recovery, fragmentation, and identifiability. Precisely which of several kinds of taxonomic abundances these techniques measure is still being evaluated (e.g., Ringrose 1993). For example, do they measure the relative abundances of taxa that were walking around the landscape, the abundances of taxa that were killed by human hunters, or the abundances of taxa recovered from an excavation?

The traditional goal of estimating taxonomic abundances has, then, resulted in some growth in the quantitative terminology and kinds of quantitative units analysts use. But another goal seems to have resulted in just as much if not more growth in that terminology and in the number of kinds of quantitative units over the past decade or two. Since the late 1970s, many of the analytical questions being asked of zooarchaeological remains have been explicitly phrased in taphonomic terms (Gifford 1981; Lyman 1987b). Numerous new quantitative terms and units are aimed at measuring taphonomic effects or identifying taphonomic agents and processes rather than estimating taxonomic abundances. This set of terms includes MNE (minimum number of elements), MAU (minimum number of animal units), %survival (proportion of bones originally present that survived attritional processes), FR (fragmentation ratio), and others, virtually all of which are labels for analytical units. Some, such as MNE, are derived units, whereas others, such as %survival, are interpretive units. As I show below, growth in the number of quantitative terms and units is chronologically coincident with growth of the taphonomic awareness of zooarchaeologists.

In writing about the recent history of biological science, Hull (1988:295) suggests that at a superficial level at least, personal "success in science is gauged as much by the spread of a particular terminology as by the ideas signified by this terminology." If your colleagues use the terms you propose, then you have at least gained their respect if not their agreement. As well, "getting one's preferred terminology adopted strongly biases the game in one's favor. But more than this, terms are out front for all to see. Meanings are a good deal less conspicuous" (Hull 1988:295). While there certainly is some competition over whose hypothesis about certain aspects of humankind's prehistoric past is correct, I doubt terms and quantitative units are proposed by zooarchaeologists to gain votes for their favored hypothesis. Even if my doubt is misplaced, it will become clear that many of the meanings of the terms listed in Table 1 are inconspicuous.

What is important to keep in mind in the following is well illustrated by Thomas and Mayer (1983:364) who note in regard to calculating MNI per skeletal portion in the sense of White (e.g., 1952a, 1952b, 1953a, 1953b, 1953c; see below) and the method of calculating the MNI per skeletal portion in the sense of Binford (1978), "each method responds to a rather different question." It is the last, of course, wherein resides a major source of variation in the quantitative units analysts use, although failure to recognize this simple fact has resulted in some inappropriate uses of several of the quantitative units listed in Table 1, a fact I will return to below. First, however, it is appropriate to outline the history of quantitative unit introduction and meaning.

QUANTITATIVE-UNIT USE AND MEANING

Since the publication of Casteel and Grayson's (1977) study, several books surveying zooarchaeological analysis (Davis 1987; Hesse and Wapnish 1985; Klein and Cruz-Uribe 1984) and several others reviewing more limited or special topics in zooarchaeology (Bonnichsen and Sorg 1989; Davis and Reeves 1990; Grayson 1984; Hudson 1993; LeMoine and MacEachern 1983; Nitecki and Nitecki 1987; Stiner [ed.] 1991), as well as countless monographs and articles, have been published. Many, but certainly not all, of these studies have used at least one or both of two basic quantitative units or measurements of *taxonomic* abundance, NISP (number of identified specimens) and MNI (minimum number of individuals). The terms NISP and MNI may not be used because they have synonyms. Sixteen of the terms Casteel and Grayson (1977) list and 17 in Table 1 here are synonymous, or nearly so, with NISP as defined above; 14 of the terms they list and 11 in Table 1 are synonymous, or nearly so, with MNI as defined above; and 4 terms they list are synonymous, or nearly so, with the biomass or weight of meat represented by the remains of a taxon. Use of NISP, MNI, meat weight, or biomass types of quantification units typically accompanies the analytical goal of assessing human subsistence practices or paleoenvironmental conditions. Given how the research questions associated with these analytical goals are typically phrased (e.g., Grayson 1981; Lyman 1982; Rackham 1983), measuring relative abundances of taxa is logically concordant with the analytical goals. In these cases, the units of quantification are meant to determine how many (NISP, MNI) or how much (meat weight, biomass) of each taxon is represented in a collection of animal remains.

Taphonomic analyses have come to the foreground in zooarchaeology in the past 20 years, accompanying an increased awareness among archaeologists that the archaeological record is not always an undistorted reflection of past human behavior (e.g., Hudson 1993). Taphonomists seek answers to questions that differ in kind or scale from those traditionally asked by zooarchaeologists. Rather than asking how many or how much of each taxon contributed to the diet, or about the paleoenvironmental implications of the relative abundances of taxa, taphonomists realize they must first ask why only certain bones, individual organisms, or taxa are represented in an assemblage of bones and teeth (Shipman 1981). In a very real way, their questions are focused more on the proximate causes for the existence of a bone assemblage, rather than focusing on the paleodietary or paleoenvironmental significance of an assemblage of animal remains. Thus the tendency is for taphonomists to focus on a broad range of attributes of bone assemblages, rather than simply taxonomic abundances, to answer their research questions.

Given the analytical goal of answering the question "what are all these bones doing here?" (Shipman 1979), taphonomists effectively shift the scale of analysis from explaining taxonomic abundances to explaining why some kinds of faunal remains are, for example, abundant while other kinds of faunal remains are rare. This shift in analytic scale is implied in Hill's (1978:88) early statement that "taphonomy ultimately deals with the differences that exist between an assemblage of faunal remains and the community of animals from which it came." Taphonomists begin with a model of a complete animal, and offer explanations as to why complete, articulated individual skeletons are, or, more often, are not found. The counting units they use are ultimately taxonomic, but within each taxon the frequencies of different skeletal elements, kinds of fragments, cutmarked bones, and the like are tallied and analyzed during taphonomic research.

The growth in taphonomic concerns has resulted in a change in the kinds of quantitative units used during analysis. Fewer units (and terms for them) proposed in the 1980s are observational and more are analytical units than in the 1960s and 1970s. Observational units listed by Casteel and Grayson (1977) inclusively span the years 1961 to 1971 and make up 43.9 percent (25 of 57) of the total terms they list. Observational units listed in Table 1 span the years 1977–1993 and make up 26.8 percent (30 of 112) of the total terms there. Those proportions are significantly different (arcsine transformation $t_s = 2.217, p = .047$). The temporal trend over the three decades represented by the terms listed by Casteel and Grayson (1977) and in Table 1 is for terms signifying observational units to decrease in proportional abundance while terms signifying analytical units increase in proportional abundance.

The shift in analytical goals to a more intensive focus on taphonomic issues can also be illustrated by noting that 30 (52.7 percent) of the 57 terms listed by Casteel and Grayson (1977) concern quantitative units geared toward measuring relative abundances of taxa such as NISP or MNI. That is in marked contrast to the 20 (17.9 percent of 112) terms in Table 1 here that are geared toward measuring relative abundances of taxa as NISP or MNI (arcsine $t_s = 4.62, p < .001$). As might be expected, the *observational units* were established early in the history of zooarchaeology. The number of proposed quantitative units has continued to grow because new *analytical units* are continually being introduced.

There is, of course, overlap between researchers answering traditional kinds of zooarchaeological questions and using taxonomic abundances, and researchers seeking answers to taphonomic questions, especially as our questions about human behavior take on a progressively greater taphonomic tone. It is now quite clear that prior to inferring human subsistence practices or paleoenvironmental conditions from taxonomic abundance data, one must first be assured that those abundances have not been skewed by taphonomic processes. This overlap between traditional zooarchaeological research questions and taphonomic questions is very apparent in the writings of Binford (1978, 1981, 1984), who has taken an explicitly taphonomic approach to answering questions about hominid behavior. Distinction of the two types of questions or research arenas hinges on the distinction between measures of *taxonomic attributes* of faunal remains, usually taxonomic abundances, and measures of *nontaxonomic attributes* of faunal remains within a taxonomic category, such as abundances of different skeletal parts or frequencies of butchery-marked bones.

The distinction demands different counting units in the two research arenas. Evidence for that is

very clear in Binford's (1978) unique definition of MNI, or minimum number of individuals (later Binford [1984] changed this to MAU [minimum number of animal units]; see *MNI and MAU per Skeletal Portion* below). His analytic goals were quite different from the traditional ones using taxonomic abundance data, thus his change of the scale of analysis from abundances of individual taxa to abundances of different kinds of skeletal parts of a taxon was a logical one. Many terms listed in Table 1 also designate new quantitative units that are meant to address how an assemblage of faunal remains differs from a set of complete, articulated skeletons. Having identified what I believe to be the reason for the growth of quantitative terminology in zooarchaeology since Casteel and Grayson's (1977) analysis, we come to the issue of outlining some of the problems and ambiguities that have accompanied that growth.

SOME PROBLEMS

[The] appearance of agreement is accentuated by the use of similar terminology, a similarity that is sometimes more apparent than real [Hull 1988:113].

General Issues

In reviewing Grayson's (1984) study of the quantitative units traditionally used to measure taxonomic abundances, Gamble (1985) suggests a major flaw with the study lies in Grayson largely ignoring taphonomic issues. Gamble (1985:404) writes "there is little point in quantifying archaeological samples if you do not know how they were formed." But Grayson (1984) implies we must explain why the quantitative units chosen to measure properties of a particular faunal assemblage take on the abundances they do, and how different measures of abundance are statistically related, if we are to ever determine how an archaeological sample was formed. Thus, while Gamble correctly notes that Grayson did not consider all possible quantitative units used by zooarchaeologists, it should be clear that (1) quantification is a necessary part of any analysis, whether analysis has as its goal answering questions about taxonomic abundances (one of Grayson's [1984:2] foci) or taphonomic histories, (2) statistical manipulation of quantitative data demands that various assumptions about the quantitative units used to create the data be met so that valid statistical tests may be performed (one of Grayson's [1984:2] foci), and (3) the statistical relations of quantitative units (one of Grayson's [1984:2] foci) may have significant taphonomic implications. The last is a fact recognized early on by researchers such as Chaplin (1971), and more recently by Klein and Cruz-Uribe (1984), all of whom examine the ratio of NISP (number of identified specimens) to MNI (minimum number of individuals) as a proxy measure of fragmentation. Considerations, like Grayson's (1984), of the issues involved in quantitative zooarchaeology and taphonomy are clearly important. There are other, equally important, but more subtle and/or more complex issues as well, and I review several of these here.

While many analysts use MAU (minimum number of animal units), some researchers use the term MNI (minimum number of individuals) in a manner similar to, but with a significantly different operationalized meaning than, Binford's (1984) MAU. Klein and Cruz-Uribe (1984; see also Cruz-Uribe and Klein 1986), for instance, derive the MNI for a paired skeletal element by taking the greatest value of either left or right specimens as the MNI value for that element. Binford calculates the MAU per skeletal element by determining the minimum number of a skeletal element, regardless of side, and divides that value by two. For example, a bone assemblage may have 10 left and 5 right humeri; Klein and Cruz-Uribe would tally an MNI of 10 humeri, whereas Binford would derive an MAU of 7.5 humeri. One could, of course, perhaps increase the MNI by considering variables such as size and age variation, which is acknowledged as an option by Klein and Cruz-Uribe (1984; Cruz-Uribe and Klein 1986), but these variables are explicitly ignored by the MAU. The important thing to realize is that neither counting unit is inaccurate; rather, each measures a different property of the faunal assemblage. Issues of comparability arise, however, if a set of MAU values for one assemblage is compared to a set of MNI values (*sensu* Klein and Cruz-Uribe 1984) for another assemblage, because while these quantitative units are often presented in similar form

and are statistically manipulated in similar or identical fashions, they may not have been, and probably were not, derived in similar manners. This is important for taphonomic concerns, as we will see below. It suffices here to simply note that both MNI (*sensu* Klein and Cruz-Uribe 1984) and MAU are analytical units, not observational units. Further, their status as interpretive units is not precisely clear because they both measure, using unique scales, the frequency of skeletal parts, and those frequencies have obscure relations to interpretive concepts (see the discussion of *Hidden Synonymy* below).

Another confusing aspect of the terms for quantitative units in zooarchaeological taphonomy can appear when a shorthand notation is used. Marean and Spencer's (1991:646) use of "MNE/MAU" and "NISP/MNI," for example, is *not* meant to denote ratios, but rather should be read "MNE and MAU," and "NISP and MNI," respectively. That is, no mathematical relationship or function is implied or intended in their notation. However, it is difficult to avoid such a connotation when later in their paper they use the same notation to denote a ratio of the variables on either side of "/" (Marean and Spencer 1991:656). Similarly, Stenton (1991:32) uses the notation "%MNI/MGUI" not to denote a ratio, but rather a bivariate scatterplot of these two variables.

With the preceding paragraphs of this section as a general background, I turn now to what I perceive to be some of the more pernicious problems facing quantitative zooarchaeology today. My discussion focuses largely on those quantitative units and terms enjoying the greatest use in modern zooarchaeological research.

Elements and Specimens

Failure to define the terms "elements" and "specimens" can lead to confusion, as implied earlier. Schick et al. (1989), for example, use these two terms as synonyms. But they also use the terms MNE (minimum number of skeletal elements) and NISP (number of identified specimens), so they must have some implicit notion about a difference between "elements" and "specimens." The difference is obscure, however, because their term TNE (according to footnotes, TNE = NISP) is apparently distinct from MNE. The confusion resides with the "E" in TNE and MNE. In the former, "E" apparently means "specimens" as I defined it above; in the latter, "E" apparently means "skeletal elements" as I defined "element" above.

Some authors use the term "bone fragments" or just "fragments" (e.g., Maltby 1985) when in fact they mean "specimens" as I defined them earlier. Thus, when either of the former two terms is used, what often are included in the tallies are both fragments of skeletal elements and complete skeletal elements (e.g., Davis 1987; Hesse 1982; Klein and Cruz-Uribe 1984; Lasota-Moskalewska and Sulgostowska 1977). "Specimens" seems to be a markedly better term as it tends to have no connotations about the kind of the part of the skeleton being tallied (bone, tooth, horn) or about the completeness of the part. The explicit distinction of elements and specimens is critical to taphonomists concerned with measuring the extent and intensity of bone fragmentation. Measures of fragmentation include NISP:MNE ratios, NISP:MNI ratios, and the like (Table 1). Obviously, if it is not clear what a specimen (or fragment) is and how it differs from a skeletal element, ratios like those indicated will not be replicable and their taphonomic significance will be obscure. For example, both Andrews (1990) and Kusmer (1990) describe equations for calculating the relative abundance of different kinds of skeletal elements that, at first glance, appear to be mathematically similar (see the definitions of R_i and PP in Table 1). However, Andrews uses NISP (number of identified specimens) values in his calculations whereas Kusmer uses MNE (minimum number of skeletal elements) values. This means that were one to detect differences between their respective samples in terms of skeletal part frequencies, one could not determine if those differences were due to variation in quantification method or variation in the taphonomy (especially, the degree of fragmentation) of the samples. This is unfortunate because it is precisely the latter that both Andrews and Kusmer seek to measure.

Because specimens, as defined above, are the fundamental observational units of zooarchaeology, it should be clear that the tenacity and identification skills of the analyst may influence NISP measures. For example, Bunn (1991) reports that he identified an NISP of 137 long-bone ends

whereas Potts (1988) reports that he identified an NISP of 139 long-bone ends in the same assemblage. This indicates that even the counting of bone specimens can produce between-analyst differences. It also seems to contradict Bunn and Kroll's (1988:136) suggestion that "counting bone specimens [is] fundamentally nonjudgmental," because while a countable specimen is often an identifiable specimen, the specimens I can identify may be different from those Potts or Bunn can identify. While interanalyst variation in what is identifiable (and thus countable) has not been studied in detail, I suspect that this source of variation is the least of our worries in quantitative zooarchaeology and taphonomy.

MNE

As noted above, the shift in zooarchaeology to focusing on taphonomic issues has brought with it a shift from measuring frequencies of taxa to measuring frequencies of portions of skeletons of individual taxa, among other things. Many analyses with such a focus use the quantitative unit MNE, or minimum number of (skeletal) elements, or some derivation thereof. An early use of this quantitative unit is found in Voorhies's (1969) seminal monograph on the taphonomy of an early Pliocene paleontological site in North America. He does not use the term MNE but lists what he calls "number of individual skeletal elements represented" for 26 different skeletal elements of an extinct form of antelope, and describes this quantitative unit as "the minimum number of elements (bones) represented by all identifiable fragments of the element in the collection," and distinguishes these values from "the [minimum] number of individual *animals* represented by nonserial paired [skeletal] elements" (Voorhies 1969:17–18; emphasis in original). Given Voorhies's concern with taphonomic processes, his use of an MNE-like quantitative unit was appropriate; the overall number of individual animals was of less analytical importance than trying to understand why some skeletal parts of those animals occurred in high frequencies whereas other skeletal parts occurred in low frequencies (see also the discussion below of *MNI* and *MAU per Skeletal Portion*).

The earliest definition of the term MNE I have been able to find by a zooarchaeologist is in Bunn's (1982) Ph.D. dissertation. Bunn's (1982:35) definition reads "the minimum number of elements," but does not explicitly state whether MNE means the minimum number of *complete* skeletal elements, or, the minimum number of skeletal portions. In citing Binford (1978:69–72), Bunn (1982) seems to imply the latter. Perhaps that is why the term MNE typically is used to signify the minimum number of a particular skeletal portion of a taxon, such as the minimum number of bovid *proximal humeri*, or the minimum number of carpine thoracic *sections* of the vertebral column. No one has, to the best of my knowledge, acknowledged this fact explicitly. We all have depended on the form of data presentation to make it clear that the MNE values we publish are not always of complete skeletal elements, but rather are sometimes of some portion of a skeletal element and other times are of some multiskeletal element portion of a skeleton.

Because MNE is the minimum number of skeletal elements or portions necessary to account for the specimens representing that portion, the same problems plague the derivation of MNE values as plague the derivation of MNI values. One may (e.g., Bunn and Kroll 1988; Hesse and Wapnish 1985; Potts 1988), or may not (e.g., Binford 1984), for instance, take into account age, sex, size, or even taxonomic differences between the specimens for which a minimum number is desired. MNE is therefore an analytical unit rather than an observational unit. The analyst uses some set of criteria by which specimens are considered to be independent (each of two or more specimens represents a separate case) or interdependent (two or more specimens represent the same case).

With zooarchaeological research questions taking an increasingly taphonomic tone, MNE has become an important quantitative unit. This reflects, I think, the fact that taphonomists are concerned with how and why archaeological faunal remains differ from the set of skeletal elements making up the complete skeleton in an organism. Each mammal, for example, has two humeri, two tibia, and seven cervical vertebrae. The relative abundances of different kinds of skeletal elements one observes in an archaeological collection can be compared to the relative abundances of those kinds of skeletal elements in a complete skeleton, or, the number of fragments per one complete skeletal element can be derived. In the former case, explaining why archaeologically observed

frequencies of skeletal elements differ from or are similar to the model of a complete skeleton has proven to be an important and fruitful analytical step (Binford 1978; Lyman 1985, 1991b; and references therein). In the latter case, ratios of NISP to MNE provide a useful analytical unit for measuring the degree of fragmentation of different skeletal elements. It is critical, then, to briefly consider how MNE values are derived from a set of specimens recovered from an archaeological site.

Marean and Spencer (1991:649–650) describe two ways to derive MNE values. One involves measuring the percent of the complete circumference represented by a long-bone shaft fragment, and then summing those percentages for each measured portion of a skeletal element. This is distinct from a method described by Klein and Cruz-Uribe (1984:108) as recording the “fraction by which an identifiable bone is represented [using] common and intuitively obvious fractions (e.g., .25, .33, .5, .67) and not attempting great precision.” The fractions are derived from the epiphyseal ends of long bones rather than long-bone shafts, and are summed to produce an MNE value for each skeletal portion. For instance, if the analyst records one complete proximal femur, a fragment representing one-half of a proximal femur, and a fragment representing one-third of a proximal femur, the sum of the fractions would be $(1.0 + .5 + .33 =) 1.83$, for an MNE of two proximal femora. Marean and Spencer’s (1991) method relatively accurately tallies the total number of bones experimentally subjected to carnivore attrition because such taphonomic agents destroy long-bone ends but not long-bone shafts. This method can, however, result in slight (and probably statistically insignificant) overestimates of the original number of bones present prior to carnivore attrition in at least experimental settings. Klein and Cruz-Uribe’s (1984) method, on the other hand, seems to have some potential for underestimates of what is present in the assemblage of bones lying on the analyst’s table. That is so because their method apparently does not account for overlapping fractions of bone portions, such that if the three proximal femora pieces noted above all include the greater trochanter, then the MNE is not two, it is in fact three. It is perhaps for this reason that the second method mentioned by Marean and Spencer (1991:652) “involves using the computer to count the number of portions with *overlapping sections*” (emphasis added), but they do not describe this method in detail.

Bunn and Kroll (1986, 1988) describe three ways to derive MNE values. The analyst may determine (1) the minimum number of *complete* limb-bone skeletal elements necessary to account for only the specimens with one or both articular ends, (2) the minimum number of *complete* limb-bone skeletal elements necessary to account for only the specimens of limb-bone shafts (without an articular end), and (3) the minimum number of *complete* skeletal elements necessary to account for both the specimens with one or both articular ends and the shaft specimens. These are labeled, respectively, the MNEends, the MNEshafts, and the MNEcomp in Table 2 and, as that table shows and Bunn (1986, 1991) emphasizes, the values are quite different. What is perhaps confusing is that all three kinds of MNE are labeled just that in the literature: MNE values, yet clearly there are significant differences between the three sets of values due to variation in how they are derived. The confusion is exacerbated by the fact that in all but one of Bunn’s (1986, 1991; Bunn and Kroll 1986, 1988) published reports on the FLK *Zinjanthropus* faunal assemblage the MNEends for femora is listed as 6 and for tibiae is listed as 11 while in Bunn and Kroll (1988) those values are easily derived as 8 and 15, respectively, from their data tables. The difference here resides in the higher values resulting from my distinguishing the size class of taxa represented by the specimens, and thus my introducing yet another kind of MNE value, one that takes into account the size of the organism represented by the bones.

Potts (1988) presents MNE values different than those reported by Bunn for the assemblage of bovid bones recovered from the FLK *Zinjanthropus* floor at Olduvai Gorge (Table 2). The difference can probably be attributed to differences between how these two analysts derived their MNE estimates. According to Bunn (1991), Potts derived a value like MNEends whereas Bunn derived MNEcomp values, as defined in the preceding paragraph. Interestingly, Bunn (1991) reports MNE values he derived from Potts’s (1988) book that are different from the values Potts reports, but I cannot find those values in Potts’s (1988) book nor can I determine how Bunn derived those values from Potts’s book. These two simple examples underscore the fact that use of the published record

Table 2. FLK *Zinjanthropus* Bovid Limb-Bone Data.

Skeletal Element	NISP-ends ^a	NISP-shafts	MNEends	MNE-shafts	MNE-comp	MNE-comp
Humerus	30	58	19		20	19
Radius	28	57	14		22	18
Metacarpal	21	32	15		16	14
Femur	14	58	6 (8 ^b)	17 ^b	22	8
Tibia	20	128	11 (15 ^b)	21 ^b	31	12
Metatarsal	24	28	15		16	16

Note: First five data columns from Bunn (1986) and Bunn and Kroll (1986). Last column from Potts (1988:374).

^a Number of identified specimens with one or both ends; the latter are complete.

^b From Bunn and Kroll (1988:142); taxonomic/size differences are accounted for in values in parentheses.

to compare quantitative faunal data can be misleading if the quantitative units used are not explicitly defined and if the methods used to derive quantitative data from the literature are not specified.

I am *not* saying any particular set, or all sets of MNE values listed in Table 2 or those described by Bunn or Potts are correct or incorrect. What I am saying is that each was derived somewhat differently from the others, yet each is, in the original literature, labeled "MNE." In choosing the FLK *Zinjanthropus* assemblage of bovid remains to illustrate this point, I do not intend to call into question anyone's analysis of that assemblage. I chose the assemblage because it is widely published, and the reader of this paper can consult the original publications to further assess the issues discussed here. I suspect the MNE values Bunn (e.g., 1986, 1991) reports are the most comprehensive because they take into account all specimens, including taxonomically nondiagnostic (to the genus or species level) shaft fragments, whereas Binford's (1981, 1988) and Potts's (1988) values apparently do not include shaft fragments. I also suspect Bunn's values are the most trustworthy of the lot because they are consistently reported as the same values across several publications. Potts's (1988) values are not consistently reported within a single publication. For example, in one place he reports the MNE value for proximal radii as 26 and for distal metapodials as 19 (Potts 1988:121), and in another place those values are reported as 27 and 20, respectively (Potts 1988:375).

Of course the ultimate concern here is that the analyst must make clear what is being counted, how it is being counted, and why the specimens are counted the way they are. Part of the key to producing reliable and valid quantitative measures resides in the accurate definition of target populations and sample populations. I touched on this issue elsewhere (Lyman 1982:337) when I indicated that zooarchaeologists interested in determining paleoenvironmental conditions from faunal remains required a measure of the fauna that had been extant at the time of site occupation whereas zooarchaeologists interested in determining prehistoric human subsistence needed to measure the fauna that had been killed. Turner (1983:312–313) made this point more completely when he distinguished among the excavated sample, the killed population, and the living population of animals. The first is the set of faunal remains recovered by the archaeologist from a site; the second is the set of animals procured by the prehistoric occupants of the site; the third is the fauna extant at the time the site was occupied. Turner was concerned with estimating taxonomic abundances within extant faunas (target population) on the basis of excavated samples (sample population), and he made it abundantly clear that the two were not necessarily related or correlated, in part because the killed population (archaeologically sampled population) need not be a random sample of the extant fauna.

Most recently, Ringrose (1993:123) follows other workers (e.g., Clark and Kietzke 1967; Klein and Cruz-Uribe 1984; Meadow 1981; see also Andrews and Cook [1985]) and distinguishes five populations: the living or life assemblage, the death assemblage, the deposited assemblage, the fossil assemblage, and the sample assemblage. The first is comparable to Turner's living population, and

the second is similar but not identical to Turner's killed population because the death assemblage consists of all whole carcasses "available for the bone accumulation agent"—but some of these may not be accumulated (Ringrose 1993:123). Ringrose's sample assemblage is comparable to Turner's excavated sample. Ringrose's deposited assemblage is that portion of the death assemblage that is deposited in a site, and the fossil assemblage is that portion of the deposited assemblage that survives postdepositional processes and is available for the archaeologist to collect. One can, of course, distinguish, as Meadow (1981) does, still other assemblages, such as a "recovered assemblage" which is that part of the sample assemblage that is actually recovered (e.g., some bones may pass through coarse-meshed screens). Another is the "identified or recorded assemblage," which is made up of that portion of the recovered specimens that consists of taxonomically identifiable specimens and/or which are recorded during analysis because they display some significant attribute such as burning or butchering marks. Finally, the "published assemblage" is that portion of the identified or recorded assemblage that finds its way into the written report produced by the analyst. The point to such reductionist considerations, of course, involves the question: Which one or more of these many possible assemblages or populations or samples is validly measured by the various quantitative units at our disposal? Ringrose (1993) provides a thorough exploration of this question and makes it clear that different quantitative units measure different ones of these many kinds of assemblages at varying levels of scale (nominal, ordinal, interval) and validity.

Brewer (1992:207) expresses the matter well when he distinguishes a *target population*, the group of things the analyst wishes to make inferences about, from a *sample population*, what the analyst works with and what serves as the basis of ones' inferences; the "sample population must be relevant to the target population, which in turn must be defined by the questions being asked." That is, there must be concordance between the hypothesis being evaluated, the analytic techniques used, and the counting units that are analyzed. It is, for example, the lack of concordance between MNI (minimum number of individuals) measures of taxonomic abundances and taxonomic abundances in extant faunas that has contributed to the fall from favor experienced by this counting unit. Likewise, it is the lack of concordance between NISP (number of identified specimens) measures of skeletal part frequencies and actual frequencies of skeletal parts resulting from differential fragmentation of skeletal elements that resulted in the introduction of the MNE (minimum number of elements) quantitative unit. We must be clear about the target population the properties of which we wish to infer, and, thus we must consider how the quantitative units we use are related to those properties. As I have suggested before (Lyman 1982:361), we must be explicit about why we have chosen the quantitative unit we have used in our analyses. In other words, we must specify how the quantitative units we use to measure the sample population relate to the quantitative properties of the target population we wish to infer. Such specification should help us determine if the quantitative unit we have chosen is the appropriate one. The critical nature of this issue is well illustrated by the difference between two quantitative units that, superficially, seem to measure the same property of a bone assemblage but which in fact measure rather different properties. It is those two quantitative units we turn to now.

MNI and MAU per Skeletal Portion

Binford (e.g., 1984) has demonstrated and popularized the use of MAU (minimum number of animal units) as an important quantitative unit. The history of this quantitative unit is interesting. Binford began his zooarchaeological studies with a chapter in a book published in 1977. In that chapter he presented quantitative data as "MNI" values, or "the minimum number of individual animals represented by each anatomical part" (Binford and Bertram 1977:79). While one might presume, given this brief description and Binford's terminology, that his MNI values are calculated like White's (see below), they are not. Binford (and Bertram 1977:146) pointed out he was not interested in the quantitative unit signified by the traditional (e.g., Whitean) meaning of MNI, but rather Binford was variously interested in the survivorship of different skeletal parts (Binford and Bertram 1977) and in how humans differentially dismember and transport carcass portions (Binford 1978). Therefore, Binford (1978:70) and Binford and Bertram (1977:146) divided the observed

bone count (MNE) for each anatomical unit (such as proximal femur) by the number of times that anatomical unit occurs in one complete skeleton. They were, in effect, standardizing the observed frequencies of all "anatomical units" according to their frequency in one animal in order to monitor how many of each of several portions of carcasses were represented. Later, Binford (1984:50) made it very clear that his "MNI" values per skeletal portion were not the same as White's MNI values per skeletal portion when he wrote "I have decided to reduce the ambiguity of language by no longer referring to anatomical frequency counts as MNIs," and introduced the term MAU for his standardized frequencies of skeletal parts.

The terminology did not become further confused when Borrero et al. (1985) introduced the quantitative unit MNU, or "minimum number of bone units," a quantitative unit apparently equivalent to MAU. Most analysts have, since 1984, used the term MAU. Bunn (1993:167) has recently suggested that MNU—which he explicitly equates with MAU—is to be preferred because it "is more consistent with conventional usage of other minimum number labels." It remains to be seen if his suggestion is followed.

White (e.g., 1953a) probably can be credited with popularizing the traditional technique for calculating MNI (minimum number of individuals) values among archaeologists and zooarchaeologists, especially those working in the Great Plains of North America (e.g., Dibble and Lorrain 1968; Gilbert 1969; Kehoe and Kehoe 1960; Wood 1962, 1968). He wrote "the method I have used is to separate the most abundant element of the species found into right and left components and use the greater number as the unit of calculation" (White 1953a:397). In fact, in some of his publications he listed not only MNI values per skeletal portion but he also listed MNI frequencies of both lefts and rights of paired bones (White 1952a, 1953c, 1955, 1956), although he did not consistently do so (White 1952b, 1953b, 1954). He suggested that to "divide [the total MNE, or minimum number, of paired elements] by two would introduce great error because of the possible differential distribution of the kill" (White 1953a:397). That is, White suspected some significant within-site distributional data might be masked by calculating what Binford calls MAU values. For example, White (1953c:59) wrote "in most of the features in the sites from which I have identified the bone the discrepancy between the right and left elements of the limb bones was too great to be accounted for by accident of preservation or sampling. This leads one to believe that studies on the distribution of the kill might be profitable." He went on to point out that in comparing, say, bone assemblages from two different houses, the analyst should look "for large discrepancies between the [frequencies of] right and left elements. Small discrepancies are not necessarily significant because they might be due to the accidents of preservation or sampling" (White 1953c:61). White did not suggest how the analyst might statistically distinguish between "great" and "small" discrepancies, nor did he study the spatial distribution of left and right elements in a site. In identifying such analytical avenues, however, White was clearly offering an argument to justify how he calculated MNI values. In fact, White's suggestions concerning the differential distribution of left and right elements of paired bones have been pursued at kill sites on the Great Plains by a procedure known as anatomical refitting (e.g., Todd 1987; Todd and Frison 1992).

White was interested in measuring a variable similar to, but not identical with, the one Binford was seeking to measure. White believed hunters, butchers, and consumers might distinguish between the left and right sides of an animal, and butcher, transport, and distribute the two sides of a large mammal differentially, yet he did not attempt to find evidence for this in any of the bone assemblages he studied. Binford's (1978:70) experience with the Nunamiat suggested to him that "hunters make no such discrimination" between left and right sides of large mammal carcasses. This substantiated his belief that investigating how people differentially butcher, transport, and distribute portions of prey carcasses demanded a counting unit that ignored the distinction of left and right elements, and focused on, say, the number of forelimbs vs. the number of hindlimbs vs. the number of rib cages that were transported. The difference between how White chose to count carcass portions and how Binford chose to count carcass portions is not a trivial distinction. If White is correct in his suspicions that carcasses may have been differentially distributed based on the side of the carcass, then calculating MNI values of both left and right elements and not dividing their sum by two would be more appropriate than deriving MAU values. MAU masks such variation, and, MAU values can

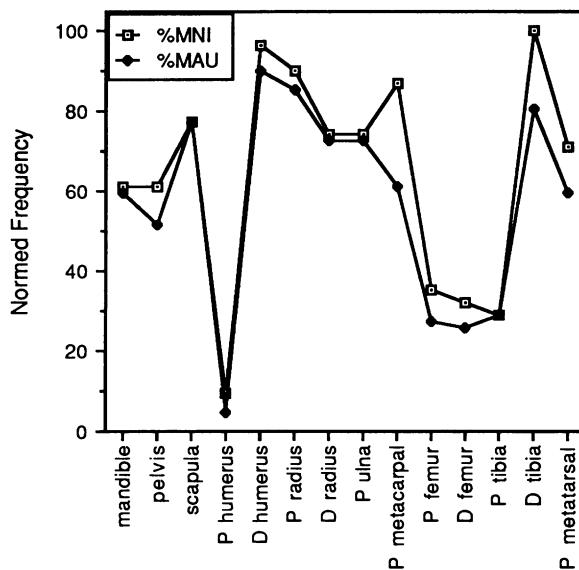


Figure 1. Normed MNI-per-skeletal-portion frequencies and normed MAU-per-skeletal-portion frequencies for pronghorn-antelope remains from 39FA83. Data from Table 3.

be easily derived from frequencies of left and right elements; simply sum the lefts and rights, and divide by two. Note that I am not saying MAU is a poor quantitative unit. It is not, as I indicate in the following section.

Binford (1978, 1981, 1984; also Binford and Bertram 1977) typically norms his MAU-per-skeletal-portion values to what are called %MAU or standardized MAU values. The norming procedure involves dividing all observed MAU values by the greatest observed MAU values and multiplying by 100 to scale the values between 0 and 100. White (1952a, 1952b, 1953b) did not norm the MNI-per-skeletal-portion values in his early publications, but did in his later ones (1953c, 1954, 1955, 1956) using a procedure identical to Binford's, except White normed MNI values rather than MAU values. I suspect White eventually normed his frequencies to allow comparison of assemblages of different sizes. It was not necessary to norm the materials when White was simply describing different assemblages, but in his later publications comparison of assemblages is a major part of his research. White's norming technique was used by other workers for comparative purposes as well (Gilbert 1969; Kehoe and Kehoe 1960; Wood 1962, 1968). Wood (1962) in fact produced graphs of the normed Whitean MNI values much like the graphs used extensively by Binford (1978, 1981, 1984; Binford and Bertram 1977), except Binford graphed MAU values. An example of such a graph, using both Whitean MNI values and Binfordian MAU values, is presented in Figure 1. Data for that graph are based on the pronghorn antelope (*Antilocapra americana*) remains recovered from site 39FA83 and reported by White (1952a) (Table 3).

The graph in Figure 1 is not only of historical interest, but more importantly in the context of this paper, it underscores the difference between the MNI and MAU quantitative units when they are used to measure frequencies of skeletal portions. For example, using the data set from 39FA83, Figure 2 shows that the MAU values for skeletal portions tend to be less than the MNI values for skeletal portions (all plotted points fall below the diagonal line). This is the predictable result when the frequencies of left and right elements differ. While the two sets of values are tightly correlated ($r = .96, p = .0001$), interestingly, the simple, best-fit regression line through the point scatter ($y = -.2931 + .9018x$) has a slope less than 1 and suggests that as frequencies of skeletal portions increase the difference between MNI and MAU values increases. In this case, however, MNI is not correlated

Table 3. Frequencies of Pronghorn Antelope Skeletal Portions from Site 39FA83.

Skeletal Part (A)	MNI Left (B)	MNI Right (C)	MNI (D)	MAU (E)
Mandible	18	19	19	18.5
Pelvis	13	19	19	16
Scapula	24	24	24	24
P humerus	3	0	3	1.5
D humerus	26	30	30	28
P radius	28	25	28	26.5
D radius	23	22	23	22.5
P ulna	23	22	23	22.5
P metacarpal	27	11	27	19
P femur	11	6	11	8.5
D femur	6	10	10	8
P tibia	9	9	9	9
D tibia	19	31	31	25
P metatarsal	22	15	22	18.5

Note: Columns B and C from White (1952a). Column D is the maximum of either B or C. E = (B + C) ÷ 2.

with the difference between the MNI and MAU values ($r = .36, p = .16$), indicating that the difference between the MNI and MAU values does not consistently increase as MNI increases.

Finally, Figure 3 illustrates the differences between frequencies of left (total = 252) and right (total = 243) elements of pronghorn antelope in the 39FA83 collection. The simple, best-fit regression line ($y = 2.7837 + .8096x; r = .72, p < .01$) indicates a slope of less than 1, suggesting increasingly greater differences between the frequencies of left and right elements as frequencies of elements increase. If left and right elements were consistently of equal or near equal frequencies, the best-fit line would be a diagonal line ($y = 0 + 1x$). Herein lies one way to analytically search for what White characterized as "discrepancies" in the frequencies of left and right elements. For example, if points above the diagonal line in Figure 3 represent bones from one archaeological context, and points below the diagonal line represent bones from another context, then perhaps White's suspicion of intrasite differential distribution of the kill is warranted. The question remains, however, are the differences between the frequencies of left and right elements significant, and if so, are such differences found for all paired elements?

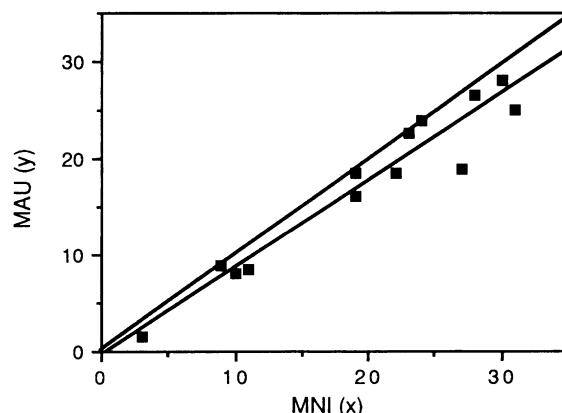


Figure 2. Bivariate scatterplot of MNI-per-skeletal-portion frequencies and MAU-per-skeletal-portion frequencies for pronghorn-antelope remains from 39FA83. Data from Table 3. Lower line is the simple, best-fit regression line.

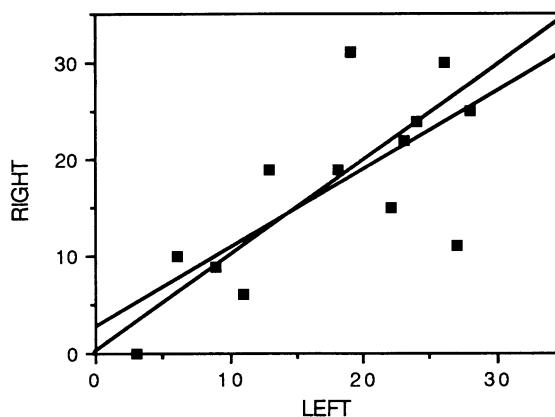


Figure 3. Bivariate scatterplot of MNI-per-skeletal-portion frequencies for left and right skeletal portions of pronghorn antelope from 39FA83. Data from Table 3. Diagonal line has a .0 origin on the y axis; simple, best-fit regression line has an origin of 2.78.

To address the preceding question, I calculated adjusted residuals for each category of skeletal part (Table 4; see Everitt [1977] for a description of the procedure; adjusted residuals are read as standard-normal deviates). That analysis suggests two, or perhaps three of the skeletal parts occur in abundances significantly different from that expected given random chance. There are more left proximal metacarpals and more right distal tibiae (and fewer right proximal metacarpals and fewer left distal tibiae) than chance alone would produce. There may also be more left proximal humeri (and fewer right proximal humeri) than chance alone would produce, but there are so few of this skeletal portion that I worry that sample size may be influencing the result. Regardless of that, it is clear that in this sample the analyst may want to examine the recovery and associational contexts of proximal metacarpals and distal tibiae to determine if, as White suggested, there is evidence for differential distribution of the kill. And, analysis of adjusted residuals provides another way to analytically search for White's "large discrepancies" in frequencies of left and right elements.

The importance of comparing frequencies of skeletal portions as measured by Binford's MAU and White's MNI is that the two units measure different properties of a bone collection. Thus,

Table 4. Observed and Expected (in Parentheses) MNI Frequencies of Pronghorn-Antelope Skeletal Portions from Site 39FA83, and Adjusted Residuals and Probability Values for Each Skeletal Portion.

Skeletal Part	MNI Left	Adjusted Residual	p	MNI Right	Adjusted Residual	p
Mandible	18 (18.8)	-.26	.397	19 (18.2)	.28	.390
Pelvis	13 (16.3)	-1.21	.113	19 (15.7)	1.22	.111
Scapula	24 (24.4)	-.12	.452	24 (23.6)	.12	.452
P humerus	3 (1.5)	1.76	.039	0 (1.5)	-1.76	.039
D humerus	26 (28.5)	-.71	.239	30 (27.5)	.73	.233
P radius	28 (27)	.29	.386	25 (26)	-.30	.382
D radius	23 (22.9)	.03	.492	22 (22.1)	-.03	.488
P ulna	23 (22.9)	.03	.492	22 (22.1)	-.03	.488
P metacarpal	27 (19.3)	2.61	.004	11 (18.7)	-2.62	.004
P femur	11 (8.7)	1.13	.129	6 (8.3)	-1.16	.123
D femur	6 (8.1)	-1.07	.142	10 (7.9)	1.09	.138
P tibia	9 (9.2)	-.10	.460	9 (8.8)	.10	.460
D tibia	19 (25.5)	-1.95	.026	31 (24.5)	1.98	.024
P metatarsal	22 (18.8)	1.09	.138	15 (18.2)	-1.10	.136

Table 5. MNI and MAU Frequencies of Selected Skeletal Parts in Two Sites.

Skeletal Part	Seal Rock Sample		Voorhies's Sample	
	MNI	MAU	MNI	MAU
Maxilla	-	-	250	243
Mandible	-	-	475	469.5
Pelvis	8	6.5	110	104.5
Scapula	2	2	75	70.5
P humerus	2	1.5	234	214.5
D humerus	5	3.5	-	-
P radius	6	4.5	143	142.5
D radius	3	3	-	-
P ulna	5	3.5	46	44.5
P metacarpal	5	4.5	237	218.5
P femur	1	1	64	62
D femur	2	1.5	-	-
P tibia	5	3	261	252.5
D tibia	5	3	-	-
Astragalus	5	3.5	195	179
Calcaneum	9	5.5	203	185
P metatarsal	6	4.5	320	301

Note: The frequencies for Voorhies's sample are for complete skeletal elements rather than just proximal ends. P = proximal; D = distal.

correlations of skeletal part frequencies with either Binford's (1978) utility indexes or a measure of the survival potential of skeletal parts (e.g., Lyman 1984) may be significantly influenced by the counting unit used. Again turning to the 39FA83 data, we find the following Spearman's rho correlation coefficients:

Quantitative Unit	Caribou Utility Index	Bone Density
MNI $r_s =$.73	-.51
$p =$.008	.06
MAU $r_s =$.64	-.53
$p =$.02	.053

This set of correlation coefficients follows the tradition of using ordinal-scale statistics when comparing bone frequencies with a utility index or the structural density of a bone part (e.g., Grayson 1988; Klein 1989; Lyman 1984, 1985, 1991b, 1992). While in this case the coefficients and probability values do not differ greatly whether one uses the MNI values or one uses the MAU values, variation between the coefficients underscores the fact that the quantitative unit used can influence these kinds of statistical results. A clearer example of the significance of the preceding observation is found in the frequencies of deer skeletal parts recovered from the Seal Rock site on the Oregon coast (Lyman 1991a). The MNI frequencies for this assemblage (Table 5) are *not* correlated with the utility index ($r = -.36$, $p = .18$) but the MAU frequencies *are* correlated with the utility index ($r_s = -.52$, $p = .045$). Using the MNI frequencies one *might* conclude the abundances of skeletal parts at Seal Rock were not the result of differential transport, whereas if one were to use the MAU frequencies one *might* conclude those abundances were the result of differential transport.

The preceding two paragraphs call into question analyses such as Klein's (1989) regarding the MNI frequencies of bovid skeletal portions in the Middle Stone Age site of Klasies River Mouth, and Stenton's (1991:31–32) interpretations of "%MNI" frequencies of caribou skeletal portions in Thule sites on Baffin Island in the Northwest Territories of Canada, although it is important to note that Stenton never defines what %MNI means or describes how those values were derived. On one

hand, MAU is the unit of choice for both correlations as it more accurately measures the relative frequencies of paired skeletal parts than MNI when (a) differences between frequencies of left and right elements are great and (b) differences between MNI values per skeletal part are slight, as in the case of the 39FA83 materials. In such cases the chance that the rank orders of the MAU- and MNI-per-skeletal-part values will differ is great. On the other hand, when frequencies of left and right skeletal elements are similar, and the MNI frequencies per skeletal part are quite different, as in the case of Voorhies's (1969) sample (Table 5), the rank orders of the MAU- and MNI-per-skeletal-part values will be similar. For Voorhies's sample, these two sets of values are perfectly correlated ($r = 1.0, p < .001$). In such a case, either MNI or MAU may be used as the quantitative unit to assess differential survivorship or transport of skeletal parts because the two sets of values rank identically. It is unclear which case applies to Klein's and Stenton's respective data sets, and that is what causes me to wonder about the validity of their respective conclusions.

Hidden Synonymy

A final potential problem is what I term "hidden synonymy." That is, two quantitative units may in fact be measuring the same property of a faunal assemblage, yet because they are given different terms and are calculated slightly differently, their mathematical equivalency is masked. The prime example of this is found in the terms %MAU (standardized or normed minimum animal unit frequencies) and %survival (proportion of originally present skeletal parts that survived attritional processes). In the following, the subscript "e" denotes a particular skeletal portion, such as proximal femur, scapula, or thoracic section of the vertebral column.

Brain (1969, 1976) originally calculated %survival in an assemblage as

$$\frac{(\text{MNE}_e)100}{\text{MNI}(\text{number of times } e \text{ occurs in one skeleton})}. \quad (1)$$

It is critical to note that the denominator in Equation 1 tells us how many of skeletal portion e to expect given 100 percent survival, and that it is equal to the maximum MNE value observed in an assemblage. It can thus be written as

$$\frac{(\text{MNE}_e)100}{\text{maximum MNE in the assemblage}}. \quad (2)$$

Equation 1 (and by implication Equation 2) is my reconstruction of Brain's (1967, 1969, 1976) procedure, as he did not use the term MNE (minimum number of elements) nor did he use the term MNI (minimum number of individuals). Brain (1967:4), for example, describes the bone assemblage he studied as variously consisting of long bone "distal ends" and "pieces" of long-bone ends and other skeletal elements and skeletal portions. He gives a good description of the derivational procedure he uses, however, when he writes "in the case of ribs, 26 of which are found in a single goat skeleton, the original number contributed by 64 [= MNI] goats must have been 1,664 [= 64×26]. Only 170 [= MNE] have been found, indicating a 10.2 percent survival" (Brain 1969:18). I presume Brain used a quantitative unit equivalent to MNE in his procedure for measuring %survival because he (Brain 1967:3, 1969:17) gives the number of rib "parts" as 174. Thus, $(170 \div 1,664) 100 = 10.2$ percent. Similarly, while Brain does not use the terms, the NISP for mandibles is given by Brain as 188, the MNE is given by him as 117, and the %survival is given as 91.4 percent ($= [117 \div (2 \times 64)] 100$).

As defined by Binford (1978, 1981, 1984), %MAU is derived with the equation

$$\frac{[\text{MAU}_e]100}{\text{maximum MAU in the assemblage}}. \quad (3)$$

Note that MAU_e is derived with the equation

$$\frac{\text{MNE}_e}{\text{number of times } e \text{ occurs in one skeleton}}. \quad (4)$$

Substituting Equation 4 into Equation 3,

$$\frac{\frac{[\text{MNE}_c \div \text{number of times } c \text{ occurs in one skeleton}]100}{\text{maximum MNE in the assemblage}}}{\div \text{number of times that skeletal portion occurs in one skeleton}}. \quad (5)$$

The denominator in Equations 3 and 5 tells us how many to expect given 100 percent survival, and is dependent on the assemblage under study. The important point to note here is that the expression “ \div number of times c occurs in one skeleton” in the numerator and denominator in Equation 5 will cancel out, and when they do, Equations 2 and 5 are identical.

That Equations 1 and 2 and Equations 3 and 5 are measuring the same property can be illustrated by using Brain's data for the rib and for the mandible. For the rib, Equation 5 is solved as

$$\frac{[170 \div 26]100}{1,664 \div 26} = \frac{[6.538]100}{64} = 10.2\%. \quad (6)$$

For the mandible, Equation 5 is solved as

$$\frac{[117 \div 2]100}{128 \div 2} = \frac{[58.5]100}{64} = 91.4\%. \quad (7)$$

These are precisely the results found when using Brain's procedure, or Equations 1 and 2. The “hidden synonymy” thus resides in how the quantitative units %MAU and %survival are calculated. While such synonymy may have been implied in the past (e.g., Lyman 1985), by explicitly revealing it potential ambiguity may be avoided in the future.

One might suggest that revealing hidden synonymy is an interesting but largely unimportant pursuit given the loftier goals of zooarchaeology and taphonomy. However, in my view, such hidden synonymy is critically important. That is so because, on one level, the interpretive connotation of the term “%survival” suggests the analyst is counting the frequencies of bones that have *survived* some destructive or attritional process (Brain 1969) whereas the majority of analytical contexts in which %MAU is used imply this quantitative unit signifies differential *transport* of skeletal parts, not differential survival. On another, more substantive level, the mathematical synonymy of %MAU and %survival, and the clear difference between MAU and MNI values per skeletal portion, underscore the fact that Klein's (1989) and Stenton's (1991) %MNI-per-skeletal-portion values, because they seem to be defined in Whitean fashion, are not equal to %MAU values and thus are not equal to %survival values, which may compromise their assessments of the frequencies of bone parts at their respective sites.

On a rather practical level, the derivation of quantitative values mathematically equivalent to %MAU and %survival values has undergone much discussion in the paleobiological and taphonomic literature (e.g., Andrews 1990; Kusmer 1990 and references therein). In reviewing that literature I have found six distinct descriptions of how to derive such values. None of these descriptions includes the term MNE or definitions of specimens and elements, and no fewer than four new terms for quantitative units (only two of which are listed in Table 1 here, R_i and PP) are included in those descriptions. The potential for miscommunication about this clearly important quantitative unit and its bearing on determining relative frequencies of skeletal parts seems too great to escape mention.

The quantitative units of choice are %survival and %MAU (or their synonyms) when one seeks to explain skeletal part frequencies as resulting from differential transport or differential destruction. That is so because, as illustrated in Figures 1 and 2, %MNI is a different property than %MAU and %survival, and the differences between the two properties will increase as the frequencies of left and right elements increasingly differ. MNI is a measure of the minimum number of individual animals necessary to account for an analytically specified set of bones by accounting for the side (and perhaps age, sex, and size) of each paired bone. The %survival and %MAU quantitative units measure the relative frequencies of different kinds of bones, and thus do not account for the side (and age, sex, and size) of each paired bone. Two left humeri represent an MAU of 1, but an MNI of 2. When one is interested in determining if frequencies of skeletal parts are the result of differential transport

or differential destruction, the number of individual animals is irrelevant; whether more humeri or more tibiae are represented is paramount. And, because not all bones of the skeleton are paired, the frequencies of skeletal parts must be weighted in order to accurately assess which skeletal parts are abundant and which are rare, compared to their relative abundances within a single complete skeleton. Weighting is accomplished by dividing the observed frequency of each skeletal part by the expected frequency (the maximum possible frequency if all were present), as shown in Equations 1, 3, and 5.

TOWARD CONCORDANCE AND CLARITY

Although terminological distinctions do not solve empirical problems, they frequently facilitate their clear statement so that they can be solved [Hull 1988:217].

In proposing a new quantitative unit for zooarchaeology, Watson (1979:129) wrote “there is nothing sacred about using the complete bone as the unit of study. . . . Any zone [or portion] of a bone [i.e., skeletal element] can be treated as a diagnostic entity in its own right and used for MNI [minimum number of individual] counts.” Watson’s (1979) new quantitative unit was labeled a “diagnostic zone,” the purpose of which was to allow flexibility in interpretation of counts and to avoid counting units with implicit meanings, particularly, I suspect, meanings concerning taxonomic abundances (see, for example, Chase and Hagaman’s [1986–1987] discussion of the influence of “landmarks” on their quantitative unit termed “s”). Similar approaches, which seek to tally the frequency of particular skeletal portions, have become commonplace in zooarchaeological taphonomy, especially in the last decade (e.g., Bunn 1986, 1989, 1991; Bunn and Kroll 1986, 1988; Lyman 1979a, 1979b; Rackham 1986, 1987; Read 1971; Todd and Rapson 1988). I have recently suggested tallying the number of particular, fine scale or small skeletal portions that consist of only a fraction of a skeletal element (Lyman 1992) while Stiner (1991) has suggested counting particular, large-scale skeletal portions that consist of multiple articulated skeletal elements. The lesson here is that, to paraphrase Watson (1979), no counting unit is sacred. What is paramount is that different counting units tally different things, and those things depend not only on how counting units are defined, but how the counting units are operationalized.

Both how quantitative units are defined and how they are operationalized must be explicit in order to ensure concordance between the counting units used and the research question addressed with those units. Some years ago, Mackin (1963) distinguished two basic kinds of quantification in geology. One kind Mackin (1963:137) called a “mechanical” or “blind empirical” quantification which “takes the place of reasoning;” the other he called a rational or well-reasoned quantification. The latter is preferred because, as Mackin (1963:139) notes, with that kind of quantification “the investigator admits to his graphs, so to speak, only items of evidence that are *relevant to the particular matter under investigation*, and that are as accurate as practicable, with the probable limits of sampling and experimental error expressed graphically” (emphasis added). Earlier I suggested I would not attempt to classify various of the quantitative units as either derived or interpretive units because the class to which particular units belonged depended in part on how units were used by different analysts and also depended in part on our understanding of the dynamic or taphonomic properties particular units are believed to measure. This is symptomatic, I think, of Mackin’s blind empirical quantification. We have a plethora of quantitative units and measures, but many of them enjoy unclear statuses as derived or interpretive units. That is so because the relation of many quantitative units to some specific biological or taphonomic property is unclear.

Hull (1988:17) writes “terms are not important. Concepts are. Some scientists can use the same term and mean different things, while other scientists can use different terms and mean the same thing.” Thus the list of 112 terms in Table 1 is not of interest by itself. What is of interest are the definitions. If one studies the definitions, and presumes that the words “elements,” “specimens,” and “fragments” are synonymous, I count no fewer than 122 unique definitions, suggesting there are more analytical units implied than terms listed in Table 1. In other words, several terms have more than one definition (e.g., MNE), and several definitions can be found to be applied to more than one term (e.g., Element MNI = MAU = MNU; %MAU = %survival). It is thus not difficult

to conceive how obscure, implicit, and ambiguous concepts (i.e., poorly defined terms) may bog down the scientific process if for no other reason than the lowered efficiency of communication of research results and implications, and the great potential for misunderstanding.

Given that there are many different counting units, and numerous ways to operationalize those units (e.g., taking ontogenetic age and taxon-size category into account, or not), the question becomes one of asking which counting unit to use, and how to operationalize it, in a particular situation. Here is where a major, two-step research effort should be directed, as it may not be clear which of several units is the appropriate one to use. The first step is to explicitly specify the target population one is trying to measure. That is, what is the quantitative property of interest? Such specification should provide clues as to an appropriate sample population and quantitative units that will allow accurate measurement of the target population's properties. The second step involves actualistic studies geared toward determining which of the analytical units (and how it is, or they are, operationalized) most clearly, consistently, and unambiguously reveal archaeologically detectable patterns that reflect the property (e.g., a particular human behavior) of interest. Such research will allow some of the analytical units to be utilized as interpretive units. Within the realm of actualistic research, the detection and definition of such units can be called "shopping for a scale of measurement." C. K. Brain (1969), for example, detected the important scale of measurement now typically called %survival (or, %survivorship) during ethnoarchaeological research, and that scale is regularly used today to help explain frequencies of skeletal portions in archaeological assemblages. Stiner (1991) likewise described several scales of measurement that allow the identification of taphonomic processes that have influenced archaeological assemblages. But both Brain and Stiner had particular research questions in mind, questions that suggested the kinds of measurement scales and counting units that logically should be used. Neither operated in a strictly inductive or blindly empirical mode, and, importantly, they both were sufficiently clear about how they defined their counting units and how they operationalized them that others can replicate and test their results, as well as evaluate the appropriateness of those counting units for measuring specific properties. The strength of studies such as Brain's and Stiner's is that their quantitative units are reliable or replicable, and the two researchers offer arguments concerning the validity or accuracy (concordance of the measured property with the property they want to measure) of their respective quantitative units. Clearly, reliability and validity of quantitative units are, after all, what are desired.

Casteel and Grayson (1977) proposed a set of sound recommendations regarding the quantitative terminology in use by zooarchaeologists at that time. Those recommendations have not, however, been followed by myself and others. Nonetheless, in comparing an early draft of this paper with Casteel and Grayson's original treatise, one anonymous reviewer suggested that "none of this is really anything new." I agree that my conclusions and suggestions are not particularly new. But, I also emphasize that this does not invalidate or compromise their significance. For example, Bunn (1993:167; see his definition of MNU in Table 1 here) has recently implied that MNI values tallied per skeletal part are the same as MAU values tallied per skeletal part. While this may sometimes be true, the fact that it is sometimes false seems sufficient reason, in my view, to belabor what may be obvious to some zooarchaeologists; such errors are apparently *not* obvious to all zooarchaeologists and thus they warrant continued study. I have no doubt that many more terms and quantitative units will be developed, proposed, and used as we shop for measures of various quantitative properties that allow us to measure attributes of faunal assemblages that are relevant to the research questions we wish to answer. The terminology in Table 1 makes it clear that we must strive for clarity in our discussions of quantitative data. Only then will it be possible to spend less time deciphering what is meant by MNE, bone fragment, and the like, and more time may be spent solving taphonomic and zooarchaeological problems and finding answers to research questions.

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