Methodological Issues in Zooarchaeology

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The main goal of zooarchaeology, as a specialty within archaeology, is to interpret human and environment interactions based primarily on the animal remains recovered from archaeological sites. This chapter is not meant to be a comprehensive text on zooarchaeology; rather it is a guide to some of the analytical methods and terminology that are used commonly by practitioners of zooarchaeology. While each researcher has her/his own way of analyzing and interpreting animal remains, some methods, terms, and analytical tools are considered standard. The purpose of this chapter is to give the reader an overview of basic methodological issues and applications within zooarchaeology. I acknowledge that not all the faunal remains recovered from archaeological sites are related to subsistence activities; however, as the chapters included in this volume are centered on discerning subsistence behaviors through the integration of multiple datasets, I focus more on subsistence practices here. This chapter addresses taphonomic and recovery issues as well as sampling and analytical methods to enable the reader to understand the case studies included in this volume (for a similar treatment of paleoethnobotanical remains, see Wright, this volume).

1 Why Study Zooarchaeology?

Animal remains can be used to inform us about a variety of issues in the study of societies, such as environment, seasonality, subsistence, hunting practices, political and social organization, settlement patterns, and resource-use. As a discipline, zooarchaeology has grown exponentially over the past three decades to include specialists working in dozens of countries on all aspects and time periods of human history (Hesse and Wapnish 1985). The formation and growth of the International Council

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for Archaeozoology (ICAZ), and the growing bibliography of papers, journals, textbooks, manuals, and CD-ROMs that deal with this topic attest to the strength and importance of this discipline. Zooarchaeology (and paleoethnobotany) is one of the few disciplines that crosscuts all cultural and temporal periods in the study of the human condition.

Knowledge of a group's subsistence is key to understanding the relationships between people and their environments, the technologies they create and use to exploit and modify their environments, as well as social and economic relationships amongst the people themselves. Different subsistence strategies reflect a variety of responses to human/environment interactions and human/human interactions. The animals that are represented in the archaeological record have been termed the "fossil assemblage" by Klein and Cruz-Uribe (1984:3), but those that are actually recovered during excavations are a sample of that, and are thus termed the "sample assemblage" (Klein and Cruz-Uribe 1984:3). The larger the sample assemblage recovered, the more robust the interpretation of human activities and choices.

The suite of taxa that are represented in the archaeological record can inform us about habitat exploitation, both in numerical terms (the number of habitats exploited) and in geographical terms (how far people traveled to obtain their food). This is not a straightforward issue, being closely related to the complexity of the human society and also to the ecological and geological history of the area under study. Which ecological niches are favored, and which are ignored? It is fundamental to determine the locations and social complexity of archaeological sites, which can aid in interpreting the importance of resources to human populations. For example, sites located immediately adjacent to rivers and estuaries are better positioned for the inhabitants to exploit these resources than groups located at a distance from the same habitats.

With regard to social complexity, we must take into account that not all citizens of a community procured food for themselves, but would have received foodstuffs via specialist producers, markets, exchange/trade, reciprocity, etc. Gumerman (1994:80) suggests that in more complex societies, such as the Chimu and Wanka of Peru and the Aztecs of Mexico, procurement is directly related to "the context of specialization, the intensity of production, and the personnel involved in production." A number of studies have shown that through analysis of data gathered at the household level, we can understand the differences in diet due to ethnicity, status, gender, or age (Crabtree 1990; Lyman 1987a; McKee 1987; Otto 1980; Peres 2008; Poe 1999, 2001; Reitz 1986, 1987; Reitz and Honerkamp 1983; Reitz et al. 2006; Reitz and Scarry 1985; Schulz and Gust 1983; Scott 2001; see also Peres et al., this volume).

The represented taxa, site location, and duration of occupation can further inform about the scheduling of seasonal resources (e.g., Russo 1991; Russo and Quitmyer 1996; Weinand et al. 2000; see also Bartosiewicz et al., Tóth et al., Hollenbach and R. Walker, all this volume). Procurement technologies such as fishing tackle, digging sticks, and storage items, may be inferred not only from the artifacts found in archaeological contexts, but also from the animal resources (represented taxa, quantity, and size) that were exploited (Kozuch 1993; K. Walker 2000; R. Walker et al. 2001). The presence of small animals in a zooarchaeological assemblage can, through the use of ethnographic analogy, inform us about the types of technologies needed to capture these animals (Cooke and Ranere 1999; Reitz and Wing 2008; Voorhies 2004; Zohar and Cooke 1997). Ethnographic analogy, coupled with archaeological data, also allows us to interpret food processing and food waste disposal behaviors (see also Jones and Quinn, Moore et al., both this volume).

Zooarchaeological remains aid in the interpretations of ancient resource choices, technological adaptations, cultural continuity, and settlement patterns. Thorough studies of human use of past environments must use multiple lines of evidence, the basis of environmental archaeology. Through the study of zooarchaeological data, specialized and utilitarian artifact assemblages, site locations and catchment areas, soils and topography, and stable isotope analysis of human skeletal remains, additional information can be obtained to strengthen or alter these interpretations. For instance, the use of stable isotope analysis of human bone collagen allows for the determination of the environmental origin of the protein resources eaten by an archaeological population. This type of analysis can also give information about continuity and variation in consumed resources through time, between populations, and within a population (Norr 1990; Pate 1992; Scarry and Reitz 2005; Schoeninger 1986; Schoeninger and Moore 1992; Schwarcz 1991; Tieszen 1991; van der Merwe 1989; see also Jones and Quinn, this volume). The study of seasonal-growth increments in the teeth of prey species (especially mammals) (Hillson 1986; Pike-Tay 1991; Pike-Tay and Knecht 1993; Weinand 2000), fish otoliths (Wheeler and Jones 1989), and invertebrates (Quitmyer et al. 1985; Quitmyer and Jones 1992; Quitmyer et al. 1997; Russo and Quitmyer 1996) can give us information about the season when a site was occupied, the scheduling of resource-use, and the age classes targeted.

2 Deposition and Preservation of Animal Remains

When analyzing and interpreting past human behaviors based on zooarchaeological samples, researchers must remember that sample size and preservation quality ultimately influence the outcome. Reitz and Wing (2008:157) state "all primary data are influenced by sample size...[the significance of which] is too frequently" overlooked "by generations of researchers." They, and others, warn that small sample size not only affects the range of taxa identified, but also negatively affects any secondary data derived from the identifications (Cannon 1999; Reitz and Wing 2008). Thus, analysts should do everything they can to ensure the study of large sample sizes, and project directors need to include zooarchaeologists at the earliest stages of planning the research design. Of course, there are samples that were previously excavated and are less than ideal in size, but can still be of value, especially if the site no longer exists and the collection is the only record we have of a group's presence on the planet. As researchers, we need to approach these samples with appropriate research questions, data collection methods, and an understanding of the biases affecting the samples, all of which affect the interpretations based on these samples.

2.1 *Potential Sources of Bias in the Zooarchaeological Record*

As researchers we must identify possible sources of bias to our scientific studies in order to best interpret past human behaviors. There are three types of biases common to zooarchaeological samples: (1) those resulting from socio-cultural beliefs and practices; (2) those introduced as a result of taphonomic history; and (3) those inadvertently introduced by the excavators and/or analysts. These biases form a continuum along the life span of an archaeological assemblage, from selection and deposition of food items by the consumers to the recovery of archaeological remains by the modern-day archaeologist. A number of authors have described these processes in great detail (see Hesse and Wapnish 1985; Lyman 1987b, 1994; Reitz and Wing 2008), and therefore they are reviewed briefly here.

2.1.1 Cultural Transformations: Collecting, Processing, and Disposal of Animal Resources

People selected certain animals and plants from the environment to be incorporated into their diet. Their belief systems, including social organization, food preferences, and taboos, would have defined the organisms included in (or excluded from) the diet (Cooke 1992; Gragson 1992). It is recognized that human groups choose to incorporate a relatively small part of the locally available foodstuffs into their diet; these choices may change on a daily, monthly, or annual basis. The mere absence of an animal from an assemblage does not imply avoidance; likewise, presence of an animal does not imply consumption. Interpreting the diet of human groups, using the presence or absence of animals as a criterion, can lead to a number of difficulties.

Specific food processing techniques, such as butchering, marrow extraction, bone grease rendering, roasting, salting and drying, among others, together with waste disposal patterns, determine which foodstuffs actually make it into the archaeological record (Alen and Ervynck 2005; Enloe 1993; Lyman 1994a; Mateos 2005; Noe-Nygaard 1977; Outram 2005; Saint-Germain 2005; Zohar and Cooke 1997). Areas may be specifically designated for disposal (e.g., kitchen middens) (Wandsnider 1997), or food remains may be scattered about a habitation area. If the purpose of one's research is to understand the environment, such socio-cultural beliefs and practices must be taken into account; but the faunal remains deposited at a site are only part of the larger picture. Once disposed of, remains of animals are acted upon by a score of taphonomic processes.

2.1.2 Taphonomic Processes Affecting Zooarchaeological Assemblages

Recovered faunal assemblages do not include all of the materials that were originally deposited. The taphonomic history, the sum of all conditions acting upon the remains of a dead animal, determines the extent of preservation of that animal in the archaeological record. Taphonomy was first defined by Efremov (1940) in relation to paleontological studies; archaeologists have taken this concept and applied it to the study of the archaeological record. At the very least, taphonomic studies and multiple lines of evidence can help us distinguish between deposits that are culturally deposited and those that are naturally accumulated (Nabergall-Luis 1990; Olsen 1989; Peres 1997; Peres and Carter 1999; Peres and Simons 2006). For example, through research of taphonomy, Nabergall-Luis (1990) has shown that many animals recovered from the Windover site, a well-preserved pre-Columbian cemetery in Florida, were part of a natural death assemblage, as were small animal remains analyzed by Peres (1997; Peres and Simons 2006) from the Pleistocene/Holocene transition site of Page-Ladson in the Panhandle of Florida.

Zooarchaeologists look to taphonomic processes to understand what has aided or inhibited a particular assemblage's preservation, and to gain a perception of what may have been lost. Taphonomic processes that can affect faunal assemblages include (but are not limited to): differential preservation, weathering, site inundation, erosion, redeposition, trampling, scavenging, human actions, soil pH, and plant intrusion (Davis 1987; Klein and Cruz-Uribe 1984; Lyman 1994a; Nabergall-Luis 1990; Peres 1997; Reitz and Wing 2008). It is important to understand the factors that affected a faunal assemblage so that we can better interpret the history of the assemblage and how we ended up with any given sample. Indeed, Lyman (1994a:464) notes: "we can say much about *what* happened to an assemblage…and *how* it happened" (emphasis in the original).

Probably the single-most important non-cultural taphonomic process that operates on a faunal assemblage is differential preservation. Faunal remains can be well-preserved, poorly preserved, or only slightly altered depending on the mode of death (Lyman 1994a:115), specific osteological characteristics (Lyman 1994a:234–258), and the conditions of the surrounding environment (Lyman 1994a:138–139, 146, 358–360). Osteological characteristics can include chemical composition (bone vs. shell), relative maturity and size of the individual, diagnostic landmarks, bone density, and friability. Some environmental conditions that affect preservation are soil acidity, climate, geographical location, and the matrix from which the remains were recovered.

The type of deposit and the geographical location of the deposit will determine which taphonomic processes will be most destructive or preservative. In general, taphonomic processes that must be considered include soil pH, erosion, weathering, and disturbance/dispersal by non-human scavengers. When there is very little evidence of destructive taphonomic processes, the sample assemblage will be a close approximation of the deposited assemblage (Klein and Cruz-Uribe 1984; Dixon 2004; Miller et al. 1998). Conversely if a sample assemblage is poorly preserved, has a high degree of non-cultural fragmentation, and has undergone diagenesis the deposited assemblage is less likely to be represented in its entirety (Klein and Cruz-Uribe 1984).

The conditions of the surrounding site matrix are important in understanding the preservational history of animal remains. While Reitz and Wing (2008:141) urge taphonomists to conduct further research into the effects of soil pH on faunal remains, we do have a basic understanding of this taphonomic agent. Bones are best preserved when the soil has a pH of 7.8–7.9 (Reitz and Wing 2008:141). When pH values rise above 8 (alkaline soils), bone mineral dissolves at higher rates (Linse 1992). When soils become acidic (below 7), greater bone destruction takes place for every degree below neutral (Gordon and Buikstra 1981). Even with less than perfect soil conditions, animal remains decompose differentially. Elements that are not as calcified, such as those from subadults, are the least likely to survive, while adult mammal teeth, due to the presence of enamel, are the most likely to survive (Reitz and Wing 2008). The unprecedented preservation of the zooarchaeological and paleoethnobotanical assemblage recovered from the Oakbank Crannog site in Loch Tay, Scotland, is due to the cold loch waters and peat silt of the loch floor. The preserved organic remains, including plants, seeds, nuts, insects, animal bones, and droppings, number in the cubic tons and provide valuable information about past lifeways and the paleoenvironment of Loch Tay (Dixon 2004:130; Miller et al. 1998). The excellent preservation of organic remains has resulted in a catalog of wooden artifacts ranging from house timbers, fruit seeds, bowls and plates to a dish with butter still adhered to the surface, as well as numerous animal remains that indicate the roles of animals in the subsistence economy of this site (Dixon 2004:146–151; Dixon and Peres 2008).

Zooarchaeological samples that are recovered from shell midden or shell mound sites tend to exhibit a high degree of preservation (Linse 1992). Scudder (1996) has shown that the median soil pH value (7.8) in an Archaic shell midden in southwest Florida is favorable to the preservation of vertebrate and invertebrate remains. Mollusk remains recovered from the Estero Island Site in Florida, and currently undergoing identification by Peres, appear to have undergone rapid deposition with little post-depositional disturbance, exposure, or weathering. This is evidenced by the intact exterior and interior colors and bands on many of the gastropods (especially Florida crown conch, *Melongena corona*). Additionally, even the smallest of vertebrate remains (e.g., Osteichthyes) are well-preserved in shell matrix sites, and easily recovered with small mesh sizes (Peres 2001).

The above should not be viewed as inclusive of all of the taphonomic factors that can affect a given assemblage. Most zooarchaeologists do not, and I am not sure that they should, strive to build a complete taphonomic history of every assemblage in their laboratory. Each assemblage should be evaluated taphonomically in light of the research objectives laid out in the research design. The proper curation of zooarchaeological collections allows them to be studied as new research questions and techniques develop.

2.1.3 Biases of Our Own Making

Appropriate measures must be taken by the archaeologist to limit the extent of excavator bias. The principal investigator, if different from the zooarchaeologist, should consult with the analyst when devising and implementing the research design for an excavation. This will ensure that the optimum methods and techniques are used in the recovery of faunal remains. Too often this has not been the case, and the specialist is sent a box of bones and asked to produce a species list, although this is becoming less common. It is imperative for the zooarchaeologist to know the recovery methods; the origin of the sample (i.e., surface collection vs. feature excavation); the field crew's ability to recognize faunal remains during excavation and screening; where the sample was separated (field vs. laboratory); and by whom the sample was separated (i.e., an individual or several people). This information is needed by the analyst to understand possible sources of bias, and to decide which types of information can be provided by the sample. Unfortunately, our ability to answer pertinent research questions is constrained by samples that are often recovered with inadequate strategies and methods. The importance of consultation with a zooarchaeologist during the project planning stages cannot be over-emphasized.

3 Recovery Methods

> Animal remains are often small and fragile and plant remains are even more so, requiring great care in their recovery and subsequent handling…Because archaeological sites are nonrenewable resources, it is our obligation to recover biological and cultural remains as carefully and thoroughly as possible and to preserve them for study. (Lee A. Newsom and Elizabeth S. Wing 2004 *On Land and Sea*, pp. 36 and 42)

If you are reading this chapter or volume, you are likely to be someone who is interested in the study of past environments and subsistence strategies. You may already know from experience that zooarchaeologists are not consulted often enough when it comes to research design and sample recovery strategy. While there is nothing we can do to compensate for first-order changes (those resulting from past decisions that we in the present have no control over), we must be more assertive in voicing our analytical needs when dealing with project directors. As Reitz and Wing (2008:146) emphasize:

> Advice from people trained in the recovery and study of geological and biological remains allows for better understanding of the excavation strategies by the entire archaeological team and permits assistance by the specialists on recovery methods during the field season.

The decisions made by the archaeologist on sampling and recovery procedures directly affect the type, quality, and quantity of samples available to zooarchaeologists. This in turn affects the types of research questions we can and cannot answer with any given sample. As Reitz et al. (2008:10) note: "Our ability to explore significant questions is influenced by the confidence we have that the material was competently recovered and accurately identified."

3.1 Standard Recovery with Mesh Screens

Choice of recovery method is usually based on two principles: (1) the research objective and (2) the sampling strategy. Of course, these are not independent of one another as the research objectives inform the sampling strategy (i.e., test units, column samples, bulk samples, etc.). In the past, and even in the present, we often deal with research plans that are focused on the recovery of artifacts important to the cultural and temporal association of a site. The standard recovery method at most archaeological sites involves dry-screening excavated soils through 1/4 inch (6.35 mm) hardware mesh. This is especially true when samples are recovered during the excavation of test units using arbitrary levels. This strategy has proven sufficient for the recovery of pottery and lithics, the artifact classes that form the basis of site chronologies. This recovery strategy is used in most places where archaeologists trained in the United States have extended their research efforts. Newsom and Wing (2004:42) note that archaeologists working in the West Indies have shifted their research objectives from cultural chronology to environmental manipulation by humans, which has led to a corresponding change in sampling and recovery strategies, particularly a shift towards the use of smaller mesh sizes.

When reconstruction of subsistence strategies and/or paleoenvironments is the main research objective, archaeologists approach features and middens with a slightly modified recovery plan that can include any, or a combination, of the following:

- Excavation of half of a feature that is dry-screened through 1/4 in. mesh
- Excavation of half of a feature that is dry-screened through 1/8 in. mesh
- Water-screening of half or all of the feature through 1/8 in. (3 mm) or 1/16 in. (1.5 mm) mesh
- Excavation of the entire feature and artifacts recovered using a flotation strategy
- Bulk sampling or column sampling, especially within middens
- Resulting samples screened through nested geological sieves

Any and all of these methods can yield adequate sample sizes for the study of paleoeconomies and paleoenvironments, but it is important that the method (or combination of methods) chosen is done so explicitly under the guidance of a trained subsistence specialist, and is carried out systematically.

A number of studies have been carried out to test the efficacy of recovery methods (Clason and Prummel 1977; Cooke and Ranere 1999; Cumbaa 1973; Gordon 1993; Payne 1972; Peres 2001; Shaffer 1992; Shaffer and Sanchez 1994; Wing and Quitmyer 1985). These experiments show that a decrease in the screen-size used for the recovery of faunal remains results in an increase in the quantity of material and variety of taxa recovered. The use of larger mesh sizes (1/2 in. and 1/4 in.) biases the recovered sample towards larger animals (generally mammals), which can result in a skewed picture of the relative abundance and importance of one class of animals compared to another. The use of 1/8 in. and 1/16 in. meshes allows for a more complete recovery of small, delicate animal remains (i.e., small fishes, shrimp mandibles [*Penaeus* sp.]). These small remains can give us information about the environmental setting of the site during and after occupation, subsistence and technology, and site formation processes (Reitz and Wing 2008:148). Additionally, the standardized use of smaller mesh sizes for the collection of animal remains allows environmental archaeologists to more readily integrate their datasets both quantitatively and qualitatively (as can be seen in case studies throughout this volume).

To highlight the importance of smaller screen sizes in the recovery of smaller taxa, Peres (2001) initiated an experiment using the vertebrate faunal remains from a 50 cm-x-50 cm column sample at the Early Ceramic site of Zapotal in Panama. The soil from each level was screened through nested 1/4 in. and 1/8 in. mesh box-screens. The faunal remains from each screen were then sorted into taxonomic classes (e.g., mammals, birds, reptiles), counted, and weighed. In the most dramatic case, a 5309% increase in quantity of faunal remains from one level was noted between 1/4 in. ($n=53$) and 1/8 in. ($n=2,814$) meshes (Peres 2001:Table 4.1). The results of this experiment support the argument that the use of finer mesh screens during recovery of faunal remains greatly increases the overall abundance. For some levels, certain taxa would not have been represented at all. For example, the bony fishes would have been underestimated in the number of taxa and overall abundance in the entire assemblage (1/4 in., $n=224$; 1/8 in., $n=12,893$). This example shows that using small mesh sizes was an effective recovery strategy for the research questions being asked at Zapotal, and should be considered when devising a recovery strategy during the excavation of all archaeological sites.

3.2 Indirect Evidence of Animal Use in the Archaeological Record

Thus far, I have described techniques for the retrieval of subsistence remains from sediments which are by no means the only source of these artifacts. We can infer past animal use through evidence from extracted collagen and apatite from human bone (Cooke et al. 1996; Norr 1990; Pate 1992; see also Jones and Quinn, this volume), tools related to subsistence activities (i.e., spear points, fish hooks) (e.g., K. Walker 2000), microscopic analysis of residues on ceramic sherds and stone tools (Burgio et al. 1997; Olsson and Isaksson 2008; Smith and Clark 2004); and elemental analysis of sediments (Hjulström and Isaksson 2009). European researchers have shown that the use of Raman microscopy to analyze fragile and perishable ancient materials is ideal because it is reliable, sensitive, and non-destructive in nature (Burgio et al. 1997; Smith and Clark 2004). By taking advantage of the technology available today, archaeologists can look for evidence of past lifeways on a microscopic level, which is extremely important when there is no readily discernible evidence for resource use via traditional artifact classes and analytical methods. For an instructional discussion of different recovery techniques within zooarchaeology, including the positive and negatives of each, the reader is directed to Reitz and Wing (2008:146–150).

4 Specimen Identification and Analytical Methods

A primary objective of any zooarchaeological analysis is to identify as completely as possible all of the represented taxa in a given sample. While care should be taken at all levels of identification, analysis, and interpretation, nowhere is it more important than during the identification stage. O'Connor (2000:39) argues that zooarchaeologists record taxonomic "attributions," meaning "this bone is attributed to white-tailed deer" and not "this bone came from the body of an *Odocoileus virginianus* and cannot be any other animal." Regardless of the terminology used for this stage (i.e., identify vs. attribute), all other units of data are dependent on this first step. The identification of animal remains will only be as good as the skill-level of the analyst and the completeness of the modern comparative osteological collections. Analysts need to secure access to comparative collections and/or collect (and macerate when necessary) modern specimens before they begin their analyses. Several archaeologists have previously distinguished between primary data collection and secondary data derivation (see Clason 1972; Lyman 1994b; Reitz and Wing 2008). These two data categories (primary and secondary) and the types of data recorded in each are discussed in detail below.

4.1 Primary Data Collection

Primary data are the building blocks of all zooarchaeological analyses. The non-quantitative part of primary data includes taxonomic identification; element representation including complete/incomplete portion, anatomical position, etc.; cultural modifications (i.e., cut marks, spiral fractures) and noncultural modifications (i.e., scavenger gnawing); thermal alteration; description of epiphyseal fusion, tooth eruption or wear, and presence of sex indicators (i.e., baculum, medullary bone). Typically, quantitative primary data include specimen counts and weights (see below).

4.1.1 Non-quantitative Primary Data: Identifications of Animal Taxa

Generally, zooarchaeological remains are given to the zooarchaeologist as an assemblage, pre-sorted from the rest of the artifacts. It is important for the analyst to know who did the sorting (and his/her respective skill-level, knowledge, and experience with zooarchaeological materials), where it was performed (field or laboratory), whether the artifacts were washed prior to sorting, and what criteria were used in the sorting (e.g., only elements identifiable by the sorter as animal, etc.). In my experience, the initial sorting of faunal remains into classes often results in the inclusion of a variety of unmodified rocks, lithics, and ceramic artifacts. This always makes me wonder how many and what kinds of faunal remains were left with the other artifact classes (i.e., fish otoliths mixed in with ceramic sherds). Once all of the bags of faunal remains have been sorted, it is good practice to send the nonfaunal artifacts back to the project director and ask for any additional faunal remains to be sent along. Remember, the archaeological assemblage is inherently biased from the start; thus, all attempts must be made to acquire as complete a sample as possible.

The identification and analysis of faunal remains typically follows standard zooarchaeological procedures as set out in Reitz and Wing (2008). Analysis and identification begins with a general rough sort of fauna into classes (Mammalia, Aves, Amphibia, Reptilia, Actinopterygii, Chondrichthyes, Gastropoda, Bivalvia, etc.) within each provenience. Using reference manuals (which should never take the place of a modern osteological comparative collection) and a modern reference collection, remains can then be identified to the lowest taxonomic level (i.e., Family, *Genus, species*). All specimens are identified to *Genus* and *species* when possible, keeping in mind the geographical location of the site so as not to identify a western squirrel in the Eastern woodlands. When this is not practical, the most specific taxonomic classification possible is assigned. In some cases specimens may be identified with "cf." (from the Latin *confere*) before the taxonomic identification (Reitz and Wing 2008:36). In such cases the identification of a specimen is not completely secure, but the specimen compares well with a particular taxon. In addition, it is not always possible to assign a specimen to a species, even if it can be assigned to a genus. In these cases, "sp." is used for species, and "spp." is used if there is more than one species possible (Reitz and Wing 2008:36). In securing identification of taxa, zooarchaeologists should err on the conservative side. Reitz and Wing (2008:164) stress that "specimens should be identified to a particular taxon only if they can be unquestionably assigned to it on the basis of morphological features found through comparison with reference specimens after all other possible attributions are excluded by the same procedure."

In addition to taxonomic identifications, zooarchaeologists also identify skeletal elements/body parts. This involves identifying the specific element (i.e., femur) or element type (i.e., molar) of a given taxon. These are then sided (i.e., left, right) where appropriate. In addition, if the elements are not complete, a description of the portion or fragment is given (i.e., distal humerus, medial scapula). Reitz and Wing (2008:161–164) offer an in-depth discussion of methods for describing specimens in greater detail; for a discussion of cranial fragment categorization, see Hesse and Wapnish (1985:73–74). Data on element representation and fragmentation can lead to interpretations about cultural modifications, taphonomic processes, skeletal part-use, butchery practices, feasting, status, and social structure. Thus, it is important, when time and funding allow, to record as much detail about element representation as possible.

Other types of information that are routinely recorded include evidence of use-wear, thermal alteration, modification, butchering, animal gnawing, and weathering. Whenever possible, age markers of animals should be recorded (i.e., tooth eruption, epiphyseal fusion), and if elements or markers for sex determination are present, these should also be recorded (i.e., a *Canis familiaris* baculum indicates a male dog).

4.2 Quantifying Zooarchaeological Samples

Measuring relative abundance is one of the zooarchaeologist's principle objectives in the collection and quantification of faunal remains. Relative abundance estimates can inform about the importance of particular animals to the diet of a group, change in animal exploitation through time, differences in diet due to status and regional differences (Jackson and Scott 2003; Kirch and O'Day 2003; Klippel 2001; Peres 2001, 2008; VanDerwarker 2006; Walker et al. 2001). Arguments have been made both for and against particular quantification tools, with a common consensus that there is no perfect strategy (Grayson 1984; Jackson 1989; Nichol and Wild 1984; Reitz and Wing 2008). Data should be quantified using tools that will yield the most information from the assemblage. Both primary data (counts and weights) and secondary data (biomass, MNI estimates, and species diversity and equitability) can be used to measure relative abundance in a zooarchaeological sample.

4.2.1 Quantitative Primary Data: Number of Identified Specimens

Quantifying zooarchaeological remains has been, and remains, the keystone upon which all other quantification and statistical analyses of assemblages are based. Taxonomic identifications and specimen counts are the two basic pieces of data that all zooarchaeological analyses should include. The Number of Identified Specimens (NISP), also referred to as count, is the basic quantification unit in zooarchaeological analyses. Each individual bone, tooth, shell, antler, horn, or scale (including complete, partial, and fragmented) is counted as a single unit, regardless of the level of taxonomic identification. Klein and Cruz-Uribe (1984:25) point out two benefits of using NISP: (1) it is calculated during identification, thus it is a basic unit of data and does not need to be further manipulated to have meaning; and (2) "NISP values are additive," meaning the NISP for a given taxon within a given provenience can be readily updated with subsequent excavations or analyses by adding the original number with the new number.

While NISP is the most basic unit of data, it is not without problems. Differential fragmentation is an issue that can result in the overestimation of particular taxa. Some animals have certain skeletal elements that are easily identified more than other animals. For example, pig (*Sus scrofa*) molars are readily identifiable to species even when highly fragmented, allowing for their counts and weights to be recorded as species-specific (Peres 2008). Compare this with the teeth from medium-sized carnivores, which, when fragmented, may only be identified to family or even class. In this instance, pigs would be potentially over-represented when compared to medium-sized carnivores. Additionally, bones of larger animals (typically mammals) are denser, and thus tend to preserve better than the light gracile bones of birds (Lyman 1987b, 1994a; Reitz and Wing 2008).

Reitz and Wing (2008:167–168) provide an indepth discussion on what to count and what not to count, how to deal with crossmends and those specimens that are assigned to more general taxonomic categories (i.e., indeterminate vertebrate). In his synthesizing 1984 work, *Quantitative Zooarchaeology*, Donald Grayson defines the basic means of quantifying faunal samples (NISP) and discusses the extent to which NISP and the more derivative Minimum Number of Individuals (see below) should be used as quantitative measures. Regardless of the method used, Klein and

Cruz-Uribe's warning should be heeded, and count should not be used as the "sole index of species abundance" (Klein and Cruz-Uribe 1984:25).

4.2.2 Quantitative Primary Data: Weights

The recording of the weight (in grams or kilograms) of bone, teeth, antler, otoliths, and shell from archaeological sites is a common practice. This data class is important for several reasons: (1) like NISP, as a basic unit of data it does not need further manipulation to have meaning; (2) it can be used to measure the relative importance of a taxon within an assemblage; and (3) it is the basis for some secondary data measures. There are problems with using sample weights to make substantial interpretations. One of these is the issue of taxa representation and size. Larger animals weigh more than smaller ones; thus if weight is used as a relative measure of abundance, the interpretations will always be biased towards large animals. In addition, this unit of measurement does not compensate for the effects of weathering or thermal alteration on specimen weight. Just as count should not be the "sole index of species abundance" (Klein and Cruz-Uribe1984:25), neither should weight be.

4.2.3 Quantitative Secondary Data: Minimum Number of Individuals

Building on the primary data categories of taxonomic identification, element identification and representation, count, sex, and age, the Minimum Number of Individuals (MNI) can be estimated. MNI is basically the smallest (hence, minimum) quantity of individual animals needed to account for all of the specimens identified to a particular taxon. MNI is widely used by zooarchaeologists and has resulted in the adoption of a variety of techniques (see Reitz and Wing 2008:205–210 for a review of these). I estimate MNI based on the procedure outlined by White (1953) and used by Reitz and Wing (2008). What I consider to be the standard accepted procedure involves using the most abundant diagnostic element of each taxon (Grayson 1984; Reitz and Wing 2008). If this element is paired (left and right), then the higher count of the two is used. Differences in size and degree of epiphyseal fusion are also taken into account when appropriate. Whichever method is chosen, it needs to be explicitly stated in the methods portion of any zooarchaeological report, article, or chapter, and used consistently within an assemblage. As with taxonomic identifications, MNI estimates should be replicable.

4.2.4 Quantitative Secondary Data: Biomass

One area of research in zooarchaeology is the study of the dietary contributions of animals identified in a given faunal assemblage. A number of methods for estimating dietary contributions have been developed, assessed, and modified over the years (e.g., Casteel 1974, 1978; Chaplain 1971; Grayson 1973, 1979; Lyman 1979;

Parmalee 1965; Reitz and Wing 2008; Smith 1975; Stewart and Stahl 1977; White 1953; Wing and Brown 1979). However, the one method that provides information on the quantity of biomass from the materials recovered (sample biomass) is used here. This method is preferred, as it is not based on assumptions of what parts of an animal were considered edible or inedible in the past; rather it is based on a biological relationship that holds true for all organisms over time (Reitz and Wing 2008:239). Thus, all invertebrate and vertebrate specimens identified in an assemblage can be included in dietary contribution estimates.

Sample biomass refers to the estimated total weight represented by the archaeological specimen (Reitz and Wing 2008). Sample biomass estimates are calculated using specimen weights and the regression formula described below. The biomass of an animal is calculated using correlation data between skeletal weight and total body weight (Casteel 1974; Reitz et al. 1987; Reitz and Wing 2008). These data are collected from modern animals for application to biomass estimates. For most faunal assemblages, biomass can be estimated using specimen weight in the following allometric formula (Reitz and Wing 2008:236):

$$Y = aX^b$$

or

$$\log_{10} Y = \log_{10} a + b\,(\log_{10} X)$$

where:

Y = the estimated sample biomass (kg) contributed by the archaeological specimen(s) for a taxon

X = specimen weight of the archaeological specimens for a taxon
a = the Y-intercept of the linear regression line
b = slope of the regression line

To calculate biomass, several values that are class or species dependent are needed. General biomass estimates can be calculated using values from Reitz and Wing (2008:68) and Wing (2001). General class and/or family values should be used in cases where values for specific taxa are not available.

4.2.5 Quantitative Secondary Data: Skeletal Allometry

Allometry is another method to estimate the total body weight of an animal, and is based on the log–log relationship that exists between the dimensions of supportive tissue and total body weight (Anderson et al. 1979; Reitz and Cordier 1983; Reitz et al. 1987; Reitz and Wing 2008). Dimensional allometry is the log–log relationship of the linear dimension of weight-bearing elements and total body weights. Measurements for certain skeletal elements correlate well with body weight and therefore are frequently used. For teleost fishes, the atlas vertebra is a frequently measured element. The atlas vertebra is measured at its widest point, following Reitz and Wing (2008). This measurement can then be used with the biomass formula to calculate the live weights of individual fishes (Y = total weight (gm); X = width of teleost atlas (mm); a = Y-intercept; b = slope).

Allometric data and corresponding weights can be used to infer cohort age or the stage in the life cycle that is represented for an individual taxon. This in turn can inform about the environment that was exploited as well as procurement technologies that were used. The reader is referred to Reitz and Wing (2008:237–242) for an indepth explanation of the various methods used to estimate dietary contributions of animals based on allometry.

4.2.6 Quantitative Secondary Data: Species Diversity for Animals

Ecologists in the second half of the twentieth century have spent much time attempting to explain the multiplicity of Earth's species by comparing the species diversity of different habitats (Colinvaux 1986:650). Colinvaux (1986:650–652) has outlined a number of difficulties or complications in determining species diversity. Objective measures are needed to compare the diversity of different habitats, but these measures have proven difficult to devise, as it is difficult to know which group of species to measure in a sample (e.g., piscivores, pelecypods). This difficulty is compounded in archaeological samples by the fact that, by their very nature, they are not complete representatives of past environments. Another complication with species diversity research is that population sizes vary by location. To overcome the problem of variability, ecologists calculate both *species richness* and *equitability*. Species richness is the actual number of species present in a sample or community. Equitability is the differing relative abundance of each species; a more detailed definition is "the relative evenness of the numerical importance of a species in a sample" (Colinvaux 1986:650). A third difficulty is that no single index measures both richness and equitability. There are several indices that have been used and can be applied to different studies (Colinvaux 1986:651). The best diversity indices are those that express heterogeneity by combining both species richness and equitability (Cole 1994:89).

Zooarchaeologists frequently use the Shannon-Weaver function (sometimes referred to as the Shannon-Weiner function) to address issues of diversity. The formula is:

$$H' = -\Sigma (p_i) (\text{Log}_{10}\, p_i)$$

where:

H' = information content of the sample (can be biomass, MNI, etc.)
p_i = the relative abundance of the ith taxon within the sample
Log p_i = the logarithm of p_i. This can be to the base 2, e, or 10.

By using the Shannon-Weaver function, assemblages with an even distribution of abundance between taxa have a higher diversity than samples with the same number of taxa, but with less even distribution of these taxa. Samples that have a high number of taxonomic categories and a similar degree of equitability have greater diversity values (Reitz and Wing 2008:110–113; see also VanDerwarker, this volume).

A second approach to sample diversity is one which looks at the number of taxa that are expected for a particular sample size, thus allowing us to control the potential bias of sample size. It is reasonable to assume that larger assemblages (in terms of NISP) tend to contain a richer composition of taxa than smaller assemblages (Baxter 2001; Kintigh 1989; Reitz 1987; Rhode 1988). It should not be assumed that larger assemblages with more taxa are more diverse than smaller assemblages with fewer taxa, as richness and equitability may be functions of sample size. To overcome the possibility that sample size biases interpretations of diversity within faunal assemblages, the statistical program DIVERS can be employed (Kintigh 1984, 1989, 1991). The DIVERS program compares the diversities of different assemblages to themselves, based on the expectations for diversity, given the sample sizes. The assemblages are then compared not to each other, but to the expected diversity for a sample of a given size (Kintigh 1984). This allows researchers to bypass the issue of sample size differences completely. The actual values are then plotted against sample size with a 90% confidence interval that is based on the expected values. Values that plot above the confidence interval are more diverse than expected, while values that plot below the confidence interval are less diverse than expected.

5 Summary and Conclusions

Interpretations of zooarchaeological assemblages demand a consideration of a number of criteria. Analysts must be aware of factors, such as sample bias caused by taphonomic conditions and recovery techniques. Of critical importance to any analysis of faunal remains is a concentrated effort to completely recover materials, to take detailed notes on their context(s), and to understand the nature of their associations. This information assists the zooarchaeologist in interpreting the remains in relation to human subsistence strategies (including diet, requisite technology, procurement, processing, and modification) and achieving an understanding of the past environment. Zooarchaeologists need to be included in the planning stages of all archaeological projects, including academic, research, and salvage. It is important for the zooarchaeologist to know the research objectives, the sampling and recovery methods used, the skill level of the field and laboratory crew, and the cultural contexts of the remains. These data are necessary so that we can determine the possible sources of bias, and structure our analysis and interpretations accordingly.

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