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Tallying and Counting: Fundamentals

Early in the twentieth century, paleontologist Chester Stock (1929) was, as he put it, faced with "recording a census" of large mammals from the late Pleistocene as evidenced by their remains recovered "from the asphalt deposits of Rancho La Brea," in Los Angeles, California. Paleontologist Hildegarde Howard (1930) was faced with a similar challenge with respect to the bird remains from Rancho La Brea. Stock and Howard could have merely listed the species of mammals and the species of birds, respectively, that were represented by the faunal remains they had – they could have constructed an *inventory* of taxa – but they chose to do something more informative and more analytically powerful. They tallied up how many individuals of each species were represented by the remains – they each produced a census. The quantitative unit they chose became known as the *minimum number of individuals*, or MNI, a unit that was quickly (within 25 years) adopted by many paleozoologists. We will consider this unit in some detail in Chapter 2, but here it is more important to outline how Stock and Howard defined it and why they decided to provide a census rather than an inventory of mammals and an inventory of birds.

Stock (1929:282) stated that the tally or "count" of each taxon was "determined by the number of similar parts of the internal skeleton as for example the skull, right ramus of mandible, left tibia, right scaphoid. In many cases the total number of individuals for any single group [read *taxon*] is probably a minimum estimate." Howard (1930:81–82) indicated that "for each species, the left or the right of the [skeletal] element occurring in greatest abundance was used to make the count. . . . It is probable that in many instances the totals present a minimum estimate of the number of individuals [per taxon] actually represented in the collection." We will explore why the procedure Stock and Howard used provides a "minimum" estimate of abundance in Chapter 2. Stock and Howard each produced a type of pie diagram to illustrate their respective censuses of mammalian and of avian creatures based on the bony remains of each (Figure 1.1).

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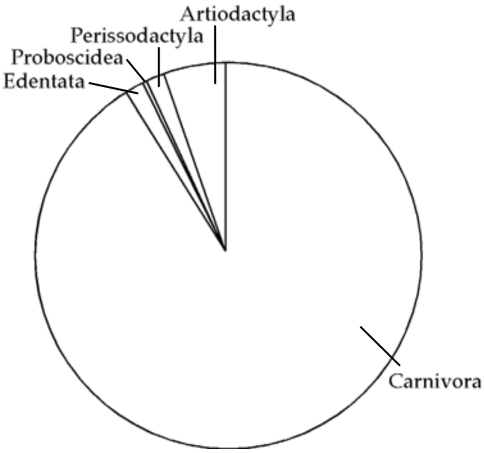

FIGURE 1.1. Chester Stock's pie diagram of abundances of five mammalian orders represented in faunal remains from Rancho La Brea. Redrawn from Stock (1929).

An inventory of the mammalian taxonomic orders Stock identified among the bones and teeth he studied would look like this:

Carnivora
Edentata
Proboscidea
Perissodactyla
Artiodactyla

Clearly, the pie diagram in Figure 1.1 reveals more about the structure of the Rancho La Brea mammalian fauna because it contains not only the same set of taxonomic orders as the inventory, but it also contains measures of the abundances of animals belonging to each order. This example illustrates one of the major reasons why paleozoologists count or tally the animal remains they study. Taxa present in a collection can, on the one hand, be treated as attributes or as present or absent from a fauna, such as is given in the inventory above (sometimes referred to as a "species list" if that taxonomic level is used). On the other hand, abundances of each taxon provide a great deal more information about the prehistoric fauna. There are times when knowing only which taxa are present, or knowing only what the frequencies of different taxa are is all that is wanted or needed analytically. (Two faunas may have the same, or quite different, frequency distributions of individual organisms across taxa, and the research question may only require knowing the frequency distributions and not the taxa.) Knowing both, however, means we know more than when we know just one or the other. And that is a good reason to count faunal remains and to determine a census. Counting faunal remains, particularly old or prehistoric remains, and the variety of attributes they display, whether the remains are from archaeological or paleontological contexts, is what this book is about.

There is already a book about counting animal remains recovered from archaeological and paleontological sites (Grayson 1984), and several other volumes cover some of the same ground, if in less detail (e.g., Hesse and Wapnish 1985; Klein and Cruz-Uribe 1984; Reitz and Wing 1999). Noting this, one could legitimately ask why another book on this topic is necessary. There are several reasons to write a new book. Much has happened in the field since Grayson (1984) published his book (and his book has been out-of-print for several years). Some of what has happened has been conceptually innovative, such as the definition of new quantitative units meant to measure newly conceived properties of the paleozoological record. Some of what has happened has been technically innovative, such as designing new protocols for tallying animal remains that are thought to provide more accurate reflections of what is represented by a collection of remains than tallies based on less technologically sophisticated methods. And, some of what has happened is misguided or archaic, such as arguing that if certain biological variables are not mathematically controlled for, then any count of taxonomic abundances is invalid. It is time (for these reasons) for a new, up-to-date examination of the quantitative units and counting protocols paleozoologists use in their studies.

There is yet another reason to produce a new book on quantitative paleozoology. Today, early in the third millennium, there are more people studying paleozoological collections than there were 20 years ago. These folks need to be able to communicate clearly and concisely with one another regarding their data and their analyses because the use of ambiguous terminology thwarts efficient communication and results in confusion. This point was made more than a decade ago with respect to the plethora of terms, many unfamiliar to those in the field, used for quantitative units in zooarchaeology (Lyman 1994a). Yet, the problem continues today. This problem had originally been identified more than 15 years earlier still by Casteel and Grayson (1977). For whatever reason, terminological ambiguity seems to plague paleozoology and continues to do so despite it being explicitly identified twice in the past 30 years.

In my earlier discussion of terminological ambiguity (Lyman 1994a), I did not advocate a particular terminology, nor am I doing so here. Clearly there are terms I prefer – the ones I use in this volume are the ones I learned as a student. What I am arguing here is that whatever terms or acronyms one uses, these must be clearly defined at the start so as to avoid misunderstanding. In reading and rereading the literature on quantitative paleozoology as I prepared this book, I was often dumbfounded when people used terms such as “bone” and “relative abundance” when it

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was quite clear that they were discussing teeth and absolute abundances, respectively. Much of the remainder of this chapter is, therefore, devoted to terminology and definitions. For quick reference, I have included a glossary of key terms at the end of this volume.

In this introductory chapter, several basic mathematical and statistical concepts are defined. This is necessary because these concepts will be used throughout subsequent chapters and thus the concepts must be understood in order to follow the discussion in later chapters. Several basic paleozoological concepts are introduced and defined for the same reason. I begin with these concepts before turning to the mathematical and statistical concepts.

PALEOZOOLOGICAL CONCEPTS

Throughout this volume the focus is on vertebrates, especially mammals, because that is the taxonomic group which much of the literature concerns and because it is the group with which I am most familiar. However, virtually every thing that is said about quantifying vertebrate remains and their attributes holds with equal force for invertebrates (e.g., Claassen 1998:106–107).

In many discussions of how paleofaunal remains are tallied, and even in some discussions of how modern animal bones should be counted, the reader may encounter the term “skeletal element.” Or, one might encounter the term “bone,” or “tooth,” or “shell,” or any of many other similar, more or less synonymous general terms for skeletal remains. But if one collection comprises ten “bones” of a skeleton and another consists of eleven “bones” of another skeleton of the same species as the first, is the latter more anatomically complete than the former? Is the taxon less abundant in the first collection than in the second? If you think the answer is “Yes” to either question, you might be correct. But you could be wrong if when the analyst tallied specimens no distinction was made between anatomically complete bones and fragments of bones. The lesson is simple. If we are going to tally up skeletal parts and want to compare our tally with that of another analyst working with another collection, we had best be sure that we counted skeletal parts the same way that the other person did. What, then, exactly is a skeletal element?

Paleontologist Michael Voorhies (1969:18) distinguished between “fragments” and “elements or bones,” but we need something more explicit and inclusive because not all skeletal elements are, technically, bones. Some are teeth, some are horns, and some are antlers, and so on. Following Arnold Shotwell (1955, 1958), Donald Grayson (1984) and Catherine Badgley (1986) provide useful terminology and definitions. A

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skeletal element is a complete discrete anatomical unit such as a bone, tooth, or shell. The critical phrase is *complete discrete anatomical unit.* Each such item is a discrete "anatomical organ" (Francillon-Vieillot et al. 1990:480) that does not lose its integrity or completeness when it is removed from an organism. A humerus, a tibia, a carpal, a first lower molar – each is a skeletal element. One might correctly note that "discreteness" depends on the age or ontogenetic stage of development of the organism, but many paleozoologists would not tally the proximal epiphysis of a humerus and the diaphysis of that humerus as two separate specimens if it was clear that the two specimens went together (an issue we return to in Chapter 2). Those same paleozoologists usually don't tally up each individual tooth firmly set in a mandible, along with the dentary or mandible bone. These are potentially significant concerns but may ultimately be of minimal analytical import once we get into tallying specimens.

Not all faunal remains recovered from paleozoological deposits are anatomically complete; some are represented by only a part of the original skeletal element because of fragmentation. Thus, another term is necessary. A *specimen* is a bone, tooth, or shell, or fragment thereof. All skeletal elements are specimens, but not all specimens are skeletal elements. A distal humerus, a proximal tibia, and a fragment of a premolar are all specimens that derive from skeletal elements; phenomenologically they are not, technically, anatomically complete skeletal elements. *Specimen* is an excellent term for many counting operations because it is value-free in the sense that it does not reveal whether specimen A is anatomically more complete, or less complete, than specimen B. We can record whether specimen A is anatomically complete, and if it isn't, we can record the portion of a complete element that is represented by a fragment, if our research questions demand such. *Specimen* is also a better generic term than *skeletal element* for the individual skeletal remains we study because *skeletal element* implies that a complete anatomical unit is represented. The problem with the terms "bone" and "tooth" and the like are that sometimes when analysts use them they mean both anatomically complete skeletal elements as defined here and incomplete skeletal elements. Failure to distinguish the two kinds of units – skeletal element and specimen – can render separate tallies incomparable and make the significance of various analyses obscure. Throughout this volume, I use the term *skeletal part* as a synonym for *specimen*, but whereas the latter is a general category that can include many and varied anatomical portions, skeletal part is restricted to a particular category of anatomical portion, say, distal humerus. *Skeletal portion* is sometimes used in the same category-specific way that skeletal part is but will usually mean a multiple skeletal element segment of a skeleton, such as a forelimb.

Henceforth, in this volume, *specimen* will be used to signify any individual skeletal remain, whether anatomically complete or not. Unfortunately, the terms "skeletal

Table 1.1. *An example of the Linnaean taxonomy*

Taxonomic level	Taxonomic name	Common name
Kingdom	Animalia	Animals
Phylum	Vertebrata	Vertebrate
Class	Mammalia	Mammals
Infraclass	Eutheria	Placental mammal
Order	Carnivora	Carnivores
Family	Canidae	Canids
Genus	*Canis*	Dogs, coyotes, wolves, and allies
Species*	*latrans*	coyote

*Technically, the species name is *Canis latrans*; *latrans* is the specific epithet.

element" and "element" are still often used to denote anatomically incomplete items. An effort is made throughout this book to make clear what exactly is being tallied and how it is being tallied. In this respect, what are usually tallied are what are termed "identified" or "identifiable" specimens. Typically, this means identified as to biological taxon, usually genus or species, represented by a bone, tooth, or shell (Driver 1992; Lyman 2005a). To identify skeletal remains, one must know the structure of the Linnaean taxonomy, an example of which is given in Table 1.1. One must also know the basics of skeletal anatomy, by which is meant that one must know the difference between a scapula and a radius, a femur and a cervical vertebra, a clavicle and a rib, and so on. Finally, the person doing the identifications must be able to distinguish intertaxonomic variation from intrataxonomic variation. *Intrataxonomic variation* is also sometimes termed "individual variation" within the species level of the taxonomy. I presume that readers of the book know these things, along with anatomical location and direction terms used in later chapters.

The importance of the requirements for identification should be apparent when one realizes that "identification" involves questions such as: Is one dealing with a mammal or a bird? If it is a mammal, is it a rodent or a carnivore? If it is a carnivore, is it a canid, a felid, a mustelid, or any of several other taxa of carnivores? The importance of the other knowledge requirement – basic skeletal anatomy – will assist in answering the questions just posed. The importance of distinguishing intertaxonomic from intrataxonomic variation is usually (and best) met by consultation of a comparative collection of skeletons of known taxonomic identity. The procedure is simple. Compare the taxonomically unknown paleozoological specimen with comparative specimens of known taxonomy until the best match is found. Often the closest match will be obvious, and the unknown specimen is "identified" as belonging to the same taxon as the known comparative specimen. Sometimes this means that

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one may be able to determine the species represented by the paleozoological specimen, but other times only the genus or perhaps only the taxonomic family or order will be distinguishable.

Taxonomic identification is a complex matter that is discussed at length in other contexts (e.g., Driver 1992; Lyman 2005a; and references therein). Blind tests of identification results (e.g., Gobalet 2001) highlight the practical and technical difficulties. For one thing, what is "identifiable" to one analyst may not be to another (e.g., Grayson 1979). Gobalet (2001) provides empirical evidence for such interanalyst variation. It is precisely because of such interobserver differences and the interpretive significance of whether, say, a bone is from a bobcat (*Lynx rufus*) or a North American lynx (*Lynx canadensis*) that paleontologists developed a standardized format for reporting their results. Specimens (not necessarily anatomically incomplete skeletal elements) are illustrated and are verbally described with taxonomically distinctive criteria highlighted so that other paleontologists can independently evaluate the anatomical criteria used to make the taxonomic identification. Zooarchaeologists have been slow to understand the importance of this reporting form (see Driver [1992] for a noteworthy exception). This is not the place to delve further into the nuances of taxonomic identification and how to report and describe identified specimens. What is important here is to note that skeletal remains – faunal specimens – are usually tallied by taxon. "There are X remains of bobcats and Y remains of lynx." So, identification must precede tallying. To make taxonomic identifications, one must first determine which skeletal element is represented by a specimen is order to know whether the paleozoological unknown should be compared to femora, humeri, tibiae, and so on. And sometimes the frequencies of each skeletal element or each part thereof are analytically important.

The final paleozoological concept that requires definition is *taphonomy*. The term was originally coined by Russian paleontologist I. A. Efremov (1940:85) who defined it as "the study of the transition (in all details) of animal remains from the biosphere into the lithosphere." Although not without precedent, Efremov's term is the one paleozoologists (and an increasing number of paleobotanists) use to refer to the processes that influence the creation and preservation (or lack thereof) of the paleobiological record. We will have reason to return again and again to this basic concept; here it suffices to note that a taphonomic history concerns the formation of an assemblage of faunal remains. Such a history begins with the accumulation and deposition of the first specimen, continues through the deposition of the last specimen, through the preservation, alteration, and destruction of remains, and up to collection of a sample of the remains by the paleozoologist (see Lyman [1994c] for more complete discussion). Along the way, faunal remains are modified, broken, and even destroyed. The modification, fracture, and destruction processes create and destroy different kinds of phenomena the observation of which can generate quantitative data.

A final note about how paleozoological data are presented in the book. Capital letters are used to denote upper teeth, lower case letters to denote lower teeth, and a lowercase d to denote deciduous premolars. Thus, a permanent upper second premolar is P2, a deciduous lower third premolar is dp3, and a lower first molar is m1. The capital letter L is used to signify the left element of bilaterally paired bones, and the capital letter R is used to signify the right element. In general, D stands for distal, and P stands for proximal. The critical thing to remember is the difference between a *specimen* and a *skeletal element*; both terms will reappear often in what follows, and both kinds of units can be identified and tallied.

MATHEMATICAL AND STATISTICAL CONCEPTS

This book is about quantification, but the topics covered include different sorts of quantification, particularly counting or tallying units, methods of counting, and analyzing counts. A term that might have been used in the title of the book, were it not for its generality, is *measurement*. Typically this term is defined as assigning a numerical value to an observation based on a rule governing the assignment. The rule might be that length is measured in linear units of uniform size, such that we can say something like “Pencil A is 5 cm long and pencil B, at 10 cm of length, is twice as long as pencil A.” *Measurement* more generally defined concerns writing descriptions of phenomena according to rules. An *estimate* is a measurement assigned to a phenomenon (making a measurement) based on incomplete data. The process of *estimation* can involve judging how tall someone is in centimeters without the benefit of a tape measure, or studying a flock of birds and suggesting how many individuals there are without systematically tallying each one. Making estimates, like taking measurements, is a way to describe phenomena. Descriptions involve attributes of phenomena that may or may not have numerical symbols or values associated with them. Whether they do or not concerns what is often referred to as the scale of measurement of the attribute that is under scrutiny.

Scales of Measurement

Stock’s census of Rancho La Brea mammals (Figure 1.1) illustrates that quantitative data describing taxonomic abundances are more revealing than taxonomic

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presence–absence data. Quantitative data often are subjected to a variety of mathematical manipulations and statistical analyses. Those manipulations and analyses are only valid if the data are of a certain kind. Four distinct scales of measurement are often distinguished (Blalock 1960; Shennan 1988; Stevens 1946; Zar 1996), and it is important that these be explicitly defined at the start because they will be referred to throughout the book.

Nominal scales of measurement are those that measure differences in kind. Of the several scales they contain the least amount of information. Numbers may be assigned to label nominal scale phenomena, such as 0 = male, 1 = female; or 11 = quarterback, 32 = fullback, and 88 = wide receiver on a football team. Or, numbers need not be assigned, but rather labels used such as Italian citizen, French citizen, and German citizen; or coyote (*Canis latrans*), wolf (*Canis lupus*), and domestic dog (*Canis familiaris*). Nominal scales of measurement do not include an indication of magnitude, ordering, or distance between categories, and are sometimes labeled *qualitative attributes* or *discontinuous variables*. They are qualitative because they record a phenomenon in terms of a quality, not a magnitude or an amount. They are discontinuous (or discrete) because it is possible to find two values between which no other intermediate value exists; there is (normally) no organism that is halfway between a male and a female within a bisexual species. Other scales of measurement tend to be quantitative because they specify variation more continuously. *Continuous variables* are those that can take any value in a series, and there is always yet another value intermediate between any two values. A tally of skeletal specimens of coyote in an archaeological collection may be 127 or 128, but there won't be a collection in which there are 127.5 or 127.3 or 127.924 specimens of coyote. But the lengths of coyote humeri are continuous; think about the numbers just noted as millimeters of length.

Ordinal scales of measurement are those that record greater than, less than relationships, but not the magnitude of difference in phenomena. They allow phenomena to be arranged in an order, say, from lesser to greater. "I am older than my children" is a statement of ordinal scale difference, as is "The stratum on the bottom of the stratigraphic column was deposited before the stratum on the top of the column" and "A year is longer than a month." There is no indication of the magnitude of difference in my age and the ages of my children, or in the length of time between the deposition of the bottom and top strata, nor in the duration of a year relative to the duration of a month. Instead, we only specify which phenomenon is older (or younger), or which was deposited first (or last), or which is longer in duration (or shorter). Sometimes when one uses an ordinal scale, measurements are said to be *relative* measurements because a measure of phenomenon A is made relative to phenomenon B; A is older/shorter/heavier than B. Ordinal scale measurements may be (and often are said to be) *rank ordered* from greatest to least, or least to greatest, but the magnitude of distance between any two measurements in the ordering is unknown. Ordinal scale measurements are discrete insofar as there is no rank of “first and a half” between the rank of first and second (ignoring tied ranks).

Interval scales of measurement are those that record greater than or less than relationships and the magnitude of difference between phenomena. Both the order of measurements and the distance between them are known. My children are 23 and 25 years old; I am 56 years old, so I am 33 and 31 years older than my two children, respectively. The stratum on the bottom of the stratigraphic column has an associated radiocarbon date of 3000 BP and the stratum on top has an associated date of 500 BP, so the stratum on the bottom was deposited about 2,500 (^{14}C) years before the stratum on top (assuming the dated materials in each stratum were formed and deposited at the same time as the strata were deposited). On average, a year is 365.25 days long whereas an average month is about 30.4 days in duration; the difference in duration of an average year and an average month is thus 334.85 days. The distance between 10 and 20 units (days, years, centimeters) is the same as the distance between 244 and 254 of those units, the same as the distance between 5337 and 5347 of those units, and so on. Interval scales are typically used to measure what are referred to as *quantitative variables*. Interval scale measurements, like ordinal scale ones, can be rank ordered from greatest to least, or least to greatest, but unlike with ordinal scale measures, the distance between any two interval scale measurements is known. Indeed it must be known else the variable is not interval scale. Interval scale measurements are generally continuous but may be discrete. If age is recorded only in whole years, then age is continuous but it is also discrete (ignoring for the sake of discussion that one might be 53.7 years old). Importantly, interval scale measures have an arbitrary zero point. It can be 0°Celsius outside, but there is still heat (if seemingly only a little) caused by the movement of molecules. The zero point on the Celsius scale is placed at a different location along the continuum of amount of molecular movement than is the zero point of the Fahrenheit temperature scale. Both zero points are arbitrary with respect to the amount of heat (molecular movement), thus both measures of temperature are interval scale.

Ratio scales of measurement are identical to interval scales but have a natural zero. Thus, the theoretical natural zero of temperature is –273° Celsius (or 0 Kelvin, or –459° Fahrenheit). There is no molecular movement at that temperature. Similarly, a mammal in a cage comprises 1 individual consisting of more than 100 bones and teeth, but if the cage is empty there are 0 (zero) individuals, 0 bones, and 0 teeth in the cage. Thus, if a taxon is represented by 0 skeletal specimens in an assemblage, it is