Prehistoric Archeology and Ecology
A Series Edited by Karl W. Butzer and Leslie G. Freeman

# Current Paleoethnobotany

## Analytical Methods and Cultural Interpretations of Archaeological Plant Remains

*Edited by*
Christine A. Hastorf and
Virginia S. Popper

The University of Chicago Press
Chicago and London

# 5

# Ratios in Paleoethnobotanical Analysis

Naomi F. Miller

Ratios provide a simple means of standardizing data. If we understand the assumptions underlying their use, we can construct ratios that are appropriate for inter- and intrasite comparisons.

Archaeobotanists use standardizing ratios to compare (1) samples of unequal size, (2) samples differing in circumstances of deposition or preservation, and (3) quantities of different categories of material that are equivalent in some respect. Although it is easy enough to calculate a ratio, assigning a valid paleoethnobotanical meaning to it is quite another matter. We use our knowledge of archaeology and related fields to choose variables and units of measurement that are appropriate to the problem under consideration. Further discussion about choosing appropriate variables will appear in later sections with reference to particular examples.[1]

For clarity of presentation only, I divide the ratios commonly used by paleoethnobotanists into two general types. For the first type of ratio, the material represented by the numerator is included within the material represented by the denominator. Density measures, percentages, and proportions are in this group. For the second, which I call *comparison ratios*, the numerator and denominator are composed of mutually exclusive items, such as nutshell and charcoal, or wheat and barley. The only numerical restriction in constructing a ratio is that the denominator not be zero.

1. For example, if *Setaria* was not eaten, then its increase or decrease in the archaeobotanical record is not directly relevant to questions about diet.





## Densitites, Percentages, and Proportions

One of the most basic ratios for paleoethnobotanists is density, where the denominator (sometimes called the *norming variable* [Mueller, Schuessler, and Costner 1974]) is the total volume of the sediment sample from which the plant remains were extracted. Typically, density is expressed as the number of charred items or the weight of the charred material in a given amount of sediment. It is largely a matter of convenience whether one uses count, weight, or some other unit of measurement. The basic assumption of density ratios is that all things being equal, larger sediment samples have more plant remains. By choosing volume of floated or processed sediment as the norming variable against which another variable can be measured, one can test the assumptions of uniform deposition, preservation, and recovery rates.

Asch and Asch use a density measure to compare rates of fuel consumption at simple village sites. They record similar densities of charred material from different *cultural features* and therefore suggest that wood use occurred at a fairly constant rate (1975:117).

Pearsall (1983:129) tests the proposition that density of charred remains is a measure of intensity of occupation. She finds that the density of charred botanical material corresponds fairly well with other archaeological measures of intensity of occupation through much of the 8,000-year history of the Pachamachay rock shelter high up on the Peruvian puna. However, a level characterized as a special purpose campsite had little archaeological material, yet had a high density of charred material. Pearsall therefore concludes that density of charred material measures intensity of activity involving fire rather than intensity of occupation.

Interpreting density measures is a little more complicated at Malyan, an ancient urban center in southern Iran (Miller 1982). First, Malyan's inhabitants burned fuel not only for cooking and heating but possibly for metallurgy and pottery firing as well. Second, some charred material was redeposited and dispersed during the thousand-year occupation of this multicomponent urban site. Much of the site consists of eroded mud brick. The density of charred material in these deposits is usually very low (less than 0.05 g/liter of sediment). Many hearths also have low densities of charred remains, which suggests they had been cleaned out in antiquity. By comparing the density of a hearth deposit with control samples from low-density mud brick collapse, I can assess how likely it is that a particular hearth contains in situ charred material. At Malyan, deposits with a relatively high density of charred material inform us about particular burning or ash-dumping episodes, but not about the overall intensity of burning activity on the site.

Another use for the measure *density of charred material* is as a test of seasonality in regions with a marked cold season. At Sharafabad, an ancient town in southwestern Iran, archaeological evidence and ethnographic analogy suggest that seasonal differences in garbage disposal practices account for the stratigraphy of a large pit (Wright, Miller, and Redding 1981). The seasonal interpretation is consistent with the seed evidence. A common seed source on Iranian sites is dung fuel (Miller and Smart 1984); at Sharafabad, "winter" strata average 28.72 to 30.55 seeds per liter of sediment, while "summer" strata average 6.35 to 9.00 seeds per liter of sediment.

Percentages and proportions are other forms of ratios in which the numerator is a subset of the denominator. A percentage is simply a proportion multiplied by 100. To compare the importance of one taxon relative to other taxa from sample to sample, paleoethnobotanists frequently use percentages to standardize the contents of each sample. In contrast to density measures, the numerator and denominator must be expressed in the same unit of measurement.

Paleoethnobotanists use percentages (or comparisons; see below) of functionally equivalent items to detect replacement of one category of material by another, through time or along a geographical cline. For example, Minnis (1978:359) identifies a period of agricultural expansion on the floodplain of the Mimbres valley, New Mexico, by comparing the charcoal percentages (based on counts) of *floodplain woods : total species of wood* in each time period. During times of relatively low population, a large percentage of the charcoal was from floodplain types; this suggests that trees grew in the floodplain then and were chopped down. In contrast, low percentages of floodplain wood during the later Classic Mimbres period indicate that the inhabitants had cleared the floodplain for agricultural land and obtained wood in other habitats.

Percentages are also used to assess variability between samples due to circumstances of preservation. For example, Green (1979:42-43) compares the percentages of plant taxa from dry and waterlogged contexts on medieval urban sites. He observes that cereal grains comprise less than 1% of the waterlogged seeds from floors but make up 31% of the charred seeds from floors. In contrast, there are no waterlogged cereals from aerobic pits, but cereals comprise 87% of the charred seeds from this context. Not only do "different types of features preserve different evidence" (1979:42), but different taxa are not equally likely to be preserved in different contexts.

Seed assemblages from different preservation contexts can be compared on other grounds, too. At Malyan, charred seeds are mostly from animal dung burned as fuel, and mineralized seeds are from latrine deposits; barley represents 92% of the identified charred cereal remains but only 33% of the



mineralized grains (data available in Miller 1982). This suggests that animals ate more barley than wheat, and that humans ate more wheat than barley.

## Comparisons

Comparisons, the second type of ratio I have designated, compare relative amounts of two different items. Comparisons focus attention on two mutually exclusive variables. They can be used to assess the effects of different preservation contexts or to identify different use contexts.

*Seed : charcoal* and *nutshell : charcoal* ratios are popular; they use charcoal or nutshell weight, count, or volume as the norming variable (Bohrer 1970; Asch and Asch 1975; Johannessen 1984; Pearsall 1983). On sites where it is reasonable to assume that charcoal represents ordinary, domestic fuel use (rather than, say, burning of structures), paleoethnobotanists put charcoal in the denominator to control for likelihood of preservation. As Bohrer (1970:423) notes, if seeds are preserved accidentally, "a greater concentration of burned seeds in a volume of charcoal should signify increased use."

The following example shows why, for investigating plant use, charcoal rather than sediment volume is the relevant norming variable (table 5.1). If nuts are as likely to fall into a domestic fire in one time period as another, a lower absolute density (*nutshell : sediment volume*) from one time period may just indicate that the charred remains from the fire were mixed with other material and dispersed. The quantity of nutshell relative to charcoal could indicate that nut use increased.

Hillman (1984:32-38) uses comparison ratios in his ethnographic model of grain processing. He observes that sieving removes only small weed seeds from a grain sample, and manual sorting is necessary to remove cereal-sized weed seeds. A simple comparison ratio-number of cereal-sized *weed seeds : number of prime grains* --can distinguish these two sorting

Table 5.1. Hypothetical example

| Nut (g) | Charcoal (g) | Sediment Volume (liters) | Nut/ Sediment Volume | Nut/ Charcoal |
|---|---|---|---|---|
| 1.0 | 2.0 | 1 | 1.0 | 0.5 |
| 1.0 | 0.5 | 2 | 0.5 | 2.0 |

practices; sieved grain has many large weed seeds and a ratio greater than 1 : 20, but hand-sorted grain generally has a ratio of less than 1 : 20 (Hillman 1984:34). These results can be applied to suitable archaeobotanical assemblages.

The numerator of a comparison ratio need not be expressed in the same unit of measurement as the denominator. Usually convenience dictates the choice of unit. For example, when seed weight is low, counts of whole seeds may provide a more accurate estimate of importance than weight. In contrast, since we cannot reconstruct the number of whole nuts from nutshell fragments, we may use the weight of the fragments. *Seed count : nutshell weight* will differ from *seed weight : nutshell weight*. However, assuming seed counts and weights are correlated, the comparisons are equivalent.

For some problems, comparison ratios and proportions are interchangeable. Because ratios cannot have zero in the denominator, we sometimes change a comparison ratio to a proportion. For example, wheat : barley (w : b) provides the same basic information as w : b + w. The latter differs only in not assuming all samples contain barley.

## Constructing Ratios

### Homogeneity

Let us say you want to estimate the fruit consumption of today. You can combine counts of apples and oranges eaten into one homogeneous variable, *fruit*. If, however, you add watermelon to your list of fruits, you will seriously skew your estimate, since one watermelon represents many portions of these other fruit types. To make the *fruit consumption* variable homogeneous, you could simply total the estimated number of watermelon portions that are equivalent to one apple or one orange and proceed. For paleoethnobotanists, who deal with more complex issues, it is a little harder to define homogeneous variables a priori.

Paleoethnobotanists use analytical categories that range from a single taxon to the sum of all botanical materials in a given sample. We frequently lump together taxa deemed similar in function, habitat, or other specified characteristics. To answer some questions, we combine species into ecological groups, as Minnis (1978) does with floodplain species in the charcoal and land use study mentioned earlier. Or following Hillman (1984), we combine taxa by seed size to identify the sieved by-products of crop processing.

Ideally, a composite variable combines equally durable and functionally equivalent taxa whose use remains constant through time. For ratios like *seed : charcoal*, where the numerator or denominator comprises more than one taxon, the composite variables must be homogeneous to accurately measure patterning in an archaeological assemblage. Even if the taxa are all members of one functional category, such as food, they may be represented by different plant parts. In this case, homogeneity cannot be assumed, and one may ask whether it is legitimate to use a conversion factor to create a theoretical comparability among disparate plant parts (see below).



Whatever the question, it may be difficult to decide which characteristics are valid when combining taxa. For example, will different breakage patterns of nut or charcoal remains mask important relationships between the numerator and the denominator (see below; cf. Lopinot 1984)? Will differential seed production of weedy species distort the numbers of weed seeds relative to grains? Because we may err in assuming that particular types of plant remains are similar on ecological or functional grounds, or that they are equally preservable, we should spell out the assumptions we have made. The reader will then be able to evaluate the argument presented.

Asch, Ford, and Asch (1972) use *seed : nutshell* to document increasing utilization of seeds relative to nuts in the Woodland period. They standardize against nutshell rather than charcoal, presumably because nuts are food items. They reasonably assume that the amount of nutshell, a regularly burned refuse product, is proportional to nut use. They use *seed count : nutshell weight* in order to compare relative quantities of seeds between sites: "At Koster, the seed/nut ratio is estimated as 230 seeds/1040 g. nuts = 0.22; at Macoupin the ratio is estimated as 2314 seeds/278 g. nuts = 8.32. The ratio of seeds to nuts is thus 38 times greater at the Middle Woodland Macoupin site than at Koster" (Asch, Ford, and Asch 1972). Asch, Ford, and Asch (1972) do not think that changes in preservation and burning conditions account for this increase. Although seeds and nuts may fall into a fire for different reasons, they assume that the circumstances of burning remained constant through time. Therefore, the increase in *seed : nutshell* reflects changing food preference.

Lopinot (1984:192) cautions against the uncritical use of *seed : nutshell* ratios in cultural interpretations. He points out that cooking practices affect seed preservation. A change from seed parching to boiling could lead one to "significantly underestimate the intensity of seed use relative to nuts" during the Woodland period, if preservation of seeds by burning depends on cooking accidents.

The homogeneity of a composite variable also depends on the physical properties of its constituents. For example, Lopinot (1984:134ff.) shows that acorn is more likely to fragment and turn to ash than a denser nutshell, such as hickory. Acorn would therefore be underrepresented in a mixed sample, because other nuts are preserved better. Since archaeobotanists are less likely to examine and identify nut fragments smaller than 2 mm, recording procedures biased against smaller fragments can also underestimate a taxon such as acorn. Thus, even if overall nut use was constant, an increase in acorn use relative to sturdier nuts could appear archaeologically as a decline in total nutshell density. In the Koster example cited above, acorn is a fairly minor component of both early and late assemblages, validating Asch, Ford, and Asch's (1972) original conclusion.

## Conversion Factors

Conversion factors can improve the homogeneity of a composite variable. A valid conversion factor reduces the effects of ancient cultural practices or physical properties that make some plants or plant parts not comparable to one another.

Sometimes calculations are based on the analog of the archaeozoologists' "minimum number of individuals." The paleoethnobotanist estimates the actual percentage of different foods in a prehistoric diet by converting disparate plant parts to equivalent whole edible plants. MacNeish (1967) introduced this approach to diet reconstruction in the Tehuacan report (see recent revisions, Farnsworth, Brady, DeNiro, and MacNeish 1985; see also Pozorski 1983). The use of dietary equivalents has some serious flaws, however. It assumes that the archaeologist knows which plants were used as food and that there are no serious absences due to sheer unpreservability or localized absence of particular types of food remains not brought onto the excavated portion of the site (see Hastorf, chapter 8, for a discussion and critique of this method; also Begler and Keatinge 1979; Dennell 1979; Lopinot 1984:193). It also does not distinguish trash (e.g., a corn cob) from food (e.g. corn kernels).

A more acceptable use of conversion factors restricts comparisons to similar categories of remains. For example, to estimate the relative importance of different nuts in the diet, Lopinot (1984:150-52) recommends converting nutshell weights to an estimate of nutmeat weight. The nutmeat equivalent is based on the charred nutshell weight multiplied by two experimentally derived conversion ratios (table 5.2). Given the high fragmentation rate of acorn, the converted values might be very different from the unconverted ones. For example, Lopinot concludes that although hickory and acorn represent 87% and 13% by weight, respectively, of the charred nutshell from the early Archaic of the lower Little Tennessee Valley, the equivalent weights and presumed dietary importance of the uncharred nutmeats would be 11% and 89%, respectively. Used with caution, a conversion factor can bring out a significant pattern of plant remains in an assemblage. It is, however, important to report the conversion factor or the original data on which the estimated quanities are based.



Table 5.2. Equation for calculating nutmeat equivalent from charred nutshell

NUTMEAT = (X) (C) (M)

X: charred nutshell (g)

C: uncharred nutshell (g)/charred nutshell (g)

M: uncharred nutmeat (g)/uncharred nutshell (g)

*Source*: Lopinot 1984:151.

## An Example

It is sometimes difficult to develop analytical categories appropriate to one's own research. For example, in search of patterning in the distribution of archaeobotanical materials from Malyan, I calculated a modified *seed : charcoal* ratio (Miller 1982; Miller and Smart 1984). The ratio I used is a proportion. The numerator is the weight of the seeds (S), and the denominator combines total charred material weight (seed and charcoal, S + C). I did not use charcoal alone because I could not assume all samples would contain charcoal. And because seed weight was negligible for most samples, I did not think adding seed weight to the denominator would significantly alter the value of the ratio.

Independent archaeological evidence suggested all burning took place in controlled fires of hearths, ovens, kilns, and perhaps a few trash deposits as well; no structures were burned. I therefore assumed all the charcoal was spent fuel. Prior to the analysis, however, I did not know the role of cultigen and weed seeds in the assemblage. The ratio therefore combined two disparate categories in the norming variable, fuel and possibly food remains.

Despite my weak justification for combining seeds and charcoal, the resulting ratio documented a major shift. The ratio S : S + C increased tenfold over the thousand-year occupation of the site. Through subsequent ethnoarchaeological research, I discovered that seeds from dung fuel could easily be preserved in contexts analogous to those found archaeologically. I concluded that the higher values of S : S + C could be explained by the increasing use of dung fuel relative to wood. This change in fuel was probably a result of tree clearance, an interpretation supported by the charcoal analysis (Miller 1985).

In retrospect, I uncovered this pattern of seed distribution because S + C was a homogeneous and appropriate variable—most seeds and all charcoal represented the same depositional context, that is, fuel use.

Recalculating the ratios without nutshell and grape pips—items which probably did not come from dung fuel—does not change the results.

## Characterizing Archaeological Assemblages With Ratios

Archaeobotanists use ratios to describe and characterize plant remains, whether they are from a series of sediment samples, a group of excavated deposits, a whole site, or a series of sites. Frequently the analyst averages the results from several samples to simplify the discussion of the material.

### Is Averaging Appropriate?

In combining samples to obtain an average value, one assumes that samples grouped together contain material from the same population. In the paleoethnobotanical context, this means that circumstances of deposition and preservation are not so wildly different as to make the samples incommensurable. For example, if charred material from a hearth and a pit represents fuel remains, the samples may be combined for analysis; if, on the other hand, the pit has a cache of charred seeds and the hearth contains charred firewood, it makes little sense to obtain an average of the two deposits. Similarly, combining the values of *nutshell : charcoal* from a hearth and a burnt structure may conflate a *food : fuel* ratio with a *food : building material* ratio. Thus it may be that a group of samples is so disparate in character that they should not be averaged together.

### Calculating Average Ratios

Calculating average ratios is not always straightforward. First, the average of two ratios is not equal to the ratio of the sum of the denominator and the sum of the numerator. In addition, because of the vagaries of excavation and preservation, one may want to give unequal weight to the various deposits when constructing a combined or average ratio.

As table 5.3 shows, average ratios are based on the individual sample ratio (in this example, *seed : charcoal* expressed as S/C) multiplied by various weighting factors. Think of the two samples as coming from two different deposits. The weighting factor for each sample is a proportion, the sum of which is equal to 1.

Equation 1 in table 5.3, a simple numerical average, assumes that the two samples are equally important for providing a fair representation of the archaeological deposits. For example, one might have a series of pits or hearths thought to be filled with similar material, like burned trash.

Equation 2 takes a different tack. Conceptually, if one is not sampling archaeological deposits so much as sampling the botanical materials preserved in them, it makes sense to give more weight to the samples that

Table 5.3. Examples of calculating average ratios

| | *Sample 1* | *Sample 2* |
|---|---|---|
| Seed weight | $S_1$ | $S_2$ |
| Charcoal weight | $C_1$ | $C_2$ |
| Sample volume | $V_1$ | $V_2$ |
| Volume of total deposit | $D_1$ | $D_2$ |
| Set the values of the variables: | $S_1 = 1$<br>$C_1 = 2$<br>$V_1 = 1$<br>$D_1 = 2$ | $S_2 = 2$<br>$C_2 = 3$<br>$V_2 = 3$<br>$D_2 = 1$ |

| | Weighting Factor | Average | Value |
|---|---|---|---|
| *Equation 1* | none | $\frac{1}{2}\left(\frac{S_1}{C_1} + \frac{S_2}{C_2}\right)$ | 0.58 |
| *Equation 2* | charcoal weight | $\frac{C_1}{C_1+C_2}\left(\frac{S_1}{C_1}\right) + \frac{C_2}{C_1+C_2}\left(\frac{S_2}{C_2}\right) = \frac{S_1+S_2}{C_1+C_2}$ | 0.60 |
| *Equation 3* | sample volume | $\frac{V_1}{V_1+V_2}\left(\frac{S_1}{C_1}\right) + \frac{V_2}{V_1+V_2}\left(\frac{S_2}{C_2}\right)$ | 0.62 |
| *Equation 4* | deposit volume | $\frac{D_1}{D_1+D_2}\left(\frac{S_1}{C_1}\right) + \frac{D_2}{D_1+D_2}\left(\frac{S_2}{C_2}\right)$ | 0.56 |

contain more material. In this example, I assume that the charcoal is the remains of fuel, so charcoal quantities reflect the amount of wood burning. The weighting factor is the proportion of charcoal contained in each sample. Sample 1 contains two-fifths of the charcoal, so its contribution to the average S/C value is weighted accordingly. The astute reader will recognize this commonly used ratio. It reduces to a simple summing of the numerators and denominators of a series of samples. Although one's first impulse may be to use this easily calculated ratio, equation 2 is not appropriate if there is no particular reason to weight by the denominator variable (charcoal, in this example).

Equation 3 is a weighted average that recognizes that some sediment samples are larger than others. It would be useful in the following situation: the excavator has provided you with two sediment samples of different size from one unstratified pit. In order to compare the first pit with others from which only one sample was obtained, the average of the first two samples weighted by the amount of sediment examined is appropriate. Equation 3 is particularly useful for evening out discrepancies in sample volume from various deposits prior to calculating a general average for the group as a whole.

Equation 4 weights the samples by the total volume of the deposits from which they come. It would be useful (in theory) for estimating ratios involving the total quantity of charred material on a site or excavated portions thereof. Ordinarily that is not an estimate paleoethnobotanists are particularly interested in, so weighting by deposit volume has relatively little utility.

The foregoing examples illustrate some of the choices involved in calculating an average ratio for a group of samples. Researchers have to decide whether their samples are uniform enough for comparison, and whether or not a particular weighted average will correct for sample variability.

## Summary

Ratios allow us to compare archaeobotanical samples despite the inherent variability in the processes of deposition, preservation, recovery and analysis of plant remains. The choice of ratio used will depend on the question one is asking. In practice, numerically different ratios are sometimes used to answer similar questions. Initial quantification may point out unexpected peculiarities or consistencies in the data. Paleoethnobotanists should therefore be alert to the assumptions behind their use of ratios and be flexible enough to adopt new assumptions when the old ones prove inadequate. To allow others to evaluate our use of ratios, we should report the raw data on which they are based.



Although I cannot make a general statement about the utility of the various ratios discussed in this chapter, not all uses of ratios are equally valid. Density of botanical material is one of the most important and basic measures for interpreting depositional and preservational variability. Proportions and comparisons are particularly useful for identifying the replacement of one functional or ecological type by another. Combining disparate taxa in the numerator or denominator is problematic, because it is so difficult to control for all of the variables attendant upon the use of the necessary conversion factors.

Finally, one must ask the following questions every time one uses a ratio in a paleoethnobotanical analysis: (1) What will a particular density, proportion, or comparison measure in a given assemblage? (2) Are the variables chosen relevant to the question asked? (3) Are assumptions of the equivalence of use and preservability among taxa and among deposits warranted?

Although we may not always be able to answer these questions, ratios serve an important function in paleoethnobotanical analysis. In our search for spatial and temporal patterning, numerical methods which help to reduce the complexity of our data and isolate key changes in them are useful tools that allow us to move beyond simple comparisons and general overviews.

## Acknowledgments

I am grateful to Donald Strickland of Southern Illinois University, Edwardsville, for sharpening my thinking about ratios, and for his incisive comments on earlier versions of this paper. He was the "astute reader" who pointed out that equation 2 is a variation of equation 1. I would also like to thank Deborah Pearsall, Virginia Popper, William Macdonald, Neal Lopinot, and an anonymous reviewer for their useful comments, and finally Christine Hastorf and Virginia Popper for suggesting a broader topic than I had originally envisioned.

## References Cited

Asch, Nancy B., and David L. Asch. 1975. Plant remains from the Zimmerman Site—Grid A: A quantitative perspective. In *The Zimmerman site*, ed. M. K. Brown, pp. 116-20. Springfield: Illinois State Museum Reports of Investigations 32.

Asch, Nancy B., Richard I. Ford, and David L. Asch. 1972. *Paleoethnobotany of the Koster site: The Archaic horizons*. Springfield: Illinois State Museum Reports of Investigations 24.

Begler, Elsie B., and Richard W. Keatinge. 1979. Theoretical goals and methodological realities: Problems in the reconstruction of prehistoric subsistence economies. *World Archaeology* 11:208-26.

Bohrer, Vorsila. 1970. Ethnobotanical aspects of Snaketown, a Hohokam village in southern Arizona. *American Antiquity* 35:413-30.

Dennell, Robin W. 1979. Prehistoric diet and nutrition: Some food for thought. *World Archaeology* 11:121-35.

Farnsworth, Paul, James E. Brady, Michael J. DeNiro, and Richard S. MacNeish. 1985. A re-evaluation of the isotopic and archaeological reconstructions of diet in the Tehuacan Valley. *American Antiquity* 50:102-16.

Green, Francis. 1979. Collection and interpretation of botanical information from medieval urban excavations in southern England. In *Festschrift Maria Hopf*, ed. U. Körber-Grohne, pp. 39-55. Cologne: Rhienland-Verlag GMBH.

Hillman, Gordon C. 1984. Interpretation of archaeological plant remains: The application of ethnographic models from Turkey. In *Plants and ancient man*, ed. W. van Zeist and W. A. Casparie, pp. 1-41. Rotterdam: A. A. Balkema.

Johannessen, Sissel. 1984. Paleoethnobotany. In *American Bottom archaeology*, ed. Charles J. Bareis and James W. Porter, pp. 197-214. Urbana: University of Illinois Press.

Lopinot, Neal B. 1984. Archaeobotanical formation processes and Late Middle Archaic human-plant interrelationships in the midcontinental U.S.A. Ph.D. diss., Department of Anthropology, Southern Illinois University. Ann Arbor: University Microfilms.

MacNeish, Richard S. 1967. A summary of the subsistence. In *Environment and subsistence: Prehistory of the Tehuacan Valley*, vol. 1, ed. D. Byers, pp. 290-309. Austin: University of Texas.

Miller, Naomi F. 1982. Environment and economy of Malyan, a third millennium B.C. urban center in southern Iran. Ph.D. diss., Department of Anthropology, University of Michigan. Ann Arbor: University Microfilms.

_____. 1985. Paleoethnobotanical evidence for deforestation in ancient Iran: A case study of urban Malyan. *Journal of Ethnobiology* 5: 1-19.

Miller, Naomi F., and Tristine L. Smart. 1984. Intentional burning of dung as fuel: A mechanism for the incorporation of charred seeds into the archeological record. *Journal of Ethnobiology* 4:15-28.



Minnis, Paul E. 1978. Paleoethnobotanical indicators of prehistoric environmental disturbance: A case study. In *The nature and status of ethnobotany*, ed. Richard I. Ford, M. Brown, M. Hodge, and W. L. Merrill pp. 347-66. Anthropological Papers no. 60. University of Michigan, Museum of Anthropology.

Mueller, J. H., K. F. Schuessler, and H. L. Costner. 1974. *Statistical reasoning in sociology* 2d ed. Boston: Houghton Mifflin.

Pearsall, Deborah M. 1983. Evaluating the stability of subsistence strategies by use of paleoethnobotanical data. *Journal of Ethnobiology* 3:121-37.

Pozorski, Shelia. 1983. Changing subsistence priorities and early settlement patterns on the north coast of Peru. *Journal of Ethnobiology* 3: 15-38.

Wright, H. T., N. F. Miller, and R. W. Redding. 1981. Time and process in an Uruk rural center. In *L'archéologie de l'Iraq: perspectives et limites d'interpretation anthropologique des documents.* Paris: Colloques Internationaux du C.N.R.S. 580:265-82.