

RE-EXAMINATION OF THE STATISTICAL METHODS USED TO DETERMINE THE NUMBER OF POINT COUNTS NEEDED FOR MICROPALAEONTOLOGICAL QUANTITATIVE RESEARCH

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ABSTRACT—Currently some controversy exists in the micropaleontological community concerning the statistically correct number of counts required for quantitative examinations, particularly with respect to the effect of variations in the number of species between samples and the significance of varying fractional abundances on the reliability of results. This analysis of the various statistical methods used to determine the number of required counts has shown that the number of species has no relationship to the number of counts required to measure accurately fractional abundances. As part of the study, logarithmic contours plotting percentage abundance against the total number of specimens, which provide abundance errors at a 95 percent confidence level, have been generated. The plot is displayed logarithmically to emphasize the significance of rare microfossil elements that dominate most assemblages, and which are important in many paleoenvironmental studies. Based on the plot, it is recommended that researchers utilize counts of at least 50 for indicator species having a fractional abundance of approximately 50 percent or greater; 300 counts for species which comprise approximately 10 percent of a sample; 500-1,000 counts for species that make up 5 percent of a sample; and counts of several thousand for defining species that comprise 1 percent of a sample. It is important to note, however, that where similar biofacies are involved, higher counts are required to accurately distinguish them. It is also recommended that researchers include fractional error abundances with their estimated abundances to provide an indication of their accuracy.

INTRODUCTION

FOR VARIOUS practical reasons, micropaleontologists typically examine only a certain proportion, or split, of the total microfossil population in any given sample. The number of specimens examined varies from researcher to researcher, depending on the degree of precision required for a particular study. The absolute number of specimens generally examined varies between 200 and 1,000 per sample. However, most workers usually count approximately 300 specimens. This latter figure was propounded by Phleger (1960) who, based on experience and on an equation derived by Dryden (1931) for counting heavy mineral grains, suggested that 300 specimens provided sufficient accuracy for most quantitative examinations.

Modern paleoceanographic studies utilize the relative abundance of various foraminiferal species such as *Nuttalides umbanifera* (Cushman, 1933), an indicator of Antarctic Bottom Water, and *Fonbatia wuellerstorfi* (Schwager, 1866), often associated with North Atlantic Deep Water, although many such indicators often make up less than 5 percent of the 300 specimens typically observed in samples (e.g., Schroder et al., 1987; Sen Gupta et al., 1988). From research, and as a result of conversations with colleagues with regard to the utility of such indicators, it was determined that a re-evaluation of the statistical base utilized in determining the number of counts required for micropaleontological quantitative examination was in order. Although much of the information presented in this paper is

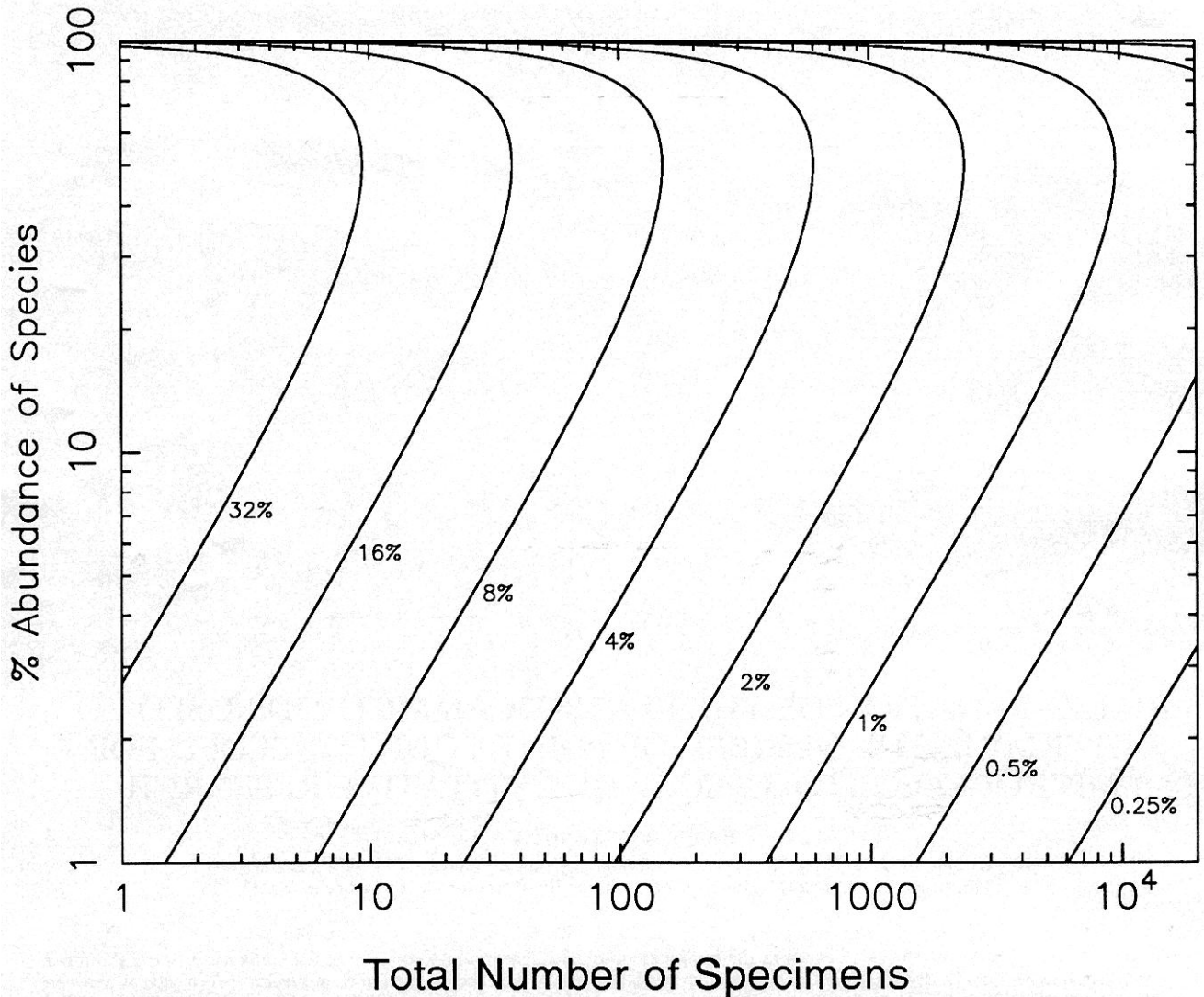


FIGURE 1- Percentage abundances versus total numbers of species plotted logarithmically. Contours are constant 95 percent confidence level errors calculated from equations (2) and (3) in text.

readily available in a variety of statistics texts, there is still considerable confusion in the micropaleontological community regarding the statistical significance of rare species, and whether variation in the total number of species between given samples has any bearing on the number of counts required.

In this paper the statistical literature is reviewed to determine the reliability of previously presented point counting statistics (Dryden, 1931; Van der Plas and Tobi, 1965; Wright and Hay, 1971) and a logarithmically scaled abundance chart is presented emphasizing, as is most common in nature (Buzas et al., 1982), the rarer elements of micropaleontological assemblages.

DISCUSSION

The question of whether variation in the total number of species present in different samples has any bearing on the number of counts required will first be addressed. When quantitatively examining a sample, a micropaleontologist seeks to obtain estimates of the species abundance fraction X_i for each of the $i = 1, 2, \dots, I$ species contained in a particular sample, where I is the total number of species contained in that sample, and i is each particular species. After having counted N specimens,

the probability of simultaneously counting n_j specimens of each of the I species obeys the multinomial distribution (Bhattacharyya and Johnson, 1977):

$$P(n_1, n_2, n_3, \dots, n_i) = \frac{n_1!n_2!n_3 \dots n_i!}{(N - n_1)!(N - n_2)!(N - n_3)! \dots (N - n_i)!} X_1^{n_1} X_2^{n_2} \dots X_i^{n_i} \tag{1}$$

where $(N = n_1 + n_2 + \dots + n_i)$.

It is felt that X_i is equal to its expected value n_i/N . The error that $E(X_i)$ deviates from X_i is normally distributed with a standard error s_{X_i} , equal to

$$s_{X_i} = [X_i(1 - X_i)/N]^{1/2} \tag{2}$$

and is independent of the number of species (equation 2). Thus, after making (N) counts, our estimate of X_i lies within

$$X_i - 1.96s_{X_i} \leq f_i \leq X_i + 1.96s_{X_i} \tag{3}$$

95 percent of the time regardless of the number of species (equation 3).

TABLE 1- Fractional abundances with 95 percent confidence error boundaries of three foraminiferal species from 11 samples from the Bathhouse Beach Locality of the Pleistocene Santa Barbara Formation, Santa Barbara, California. Biofacies were determined from a Q-mode analysis of 38 species, while the inferred biofacies are based on the percent abundance of individual indicator species in each sample.

Sample		1	2	3	4	5	6	7	8	9	10	11
Total individuals (all species)		385	1,067	571	333	414	475	508	874	549	442	489
Biofacies (from Q-mode of 38 spp.)		1	2	2	1	1	2	2	2	2	2	2
<i>Buccella frigida</i>	Fract. abund. %	3.9	6.7	8.1	3.5	3.6	3.8	6.7	16.5	18.2	15.4	16.3
	Uncertainty \pm	1.9	1.5	2.2	1.5	1.8	1.7	2.2	2.5	3.2	3.4	3.3
	Inferred biofacies	1	2	2	1	1	1	2	2	2	2	2
<i>Islandiella limbata</i>	Fract. abund. %	11.9	41.3	21.0	15.5	11.1	49.6	27.2	25.2	32.6	17.9	14.1
	Uncertainty \pm	3.2	3.0	3.3	3.0	3.0	4.5	3.9	2.9	3.9	3.6	3.1
	Inferred biofacies	1	2	2	1	1	2	2	2	2	2	1
<i>Lobatula fletcheri</i>	Fract. abund. %	17.1	12.4	12.1	17.2	12.6	8.4	13.3	7.4	5.3	9.3	5.9
	Uncertainty \pm	3.8	2.0	2.7	3.1	3.2	2.5	3.0	1.7	1.9	2.7	2.1
	Inferred biofacies	1	2	2	1	2	2	1	2	2	2	2

Counting reliability. - Previous discussions of counting reliability by Dryden (1931), Phleger (1960), and Van der Plas and Tobi (1965) have based their estimates of reliability on the standard deviation of the distribution (equation 4)

$$s_i = [n_i(1 - f_i)]^{1/2} \quad (4)$$

and the fractional standard deviation (equation 5). These researchers have

$$\%s_i = s_i/n_i = [(1 - f_i/Nf_i)]^{1/2} \quad (5)$$

either used a 50 percent confidence interval (Dryden, 1931; Phleger, 1960) or a 95 percent confidence interval (Van der Plas and Tobi, 1965). Using the standard deviation as a statistic quantifies the variation in species abundances between many samples, as opposed to addressing variation in species abundance in particular environments. Alternatively, Wright and Hay (1971) based their estimates on standard error (equation 2) which the authors feel more properly characterizes the accuracy of the assessment of the fractional abundance. However, both the standard deviation of a species distribution and the mean distribution normalized by the expected abundance, or abundance fraction, are equivalent and interchangeable.

As the desired accuracy of a quantitative analysis depends on the requirements of the study at hand, a plot of 95 percent confidence levels has been generated to determine the uncertainty of species abundances (Figure 1). Buzas et al. (1982) determined that most species tallied in paleontological analyses are rare and, as stated in the introduction, many of these rarer species are important in making paleoenvironmental interpretations. The plot has therefore been generated on a logarithmic scale, emphasizing rarer fractional abundances. Utilizing this plot, it can be seen that for rare species having abundances between and 10 percent, the number of specimens counted must be between 100 and 850 before environments which differ by 2 percent abundance can be distinguished. However, it would be dependent on the objectives of the research project to determine whether accuracies of 1 ± 2 percent, or 10 ± 2 percent would provide adequate enough precision. To allow the reader to infer whether sufficient counts have been made, researchers should include abundance errors when presenting data (equation 2).

The value of including percent abundance errors and the relative effect of making too few counts is illustrated by the following example. Based on a cluster analysis of 11 samples, Patterson, Brunner, and Dahl (personal commun.) recognize two different biofacies in the Pleistocene carbonate marl deposits of the Bathhouse Beach locality of the Santa Barbara Formation. From the results of the Q and R mode analysis the relative

proportions of several species which seemed to best define the biofacies were intuitively charted. Samples belonging to Biofacies 1 were best characterized by *Buccella frigida* (Cushman, 1912) abundances <4 percent, *Islandiella limbata* (Cushman and Hughes, 1925) abundances <16 percent, and *Lobatula fletcheri* (Galloway and Wissler, 1927) abundances >12 percent. Biofacies 2 was characterized by higher proportions of *Buccella frigida* and *Islandiella limbata*, and lower proportions of *Lobatula fletcheri*. The total number of counts, the uncertainties in the abundances (equation 3), the biofacies as determined from a Q-mode analysis of 38 species, and the inferred biofacies based on fractional abundance are tabulated in Table 1. For samples 1, 2, 3, 4, 8, 9, and 10 the paleoenvironments inferred from *Buccella frigida*, *Islandiella limbata* and *Lobatula fletcheri* are in agreement. However, in sample 5 the abundances of *Islandiella limbata* and *Buccella frigida* indicate an affinity to Biofacies 1, while the *Lobatula fletcheri* abundance indicates a closer affinity to Biofacies 2. The position of all three abundances are close to the cut-off between biofacies, and the size of the uncertainty leads to the conclusion that 414 counts do not provide accurate enough statistics to conclusively infer the paleoenvironment of this sample based on these three species alone. Similarly, the statistics of *Islandiella limbata* and *Lobatula fletcheri* for Sample 6 and the large uncertainty associated with the *Buccella frigida* abundance of 3.8 ± 1.7 percent lead to the conclusion that Sample 6 is more representative of Biofacies 2. In addition, based on just these three species, samples 7 and 11 belong to both Biofacies 1 and 2, because the contradicting statistics, as shown by the abundance errors, are not sufficiently resolved to make an absolute determination. Therefore, as demonstrated by this example, while 300 counts would have been more than sufficient to resolve the abundances of sample 1 and 3, 414 counts were not sufficient for Sample 5. Furthermore, since the abundances of the three proposed indicator species in Sample 5 lay close to the boundaries between biofacies, counts in excess of 2,000 (Figure 1) would be required to obtain useable statistics (an error <2%). Thus, it becomes important to consider the similarity of the environments one is trying to differentiate, in addition to taking the rarity of a species into consideration, when determining the number of required counts.

CONCLUSIONS

1. The number of species in a sample has no relationship to the number of counts required to measure accurately fractional abundances.

2. When examining larger fractional abundances of species, the differences between environments tend to be larger and one can settle for larger errors; thus, fewer counts. Conversely, with

smaller fractional abundances, differences in environment tend to be smaller and larger counts are needed, to provide the required smaller errors. Based on the plot (Figure 1), it is suggested that if an indicator species has a fractional abundance of approximately 50 percent or greater, as few as 50 counts are required; a species making up 10 percent of a particular sample requires at least 300 counts; species making up 5 percent of the sample require 500-1,000 counts; and species making up 1 percent of a sample require several thousand counts to provide reliable statistics. In addition, as shown by the example (Table 1), similar environments require greater numbers of counts to distinguish them.

3. It is also recommended that researchers calculate fractional error and include it with their abundance data to provide an easier assessment of the results.

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REFERENCES

- BHATTACHARYYA, G. K. AND R. A. JOHNSON. 1977. *Statistical Concepts and Methods*. Wiley, New York, 639 p.
- Buzas, M. A., S. J. KOCH, S. J. CULVER, AND N. F. SOHL. 1982. On the distribution of species occurrence. *Paleobiology*, 8:142-150.
- DRYDEN, A. L. 1931. Accuracy in percentage representation of heavy mineral frequency. *Proceedings of the National Academy of Science*, 17:233-238.
- PHLEGER, F. B. 1960. *Ecology and Distribution of Recent Foraminifera*. John Hopkins Press, Baltimore, 297 p.
- SCHRODER, C. J., D. B. SCOTT, AND F. S. MEDIOL. 1987. Can smaller foraminifera be ignored in paleoenvironmental analyses? *Journal of Foraminiferal Research*, 17:101-105.
- SEN GUPTA, B. K., I. C. SHIN, AND S. T. WENDLER. 1988. Relevance of specimen size in distribution studies of deep-sea benthic foraminifera. *Palaos*, 2:332-338.
- VAN DER PLAS, L., AND A. C. TOBI. 1965. A chart for judging the reliability of point counting results. *American Journal of Science*, 263:87-90.
- WRIGHT, R. C., AND W. W. HAY. 1971. The abundance and distribution of foraminifera in a back-reef environment, Molasses Reef, Florida. p. 121-174. *In* J. I. Jones and W. D. Bock (eds.), *A Symposium of Recent South Florida Foraminifera*. Miami Geological Society Memoir 1.

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