REPLY: DISTRIBUTION MAP OF CAVES AND CAVE ANIMALS IN THE UNITED STATES

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First, we would first like to thank Professor Curl for his comments and interest in our recent work on the geographic distributions of caves and subterranean fauna in the coterminous United States (Culver *et al*. 1999). We welcome the opportunity to discuss and clarify some of the statements made in our manuscript.

Each comment of Professor Curl's is addressed in turn. We wish to emphasize that any statistical analysis presented in the paper was solely exploratory in nature in order to provide some initial confirmation for the conclusion of similar spatial distributions for the caves and cave species (Figs. 1 & 2).

1) We did not test whether the relationship between S (number of species) and C (number of caves) was linear for two reasons.

a) The emphasis in this paper was on demonstrating graphically that a relationship (linear or otherwise) exists between S and C. That can be seen quite clearly in figure 3, which also shows that for large numbers of caves the relationship is at least approximately linear.

b) A lack of fit test at this stage of the analysis would have been inappropriate since no detailed study had yet been performed. Such a test would be part of a more detailed, not exploratory, analysis.

2) Curl is certainly correct in stating that the variance of S is increasing in C. Constant variance and a normal distribution for the response variable are the usual assumptions for testing in linear regression. We agree that a full analysis would certainly account for failure of the data to meet these assumptions. We did cite the t-statistics and their p-values without noting the failure of these assumptions for these data but we wish to point out the following:

a) The assumption of normality can be relaxed somewhat since i) the t-test is quite robust to the failure of this assumption and ii) the sample size is so large that the estimates of the model coefficients are likely normally distributed anyway (they are weighted averages of the response variable and hence the Central Limit Theorem can be applied).

b) In general, the failure to account for heteroscedastic variance has the unintended consequence of overestimating the variance that is assumed to be constant (Draper & Smith 1967). As a result of the overestimation, the t-test is conservative and is less likely to support the conclusion of a relationship unless that relationship is quite strong.

3) The assumption of no measurement error in C, the number of caves in a county, is certainly violated here for many reasons, including those mentioned by Professor Curl. Unfortunately, there is literally no means by which we might assess the magnitude of the measurement error based on the available data. The only alternative is to make some strong assumptions about the error associated with the number of caves per county for every single county in the United States. That, itself, would introduce an additional source of error to the analysis so that any inferences would be dependent on the validity of these additional assumptions. Instead we recognize that the number of observed caves in a county is a surrogate measure for the more important but unobservable variable that might be called habitat availability.

A more suitable measure might be the total length (or volume) available in a county, but this in turn would require, in addition to a complete enumeration of cave lengths (and volumes), an estimate of the fractal dimension of the karst. Curl has, of course, pioneered in this area (Curl 1966, 1988), but there are simply not data available at the scale needed. It is worth pointing out that if the fractal dimension is more or less constant, then an estimate of habitat by number of caves may be relatively robust.

4) We are pleased that the contingency table analysis performed by Professor Curl supports our own preliminary conclusions that the number of species and the number of caves are related. The advantage of the 2x2 test is that it relies less on assumptions than the test of the slope of a linear regression. There are also disadvantages such as being unable to infer the direction of the relationship of the two variables without further analysis and the dependence of the test on the researcher's choice of the levels or categories for analysis.

5) Professor Curl implies that the observed relationship may be due to a latent variable, county area, which influences both S and C. Neither the number of caves nor the number of species in a county is correlated with the size of the county for those counties in which at least one species has been reported (r = - 0.064 for S and Area and r = - 0.017 for C and Area). Hence, the relationship is not due to the potentially latent effects of area.

Professor Curl rightly points out that many other variables may be as or more important than the number of caves for explaining the distribution of the number of cave species in the United States. There is no doubt that a complete analysis would include such information as climatic variables, vegetative cover, and many other potential explanatory variables, if data were available. As a first step, we recently completed a more detailed account of the relationship between cave numbers and species counts for the southeastern region of the United States (Christman & Culver in review). We show that, based on the available data, the relationship between S and C is best described as a log-log function, with different functions for different karst regions. We further show that there is spatial dependence in the dataset. Even after the effect of the number of caves is accounted for, there is unexplained variability in the number of species that can be explained in part by the species density in neighboring counties. This suggests that species have migrated in subsurface routes between counties or have been influenced similarly by unmeasured factors such as the Pleistocene ice sheet boundary.

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