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

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Culver *et al.* (1999) counted numbers of caves (C) and of obligate cave-dwelling organisms (S) in each of 1144 counties in the United States with known caves, and presented distributions maps and a scatter plot (their figure 3) of S *versus* C. They used the latter to display a linear regression in the form S = a + bC, and conducted tests of the null hypotheses a = 0 and b = 0. They used the standard Student t tests of these hypotheses and, rejecting them, asserted a positive correlation between S and C. Although there may indeed be a significant correlation between S and C, their data do not satisfy the conditions for applying the t test. These are:

1) There must be a justification for assuming the expected value of S is linear in C, but the hypothesis is not tested.
2) The variable S must be (at least approximately) normally distributed about its expected value, and the variance of S must be independent of C (homoscedastic). It is apparent from inspecting figure 3 that neither of these is true.
3) There must be insignificant variance of the variable C within counties, compared to that of the variable S. However, C is only a small fraction of the total number of proper caves in any region, and it has been shown that a stochastic process leads to most caves losing all proper entrances in such a way that the variance of the number of proper caves with proper entrances is large (Curl 1966).
4) Cave organisms do not restrict themselves to proper caves. There is a much larger number of non-proper caves, caves too small for human entry, than of proper caves (Curl 1986). The value of C, therefore, is not only an indirect but also an imprecise measure of the subterranean habitat accessible to cave organisms.

Since too little is known about the variables S and C and their relationship, including what both the functional form and statistical distributions are, a non-parametric, distribution-free test of statistical independence is required. I applied a 2x2 contingency test to data shown in figure 3, with levels defined as $[0 < S \leq 12, 12 < S]$ and $[0 < C \leq 150, 150 < C]$, and obtained the test statistic $\chi_1^2 = 102$, with one degree of freedom. This is significant at less than the 0.1 % level, and the null hypothesis of statistical independence of S and C is rejected at that level. This test emphasizes the cited upper levels of S and C, which constitute only 8 % of the data.

There are possible sources of statistical dependence that may or may not be related to causations of ecological interest, in the form of common variables affecting both S and C. The area of counties may be one such variable. The number of caves observed in a karst region would increase with the area of the region and one might expect the number of observed species to increase, also. This common-mode effect might be suppressed by dividing each S and C pair by the area of karst in that county. Another common variable, but of ecological significance, might be climate. Karst areas with heavier precipitation might simultaneously have more cave development and be biologically richer than more arid areas.

In summary, while a linear regression t test and a contingency test arrive at the same conclusion that S and C are statistically dependent, the several assumptions inherent in linear regression are not supported. The relationship between S and C, and these to other variables that may be common sources of the statistical dependence observed, need to be elucidated, especially to identify ecological processes and parameters that relate S to C. I look forward to these considerations being addressed with the authors' promised more complete analysis of their data.

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