

## This Week's Citation Classic®

Hurlbert S H. Pseudoreplication and the design of ecological field experiments.

*Ecol Monogr.* 54:187-211, 1984.

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Massive amounts of incorrect statistical analyses exist in the experimental ecological literature. This paper describes three of the commonest errors, naming them simple, temporal, and sacrificial pseudoreplication, and cites numerous examples of each. Some ways of improving the situation are proposed. [The SC<sup>i</sup>® indicates that this paper has been cited in more than 610 publications.]

### Dragging Statistical Malpractice into the Sunshine

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The genesis of this article was a review that I carried out in the early 1970s on the effects of pesticides in aquatic ecosystems.<sup>1</sup> The high frequency of weak experimental designs and invalid statistical analyses in the primary literature on that topic particularly caught my attention. As time went on I became aware that the same problem existed in the ecological literature generally. In 1980,<sup>1</sup> was invited to a symposium sponsored by Florida State University and asked to give a presentation on a topic dealing with community ecology. This seemed a good opportunity to blow the whistle, so I reviewed the statistical analyses in 156 papers reporting ecological field experiments, and presented my finding at the symposium in March 1981. The principal finding was that 48 percent of the studies using inferential statistics had badly misanalyzed their data.

The manuscript presented orally at the symposium was a rough and somewhat naive document and underwent marked expansion and revision during the following two years. After reviewing it, the editors of the proceedings<sup>2</sup> decided not to accept it as it was outside the main theme and longer than the specified page limit. A reasonable decision.

It was then submitted to *Ecological Monographs*, where Nelson Hairston, Sr., was assigned to handle it. Within two months (!) he had

obtained two reviews and decided to accept it. One review was very favorable. The other reviewer said he "enjoyed reading" the manuscript but opined that "there is nothing new here, neither as to ecology or applied statistics" and that the 90 pages would be better reduced to "a letter to the *Bulletin* [of the Ecological Society of America]." Hairston, who had heard the original presentation at the Florida symposium and who later recalled some in the audience "squirming in embarrassment as Humbert's revelations thrust home," cast the deciding positive vote.

Some minor additional revision and expurgation was requested. Prompted by a reviewer's charge that I used "private language and humor by misstatement," the managing editor, Lee Miller, questioned some of my metaphors such as "demonic intrusion" and "biting the bullet as well as the apple," and the copy editor, Sarah Gagnon, thought I was pushing matters by acknowledging the helpful comments of colleagues and then saying that "Any errors that remain are their responsibility and theirs alone." In the end, they kindly relented and let me have my fun.

The paper was very favorably received. The American Statistical Association gave it the Snedecor Award for the best paper in the field of biometry in 1984. Thousands of reprint requests and many speaking requests have been received, and the term 'pseudoreplication' has been widely adopted by both biologists and statisticians.

The paper's impact derives primarily from the fact that it documents the surprising extent of certain statistical problems in the ecological literature, gives clear, nontechnical descriptions of their nature and of how to avoid them, and provides clear labels for some of the commoner errors. The paper also attracted attention because it listed all the papers found to contain the errors discussed, a tactic avoided by other reviews of this sort. That certainly got the attention of the cited authors as well as, perhaps, that of their friends and students. Despite the critical tone of the article, however, it identified such a large number of misanalyzed studies that I believe no author felt unfairly singled out.

This venture led to an NSF grant for the preparation of additional critiques of statistical malpractice, two of which have been completed<sup>3,4</sup> and several others of which are in preparation. This is a fertile field of endeavor; there is no indication yet that the quality of statistical analyses in published reports is improving.

1. Hurlbert S H. Secondary effects of pesticides on aquatic ecosystems. *Residue Rev.* 57:81-148, 1975. (Cited 50 times.)

2. Strong D R, Jr., Simberloff D, Abele L G & Thistle A B, eds. *Ecological communities: conceptual issues and the evidence*. Princeton, NJ: Princeton University Press, 1984. 613 p. (Cited 200 times.)

3. Hurlbert S H. Spatial distribution of the montane unicorn. *Oikos* 58:257-71, 1990.

4. Hurlbert S H & White M D. Experiments with fresh water invertebrate zooplanktivores: quality of statistical analyses. *Bull. Mar. Sci.* (In press.)

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