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Introduction: Ecological Applications of Bayesian Inference

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Bayesian Inference

Introduction: Ecological Applications of Bayesian Inference[1]

Statistical analysis is usually needed to extract usable inferences from highly variable ecological data. However, there are continuing discussions and arguments about many aspects of statistical design and analysis. Two recent examples include the design of studies to detect an environmental impact (Underwood 1994, Wiens and Parker 1995) and the choice of parametric or nonparametric statistics (Stewart-Oaten 1995).

Less well known to ecologists is another disagreement about the fundamental statistical process: making inferences from data. Should one use "frequentist" or "Bayesian" statistics? Frequentist statistics uses tools like unbiased estimates, confidence intervals, and *P* values to make conclusions from data. Bayesian inference uses different tools: posterior distributions, credibility intervals, and Bayes factors. Most ecologists use frequentist analyses because those are taught in most statistical methods courses, but papers using Bayesian approaches are beginning to appear in the ecological literature (e.g., Gazey and Staley 1986, Stow et al. 1995). However, most ecologists are unaware of the differences between the two statistical methods, partly because it is difficult to find accessible discussions of their differences.

The statistical problem is similar for both frequentist and Bayesian methods. An ecologist studies a small sample of objects (probably individuals, perhaps populations or species). Statistics computed from the sample are used to make more general conclusions about unknown parameters that describe a larger, and more ecologically interesting, statistical population. Statistical inference is the process of making conclusions about unknown parameters from the observed statistics.

Frequentist inference assumes that the population parameters are fixed constants (Ellison 1996). The data are random observations from some unknown statistical population. Test statistics, such as *t* statistics, are random quantities because they are computed from the data. Frequentist approaches are presented in most biometrics texts, taught in most statistical methods courses, and used by most ecologists. However, fundamental concepts, such as confidence intervals, are often misinterpreted, and there can be theoretical difficulties and philosophical dilemmas applying frequentist inference in complex problems (Ellison 1996).

Bayesian inference assumes that the population parameters are random. Instead of talking about "the value" of the parameter, it makes sense only to talk about the statistical distribution of the values. The data are treated as fixed. All inferences about the parameters are made conditionally upon the observed data. Bayesian methods use a probability rule (Bayes' theorem) to calculate a "posterior distribution" from the observed data and a "prior distribution," which summarizes the pre-experiment knowledge of the parameter (see Ellison 1996 for an example). Because Bayesian information is summarized as a probability distribution, it is easy to combine results of multiple experiments or data from different sources (Cox and Hinkley 1974).

Prior and posterior probabilities are interpreted differently by different groups of Bayesians. One school of Bayesians treats probabilities as subjective quantities (e.g., Wolfson et al. 1996). This is quite different from the frequentist definition of probability as the frequency of some often-repeated event. Much of the acrimonious debate over Bayesian methods in the statistical literature concerns the use of subjective probabilities. However, not all Bayesians use subjective probability (Cox and Hinkley 1974).

The seven papers in this special section present a technical introduction, four ecological applications, and two discussions of Bayesian inference. The first five papers were invited presentations in a symposium at the 1995 annual meeting of the Ecological Society of America. Ellison (1996) elaborates on the contrast between frequentist and Bayesian inference and presents a

[1] Reprints of this 70-page group of papers on Bayesian inference are available for $10.50 each. Order reprints from the Office of the Executive Director, Ecological Society of America, 2010 Massachusetts Ave., NW, Washington, D.C. 20036.

simple worked example. Ver Hoef (1996) describes and gives three applications of parametric empirical Bayes methods, which combine observed data with group information (the prior) to improve predictions. Ludwig (1996) describes the differences between Bayesian and frequentist population viability analysis. The choice of method leads to substantially different estimates of extinction probabilities. Taylor et al. (1996) use Bayesian methods to estimate population decline rates of Spectacled Eiders by combining information from multiple studies and multiple sources of uncertainty. Wolfson et al. (1996) use Bayesian methods with subjective probabilities to evaluate cleanup decisions around hazardous waste sites.

The papers were followed by a long and insightful discussion on Bayesian inference, statistical analysis, and their consequences for ecologists. Two major participants in that discussion were asked to write papers (Dennis 1996, Edwards 1996) summarizing their views on Bayesian inference and the five invited papers. Discussions like these, published with the original paper(s), are common in the statistical literature, but unusual in the ecological literature. With the approval of the editor-in-chief, we edited them in the same way that statistical discussion papers are edited. Because they present viewpoints, not new research, the discussions were not sent out for external review; they were reviewed for tone and technical accuracy by one of the editors of this special feature.

The choice between Bayesian and frequentist inference is not an arcane philosphical discussion. It affects all aspects of how one makes inferences from data. This special feature presents to ecologists an understandable discussion of the two approaches and their consequences. It also presents examples of ecological problems that may be more easily answered by Bayesian approaches, and finally gives some flavor of the controversy associated with the choice of method.

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