Ecological Society of America Guidelines for Statistical Analysis

This information is derived from the guidelines on "Statistical analysis and data presentation" prepared by the Statistical Ecology Section of the Ecological Society of America (ESA) in collaboration with the Editors-in-Chief of the ESA journals (May, 2022).

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Basic philosophy

These suggestions proceed from two principles:

(1) Authors are free to perform and interpret statistical analyses as they see fit.

(2) The detail provided should be sufficient for a knowledgeable reader to reconstruct the analysis for an independent assessment of the appropriateness of the methods.

Thus, the assumptions and (or) the model underlying statistical analyses must be clearly stated and results must be sufficiently detailed. When a method is highly established, such as linear models or generalized linear models, authors can rely upon readers' knowledge of standard assumptions rather than state them explicitly. Details that are deemed peripheral to assessment of the methods by most readers should be included in an appendix.

Data description

Sampling designs, experimental designs, data collection protocols, sampling units, and experimental units must be clearly described. Reported information usually includes the sample size and a measure of the precision of data collection procedures (e.g., instrument or sampling error), although this may not be necessary or possible in all instances. Any pre-processing of data should be clearly described. This includes the treatment of missing values, data points deemed outliers, combinations of multiple observations, transformation of variables, and gap-filling or interpolation procedures.

Assessment of assumptions

Ideally, documentation that the data meet the assumptions for all statistical models will be included as part of the primary manuscript or as an appendix. For example, models that assume linear associations among individual variables should be supported by supplemental figures demonstrating that linearity, while models based on means should be supported by either primary or supplemental figures confirming that the underlying distributions are sufficiently unimodal and symmetric without outliers. For less-established methods or unusual assumptions, authors should state clearly the assumptions being made in each analysis and provide sufficient graphical or statistical information in the supporting material for readers to assess departures from those assumptions. If there is reasonable concern that assumptions are violated, authors should examine the sensitivity to assumptions of any relevant conclusions. The amount of detail provided in any particular instance will depend on the centrality of the statistical analysis to the conclusions.

Reporting of analyses

The specific statistical procedure must always be described in plain language or using equations (i.e., just referring to a function within a specific statistical program is not sufficient), with the goal that a knowledgeable reader could reproduce the results when provided with the raw data. In addition, key components of the computing environment should be cited, and version numbers should be included. For example, analysis in R using several packages should cite each package based on its requested citation format. Where appropriate, authors should indicate which procedure within a package was used and which methods or options within a procedure were chosen. Relatively novel statistical procedures need to be explained in sufficient detail, including references if appropriate, for the reader to reconstruct the analysis. The authors should publish their code for analyses according to the ESA Open Research policy. All statistical tests that were performed should be clearly described to avoid problems associated with p-hacking, data dredging, etc., and corrections for multiple testing should be employed when appropriate. Randomization procedures should be clearly described, including the number of randomizations employed.

Reporting of results

Graphical data presentation is encouraged. Carefully composed graphs often permit the reader to comprehend important patterns in data and qualitatively assess statistical assumptions. Parameter effect sizes and biological importance should be reported and should not be confused with statistical significance. Each estimated parameter should be accompanied by its estimated uncertainty (e.g., standard error, confidence interval, or credible interval). When hypothesis tests are used, actual P values should be reported alongside the test statistic and all appropriate degrees of freedom. Avoid the use of symbols such as * and ** to denote qualitative levels of "significance". Power analyses (determination of type II error rates) occasionally can be useful, especially if used in conjunction with descriptive procedures such as confidence intervals. Avoid reporting the same statistics multiple times in the manuscript (i.e., report in main text, tables, or figures).

Study design

Keep in mind that ecological conclusions are only as good as the underlying study design. In experiments, proper randomization, controls, and replication are needed to draw causal conclusions. In observational studies, it is important not to confuse associations between variables with underlying causal relationships. Developing a clear plan for the intended statistical analyses prior to data collection will often help identify flaws in the design that require adjustment; we encourage authors to consider the value of pre-registering their design and analysis plans when appropriate.

Guidance for commonly used statistical approaches

- If conclusions are based on general linear models such as analysis of variance or regression, information sufficient to permit the construction of the full analysis of variance table (including the degrees of freedom, the structure of F ratios, and P values) must be presented or be clearly implicit. Note that F statistics have both numerator and denominator degrees of freedom; it is insufficient to include only the F ratio or only the F ratio plus the numerator degrees of freedom. When generalized linear (mixed) models are used, the probability distribution of the response variable and link functions should be described and justified; overdispersion should be reported when present. In mixed models where ambiguity is possible, the authors must indicate which effects were considered fixed or random and why, and describe both the structure of any random effects (e.g., for slopes, intercepts, or both) and any assumptions made in constructing variance-covariance matrices.
- For Bayesian models, a description of the priors and a justification of why they were selected should be provided. For analyses that rely on Markov chain Monte Carlo (MCMC) methods, a description of how chain convergence was assessed should be included. In some cases, an evaluation of the sensitivity of the results to the adopted priors might be warranted. Code for software packages should be provided, as stated above, and must follow the requirements of the ESA Open Research policy. If authors wrote their own analysis code, the methods implemented in the code should be described in sufficient detail for a knowledgeable reader to reproduce the method. For example, this could include mathematical expressions for full conditional distributions used for Gibbs sampling or description of other MCMC sampling algorithms.
- When model selection was performed, all models compared (not just the top models) should be presented along with the values used for ranking them. Providing the change in the AIC or BIC among models (e.g., ΔAIC) is typically more useful than the raw values. If the list of models is large, a selected number of top models can be included in the main text, and the rest placed in an appendix. The model selection procedure should not be confused with the test of goodness of fit.