The Journal of Wildlife Management; DOI: 10.1002/jwmg.21461

GUEST EDITORIAL

Explicitly Reporting Tests of Hypotheses Improves Communication of Science

Hypothesis testing is fundamental to producing the rigorous biological inferences needed to reliably inform wildlife management (Platt 1964, Romesburg 1981, Williams 1997, Sells et al. 2018). Hypothesis testing results in inferences that have significantly stronger support than those derived without it. The neurophysiologist W. A. H. Rushton famously observed that "a theory that cannot be mortally endangered cannot be alive" (Platt 1964:349). By that reasoning, only biological hypotheses that have survived falsification attempts can be considered alive enough to provide insights and management applications that are reliable. Falsification of a hypothesis rules out a potential source of causation authoritatively and thereby reduces epistemic uncertainty about the natural world. Hypotheses that remain unfalsified gain support and resulting inferences can be more confidently used to inform management decisions. Importantly, exposing a hypothesis to falsification reduces the likelihood that the confirmation bias inherent to human thinking will influence inferences. Falsification, however, is not logically possible if *a priori* hypotheses are not developed, stated, and then rigorously tested (Platt 1964, Romesburg 1981, Williams 1997, Sells et al. 2018).

We suggest that effective communication of scientific research requires a clear presentation of *a priori* hypotheses, results of their tests, and the inferences thereby produced. Omitting these elements can obscure critical questions motivating the research, the logical rigor of a study, and the reliability and usefulness of inferences offered. Nonetheless, this information is often missing or insufficiently communicated in scientific papers. We recently showed that of 287 papers offering biological inferences in the *Journal of Wildlife Management* (*JWM*) from August 2013 to July 2016, approximately 44% did not explicitly state or test hypotheses and 14% appeared to do so ambiguously (Sells et al. 2018).

Guidelines for *JWM* specify that the introduction section of a paper end "with a clear statement of objectives and hypotheses (if applicable)" (Cox et al. 2018:4). Authors might reasonably ask how applicability of *a priori* hypotheses is determined. *A priori* hypotheses are generally applicable to any research that produces biological inference. An exception may be a truly pioneering study that lacks the theoretical and empirical foundations needed to construct testable hypotheses. This circumstance should be exceedingly rare in wildlife biology, where precedents abound. *A priori* hypotheses are generally not applicable to studies designed to develop or evaluate analyses and research techniques if they offer no biological inferences. Of papers published in *JWM* over the period we evaluated, 92 papers fell into this category and were thus excluded from our analysis (e.g., Stansbury et al. 2014, Buxton et al. 2016). Finally, *a priori* hypotheses are not applicable to studies intended from the outset to be descriptive (i.e., natural history surveys or exploratory analyses producing *post hoc* biological inferences; Sells et al. 2018). A descriptive study should be explicitly acknowledged as such in the introduction, in lieu of stated hypotheses.

Most wildlife studies offer biological inferences, suggesting hypothesis testing should be the norm. In fact, *a priori* hypotheses are nearly ubiquitous in biological research whether they are stated explicitly or not. Research results are rarely unanticipated; theoretical and empirical precedent available prior to a study (e.g., produced by a literature review) is almost always sufficient for researchers who do not explicitly test hypotheses to offer detailed *post hoc* interpretation of their results. This approach describes most of the *JWM* papers we evaluated that did not state *a priori* hypotheses (Sells et al. 2018), suggesting that the studies were descriptive despite available precedents and thus missed the opportunity to improve reliability of results through hypothesis testing, or the studies tested *de facto* hypotheses but the lack of explicit communication voluntarily sacrificed logical rigor and evidence for the reliability and usefulness of inferences. Most, if not all, biological studies are motivated by ideas, questions, and possible answers conceived before they are conducted; almost any study, in fact, tests *a priori* hypotheses in one form or another. We see no benefit to keeping that process hidden when communicating it explicitly adds substantial value and credibility to research findings and science.

Guidelines for *JWM* specify that the discussion section of a paper "should begin with a statement of how the study did or did not support the hypotheses and then follow up with an explanation as to why or why not..." (Cox et al. 2018:5). This discussion is the beating heart of any biological paper, where inferences are offered based on results of statistical analyses that explicitly tested hypotheses (Platt 1964, Romesburg 1981, Williams 1997, Sells et al. 2018). Hypotheses that are mortally wounded through testing are put to rest; those that survive gain support and provide the foundations for future research designed to threaten them or their intellectual offspring. Results of well-crafted hypothesis tests have implications within and beyond the scope of a single study, offering rich fodder for discussion sections and future research. They provide definitive answers to research questions. They shed light on the biological concepts used to generate and justify them, either lending support to existing theory or calling it into question. They help distinguish idiosyncratic patterns from general processes, facilitating extrapolation of findings to other times, places, and systems. They advance knowledge for ecology and management by logically discarding unsupported information and refining potentially useful information. In the absence of hypothesis testing, the biological insights offered by a study, the strength of their support, and their meaning beyond the immediate temporal and spatial bounds defining the research become unclear; the novelty and contribution of the research are thus diminished. This lack of clarity can call into question the reliability with which research results can be applied to management. Thus, studies offering insights from *post hoc* interpretation of correlations should acknowledge their limited reliability by presenting inferences as tentative, untested hypotheses (in need of mortal endangerment).

Ultimately, the effective presentation of hypothesis tests requires a logical, predictable flow of information in a paper. We recommend a template for the organization of a research paper (Fig. 1) that presents a logical flow of information; this template is not meant to imply a rigid, universally applicable format. We suggest that the flow of a paper presenting tests of hypotheses can be thought of as hourglass in shape. The top half of the hourglass logically narrows the reader's focus from general concepts and research context to the questions the study seeks to answer, and the hypotheses that will be tested to provide the answers. When well-written, this organization can allow readers to intuit the hypotheses before seeing them. Depending on their complexity or number, hypotheses can be presented in the text, a table, a figure, or even at the beginning of a methods section, provided they mark the critical transition between why a study is being done and how it is being done. Material in the neck of the hourglass specifies the methods that will be used to test the hypotheses and the results of those tests. Methods and results are most clear when organized explicitly according to the hypotheses being tested, without assuming the relationships are self-evident. The bottom half of the hourglass reverses the logical organization of the top half, drawing inferences from hypothesis tests and describing their implications for the immediate study through the broader conceptual background in which it is nested. This organization provides context essential to thorough interpretation of research results, makes the novelty and scholarly impact of research clear, and sets up an unambiguous discussion of management implications inferred from the strengths and weaknesses of biological insights produced.

The logic and inferential merits of hypothesis testing are far older than *JWM* and wildlife science (Sells et al. 2018). The journal does not reinvent the wheel by asking its authors to explicitly state and test hypotheses, rather it affirms that wildlife research designed to inform management needs to be as rigorous and reliable as possible because misleading inferences can be consequential for conservation. We argue that rigor and reliability is generally latent, not absent, in *JWM* papers that do not state and test *a priori* hypotheses. Making implicit thought processes explicit through hypothesis testing would strongly clarify the rigor and usefulness of wildlife research and reduce the substantial percentage of *JWM* papers we found that appear to produce unreliable knowledge (Romesburg 1981).

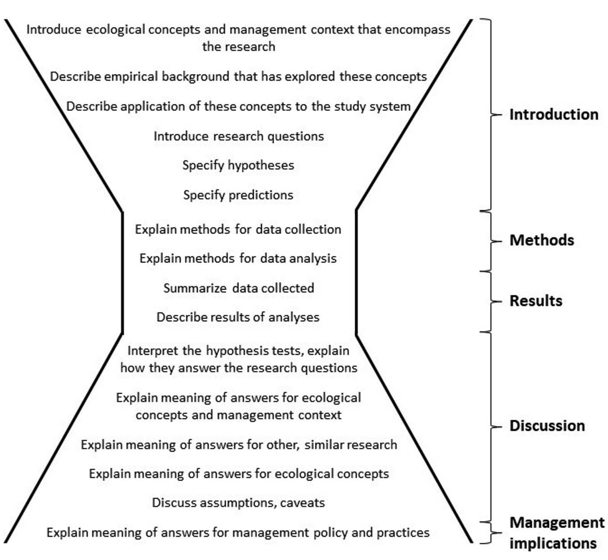

Figure 1. The effective presentation of hypothesis tests requires a logical, predictable flow of information in a paper. Although no single organizational scheme will apply to all scientific papers, we suggest the organization for a research paper depicted here as a template. This organization necessarily narrows the presentation from general ecological concepts down to the specific hypotheses, methods, and results of the study, then broadens back out to wider implications.

—Michael S. Mitchell
U.S. Geological Survey, Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana
—Sarah N. Sells
Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana
—Sarah B. Bassing
School of Environmental and Forest Sciences, University of Washington
—Kristin J. Barker
Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana
—Allison C. Keever
Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana
—Shannon C. Forshee
Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana
—James W. Goerz
Montana Cooperative Wildlife Research Unit, Wildlife Biology Program, University of Montana

LITERATURE CITED

Buxton, R. T., A. M. Gormley, C. J. Jones, and P. O'B. Lyver. 2016. Monitoring burrowing petrel populations: a sampling scheme for the management of an island keystone species. Journal of Wildlife Management 80:149–161.

Cox, A. S., A. S. C. Knipps, J. L. Wallace, T. E. Boal, P. R. Krausman, D. A. Haukos, and M. Ben-David. 2018. *Journal of Wildlife Management, Wildlife Society Bulletin, and Wildlife Monographs* author guidelines. <http://wildlife.org/publications/>. Accessed 12 Mar 2018.
Platt, J. R. 1964. Strong inference. Science 146:347–353.
Romesburg, H. C. 1981. Wildlife science: gaining reliable knowledge. Journal of Wildlife Management 45:293–313.
Sells, S. N., S. B. Bassing, K. J. Barker, S. C. Forshee, A. C. Keever, J. W. Goerz, and M. S. Mitchell. 2018. Increased scientific rigor will improve reliability of research and effectiveness of management. Journal of Wildlife Management 82:485–494.
Stansbury, C. R., D. E. Ausband, P. Zager, C. M. Mack, C. R. Miller, M. W. Pennell, and L. P. Waits. 2014. A long-term population monitoring approach for a wide-ranging carnivore: noninvasive genetic sampling of gray wolf rendezvous sites in Idaho, USA. Journal of Wildlife Management 78:1040–1049.
Williams, B. K. 1997. Logic and science in wildlife biology. Journal of Wildlife Management 61:1007–1015.