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Multimodel inference and adaptive management

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ABSTRACT

Ecology is an inherently complex science coping with correlated variables, nonlinear interactions and multiple scales of pattern and process, making it difficult for experiments to result in clear, strong inference. Natural resource managers, policy makers, and stakeholders rely on science to provide timely and accurate management recommendations. However, the time necessary to untangle the complexities of interactions within ecosystems is often far greater than the time available to make management decisions. One method of coping with this problem is multimodel inference. Multimodel inference assesses uncertainty by calculating likelihoods among multiple competing hypotheses, but multimodel inference results are often equivocal. Despite this, there may be pressure for ecologists to provide management recommendations regardless of the strength of their study's inference. We reviewed papers in the Journal of Wildlife Management (JWM) and the journal Conservation Biology (CB) to quantify the prevalence of multimodel inference approaches, the resulting inference (weak versus strong), and how authors dealt with the uncertainty. Thirty-eight percent and 14%, respectively, of articles in the JWM and CB used multimodel inference approaches. Strong inference was rarely observed, with only 7% of JWM and 20% of CB articles resulting in strong inference. We found the majority of weak inference papers in both journals (59%) gave specific management recommendations. Model selection uncertainty was ignored in most recommendations for management. We suggest that adaptive management is an ideal method to resolve uncertainty when research results in weak inference.

1. Introduction

Ecology is an inherently complex science studying phenomena characterized by nonlinear interactions that make it difficult to understand basic relationships and responses to management. Most ecological field research is conducted in relatively short, small scale studies (Wiens, 1989) which are often inadequate to untangle ecological complexity. Wildlife managers and policy makers, whose decisions affect ecosystems at larger scales in space and time, rely on ecologists to provide management recommendations drawn from these short, small scale studies. To cope with the difficulties associated with drawing conclusions from such studies, ecologists are, with increasing frequency, using alternatives to traditional statistical null hypothesis testing in order to disentangle the underlying trends in complex data (Anderson et al., 2000; Johnson and Omland, 2004; Stephens et al., 2007).

Strong inference, where multiple alternative hypotheses are tested with experiments to falsify those hypotheses (Platt, 1964), and adaptive inference, an iterative process of investigation that alternates between minimizing Type I and Type II errors at different places in the investigative process (Holling and Allen, 2002) have been suggested as approaches appropriate to understanding complex problems. Both approaches pose and test branch points in a tree of logically alternative hypotheses. But strong inference relies on situations where causes can be single and separable and where discrimination between pair-wise alternative hypotheses can be determined experimentally by a simple yes or no answer. As Platt (1964) demonstrates, strong inference is a powerful and rapid way to deal with questions in molecular biology, cell biology and physiology. Strong inference is less applicable in ecological systems, where causes are not entirely separable (Hilborn and Stearns, 1982; Pickett et al., 1994). Frequently, competing hypotheses cannot be distinguished by a single unambiguous test or set of controlled experiments, but only by a suite of tests that accumulate a body of evidence supporting one line of argument and not others. Instead of pitting hypotheses against each other, adaptive inference relies on multiple, competing hypotheses followed by tests that develop

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a consistency of pattern lending support to a particular line or lines of argument.

Strong inference and adaptive inference are useful, but not appropriate in all situations. One method that is increasing in prevalence within the fields of ecology and conservation is multimodel inference (Guthery et al., 2005; Hobbs and Hilborn, 2006). Multimodel inference is a statistical technique where alternative plausible models are assessed given the data, based on relative likelihoods (Anderson et al., 2000). These models are selected *a priori* based on thoughtful, science-based consideration of the problem to be answered and hypotheses about the causal effects behind this problem. These plausible models are then analyzed simultaneously as a set to determine the best approximating model or set of models using information theoretic approaches (Burnham and Anderson, 2002). However, model results are often equivocal due to uncertainty in model selection (Guthery et al., 2005), and researchers are left with the resulting weak inference, with multiple models plausible given the data at hand. Researchers are thus faced with the dilemma of providing management recommendations to managers based on weak inference.

When researchers are required to draw conclusions from multiple plausible models, they have at least three alternatives open to them. One method is to average otherwise equivocal results. Model averaging uses model weights to derive more robust model parameters or model estimates (Johnson and Omland, 2004). Another alternative is to repeat the experiment and postpone initiating a management regime. However, when management decisions must be made and it is not feasible to repeat the experiment, a third option, adaptive management, is a logical follow up for researchers and managers when drawing conclusions from research with weak multimodel inference. Adaptive management permits management to continue while managers increase their knowledge through monitoring coupled with well designed management experiments. Management is able to continue because in adaptive management uncertainty is acknowledged, management is designed to reduce sources of uncertainty over time, and management actions are designed to be optimal within the current state of uncertainty (Holling, 1978; Walters, 1986).

The use of adaptive management has been increasing over the last decade (McFadden et al., 2011). Given the changing paradigms in ecological research, that is, the increasing prevalence of multimodel inference, we sought to document the use of multimodel inference in two top management and conservation journals, and the pervasiveness of weak inference resulting from its use. Where weak inference was present in the results from reported field studies, we sought to determine if authors were communicating the uncertainty underlying weak inference to managers, and the type of recommendations that followed from results. Specifically, we evaluated peer-reviewed papers in two journals to (1) quantify the prevalence of multimodel inference, (2) quantify the prevalence of weak inference, and (3) determine what type of management recommendations authors draw from multimodel inference results. We expected weak inference to be abundant within papers that used multimodel inference, and therefore, given the increasing use of adaptive management, we specifically searched within the management recommendations for the endorsement of an adaptive management approach.

2. Methodology

2.1. Inference strength

We reviewed articles in the 2008 issues of the Journal of Wildlife Management (volume 72) and Conservation Biology (volume 22). We selected these journals because their target readership includes managers and conservationists, and we wished to understand our objectives within the context of the literature available to these interest groups. Papers were included in our review if (1) data reported were collected from field studies, (2) data were analyzed using multimodel inference (MMI) or statistical null hypothesis testing, and (3) management or conservation predictions or recommendations were drawn from the reported statistical analyses. We excluded commentaries, literature reviews, statistical theory papers, and papers where the objective was to theoretically develop or test a specific type of model (*e.g.*, population growth models) without testing multiple competing statistical hypotheses. Subsequent analyses were restricted to papers that used MMI as a method of comparing hypotheses (Burnham and Anderson, 2002). In the reported results of MMI papers, we determined the number of models in a confidence set of models based on the minimum cutoff point suggested by Royall (1997) where models in the confidence set are within 10% of the Akaike weight of the top model. Models within the confidence set are considered to be the best supported given the data and the models selected for analysis. It is important to define the confidence set because these models should be taken into consideration when model averaging or discussing model selection results. Where papers did not report Akaike weights, or where Akaike weights were not applicable (*i.e.* Schwartz's criterion (Schwarz, 1978) and deviance information criterion, (DIC) (Spiegelhalter et al., 2002)), we designated the confidence set as the set of models within 2 ΔAIC or ΔDIC of the top model (Burnham and Anderson, 2002). We categorized papers with only one model supported in all model analyses (a confidence set of one) as strong inference and papers with > 1 top model in all model analyses as weak inference. We selected this narrow definition because it most closely approximates the unequivocal conclusion of the null hypothesis test as described by Platt (1964). If some model analyses contained one top model and other analyses within the same paper contain >1 top model, we classified the paper as including both types of inference. Papers that did not provide sufficient information to determine confidence sets were categorized as “unknown” inference.

2.2. Management recommendations

We categorized each paper's recommendations as non-management, vague, specific, or adaptive. Some papers did not provide explicit management recommendations but predicted how factors beyond local management control (*e.g.*, climate change, urban expansion) may change ecosystems or organisms. Vague recommendations listed how the ecosystem needed to be structured or what changes needed to occur without providing managers with explicit actions to implement. Specific recommendations were explicit in what actions managers needed to take and how these actions would directly affect the organism or ecosystem in question. Adaptive recommendations explicitly evoke the implementation of management actions while reducing uncertainty through monitoring in an iterative, learning process.

2.3. Uncertainty

To determine if authors acknowledged model selection uncertainty, we searched each paper containing MMI for the term “uncertainty” and recorded the context in which it was used. Authors that did not use the term uncertainty or used the term outside of their model selection results were categorized as not acknowledging uncertainty. If authors mentioned uncertainty as the reason for model averaging or explicitly stated their model selection as having uncertainty, we categorized them as