Benefits of Bayesian Modelling For Conservation

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Abstract

INTRODUCTION:The challenges and needs of conservation science are well-suited for Bayesian data analysis

Conservation science in the 21st century seeks to address the dual crises of climate change and rapid biodiversity loss. These are urgent problems that require action.

1. Accelerating loss of biodiversity, nature and benefits (Brondizio et al., 2019) Ripple et al., 2017; Tittensor et al., 2014.
2. Conserving biodiversity is at the heart of the Convention on Biological Diversity's (CBD) Aichi targets (UNEP CBD 2010) and of Sustainable Development Goal 15 (General Assembly of the United Nations 2015).
3. Williams et al 2019 https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/conl.12720

Though action is urgently needed, effective biodiversity conservation and durable climate change solutions rely on evidence to make decisions.

1. âĂIJbest available scienceâĂİ often required by policy
2. part of science process, though often âĂIJidealâĂİ data are not available
3. synthesizing multiple data sources and incomplete datasets may be required

A critical part of building the evidence base is transparency and reproducibility in science.

1. This includes being transparent and clear about uncertainty
2. Communicating/quantifying uncertainty about climate change mitigation (e.g., principles of Natural Climate Solutions, Ellis 2023, IPCC requires uncertainty (Chap 3 from 2006))

Bayesian data analysis provides a framework and approaches that align well with these needs of conservation biology.

1. Moving beyond null-hypothesis testing

2. Propagation of uncertainty

3. Priors as a way to synthesize âĂIJbest available scienceâĂİ T

4. hough some fields within conservation biology and natural resource management have adopted Bayesian methods (wildlife mark and recapture models/occupancy models, fisheries) these approaches generally are not widely used in conservation science

5. consider adding- easier now to do it! computer power plus tools

We aim to help accelerate adoption of Bayesian data analytical approaches in conservation science because we believe these approaches offer features that are well-suited to the field and could enhance progress, with more widespread adoption. We describe the benefits of using Bayesian methods for conservation science questions, describe what is required to use these methods, provide example code relevant to current conservation problems, and share resources and a glossary that we hope will make Bayesian tools more approachable to those who have not used them before.

Benefits for Conservation

Conservation questions can be complex, sometimes requiring analyses for which frequentist statistics are unable to compute the associated uncertainties (Bolker et al., 2009; Bates, 2006). Fortunately, Bayesian methods contain the flexibility to tackle this complexity. Often conservation scientists might be interested in deciding whether an alternative management practice produces the same result as a current management practice. But frequentist statistics cannot provide such evidence; it can only provide evidence against a null hypothesis (Gallistel, 2009). But Bayesian analysis can provide evidence to support a null hypothesis, e.g., that the alternative and current management practices produce similar results (Gallistel, 2009). Conservationists are often particularly interested in species with small populations, since these are often the ones most at risk of extinction, or ones that are poorly understood (Stinchcomb et al., 2002). Frequentist statistics rely on asymptotic behavior, which makes it difficult for these methods to draw useful conclusions from small sample sizes (McNeish, 2016). Bayesian methods, however, do not have this same reliance, and so are better able to accommodate small sample sizes (McNeish, 2016). However, these methods still require care when working with small sample sizes, because priors matter much more; yet this is also an opportunity to include the full gamut of prior knowledge from many sources that may not typically be included in quantitative analyses (McNeish, 2016). Frequentist statistics produce metrics like confidence intervals and p-values, which have very specific interpretations (Fornacon-Wood, 2021). However, these metrics are often misinterpreted. Bayesian statistics, in contrast, produces credible intervals, for which the intuitive interpretation matches the technical definition, yielding much more easily interpretable results, particularly for non-statistician colleagues and decision-makers (Fornacon-Wood, 2021). Conservation often requires making easily-interpretable wildlife status categories to inform decision making (Brooks, 2008). For example, conservation might be prioritized for species declining âĂŸâĂŹrapidlyâĂŹâĂŹ versus âĂŸâĂŹmoderately.âĂŹâĂŹ These discrete categories require information about when a speciesâĂŹ population has passed a particular threshold (Brooks, 2008). Bayesian models make it assess the evidence for whether a species has surpassed a given threshold (Brooks, 2008). Conservation evidence comes in many forms, including from quantitative studies, community knowledge, expert knowledge, traditional ecological knowledge, and others. Effective conservation decisions require integrating these types of information (Stern Humphries, 2022). Bayesian methods enable two fruitful avenues for such inclusion. First, information can be amalgamated into Bayesian Belief Networks (Marcot et al., 2001, Newton et al., 2007). Second, extant information can be used to inform prior distributions (OâĂŹLeary et al., 2008). These Bayesian methods are particularly useful because they not only include a range of informating types, but also include associated uncertainty (Stern Humphries, 2022). Ecosystems are dynamic and often yield unexpected behaviors (Gross, 2013;Levin et al., 2012). Adaptive management is designed for just such systems that may respond unexpectedly to interventions (Holling, 1978). Yet frequentist statistical frameworks rarely provide information necessary to inform adaptive management (Prato, 2005). Specifically, frequentist statistics incapacity to compare support for a variety of hypotheses (including a âĂŸnullâĂŹ hypothesis) prevents this method from informing what interventions will most likely bring about conservation gains (Prato, 2005). Many conservation/environmental problems require integrating multiple datasets, multiple sources of uncertainty, or multiple modeling steps. Bayesian approaches enable straightforward propagation of uncertainty (Draper, 1995; Gilbert et al., 2023; Eyster et al., 2022, Saunders et al., 2019))

Why now?

Case Studies

Future Vision

Box 1: Defining Bayesian Analysis

Box 2: Resources to Get Started

References

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Figures