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978-0-521-61559-4 - Bayesian Methods for Ecology  
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## **Bayesian Methods for Ecology**

The interest in using Bayesian methods in ecology is increasing, but most ecologists do not know how to carry out the required analyses. This book bridges that gap. It describes Bayesian approaches to analysing averages, frequencies, regression, correlation and analysis of variance in ecology. The book also incorporates case studies to demonstrate mark-recapture analysis, development of population models and the use of subjective judgement. The advantages of Bayesian methods, including the incorporation of any relevant prior information and the ability to assess the evidence in favour of competing hypotheses, are also described here. The analyses described in this book use the freely available software WinBUGS, and there is an accompanying website (<http://arcue.botany.unimelb.edu.au/bayes.html>) containing the data files and WinBUGS codes that are used in the book. The Bayesian methods described here will be of use to ecologists from the level of upper undergraduate and above.

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CAMBRIDGE UNIVERSITY PRESS  
 Cambridge, New York, Melbourne, Madrid, Cape Town,  
 Singapore, São Paulo

Cambridge University Press  
 The Edinburgh Building, Cambridge CB2 2RU, UK  
 Published in the United States of America by  
 Cambridge University Press, New York

[www.cambridge.org](http://www.cambridge.org)  
 Information on this title: [www.cambridge.org/9780521850575](http://www.cambridge.org/9780521850575)

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First published 2007

Printed in the United Kingdom at the University Press, Cambridge

*A catalogue record for this publication is available from the British Library*

*Library of Congress Cataloging-in-Publication Data*

McCarthy, Michael A., 1968-  
 Bayesian methods for ecology / Michael A. McCarthy.  
 p. cm.

Includes bibliographical references and index.

ISBN-10: 0-521-85057-6

ISBN-13: 978-0-521-85057-5

ISBN-10: 0-521-61559-3 (pbk.)

ISBN-13: 978-0-521-61559-4 (pbk.)

1. Ecology—Research—Statistical methods. 2. Bayesian statistical decision theory. I. Title.

QH541.2.M38 2007  
 577.072'4—dc22 2006102405

ISBN-13: 978-0-521-85057-5 hardback  
 ISBN-13: 978-0-521-61559-4 paperback

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*To Kirsten and Owen*

Contents

<i>Preface</i>	<i>page xi</i>
<b>1 Introduction</b>	<b>1</b>
Example 1: Logic in determining the presence or absence of a species	4
Example 2: Estimation of a mean	20
Concluding remarks	29
<b>2 Critiques of statistical methods</b>	<b>30</b>
Introduction	30
Sex ratio of koalas	31
Null hypothesis significance testing	35
Information-theoretic methods	45
Bayesian methods	52
Estimating effect sizes	58
Concluding remarks	61
<b>3 Analysing averages and frequencies</b>	<b>63</b>
The average	63
The Poisson distribution with extra variation	71
Estimating differences	71
Required sample sizes when estimating means	73
Estimating proportions	81
Multinomial models	88
Concluding remarks	92
<b>4 How good are the models?</b>	<b>94</b>
How good is the fit?	95

	How complex is the model?	101
	Combining measures of fit and simplicity	105
	The Bayes factor and model probabilities	108
	Evaluating the shape of distributions	116
	Concluding remarks	118
<b>5</b>	<b>Regression and correlation</b>	<b>119</b>
	Regression	119
	Correlation	148
	Concluding remarks	156
<b>6</b>	<b>Analysis of variance</b>	<b>158</b>
	One-way ANOVA	158
	Coding of variables	159
	Fixed and random factors	162
	Two-way ANOVA	165
	Interaction terms in ANOVA	167
	Variance partitioning	167
	An example of ANOVA: effects of vegetation removal on a marsupial	170
	Analysis of covariance	180
	ANCOVA: a case study	182
	Log-linear models for contingency tables	190
	Concluding remarks	193
	<b>CASE STUDIES</b>	
<b>7</b>	<b>Mark-recapture analysis</b>	<b>197</b>
	Methods	197
<b>8</b>	<b>Effects of marking frogs</b>	<b>207</b>
	Logistic regression	209
	Model A	210
	Models B and C	211
<b>9</b>	<b>Population dynamics</b>	<b>217</b>
	Mountain pygmy possums	217
<b>10</b>	<b>Subjective priors</b>	<b>225</b>
	Eliciting probabilities	225

Handling differences of opinion	226
Using subjective judgements	227
Using the consensus of experts	227
Representing differences of opinion with subjective priors	230
Using Bayesian networks to represent expert opinion	236
Concluding remarks	243
<b>11 Conclusion</b>	<b>244</b>
Prior information	244
Flexible statistical models	245
Intuitive results	245
Bayesian methods make us think	245
A Bayesian future for ecology	246
<b>APPENDICES</b>	
<b>A A tutorial for running WinBUGS</b>	<b>249</b>
A summary of steps for running WinBUGS	249
The steps in more detail	249
How to write WinBUGS code	253
<b>B Probability distributions</b>	<b>255</b>
Discrete random variables	255
Continuous random variables	257
Univariate discrete distributions	261
Univariate continuous distributions	266
Multivariate discrete distributions	272
Multivariate continuous distributions	273
Conjugacy	275
<b>C MCMC algorithms</b>	<b>277</b>
Why does it work?	280
References	282
Index	293

## Preface

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I have three vivid memories about learning statistics as an undergraduate that all involve misconceptions. Firstly, I remember my lecturer telling me that, after obtaining a result that was not statistically significant, I should conclude that timber harvesting did not have an effect (on what, I cannot remember). While the logic was flawed, I have since realized that it is a misconception shared by many ecologists.

My second memory is of reading about Bayesian analyses in journal articles. I wondered what Bayesian methods were, how they differed from the statistical approaches I had been taught (frequentist methods such as null hypothesis testing and construction of confidence intervals), and why I had never heard of them before. On reading the articles, I concluded that Bayesian methods must be hard to do. It turns out that I was incorrect again.

My third memory is that statistics was boring. I was wrong again. I was reasonably good at the mathematics involved, but it was not until I started doing my own data analyses during my Ph.D. that I saw the benefits of using statistics. I began to learn about different ways to do statistics (e.g. likelihood-based methods), and also re-learned some old topics (e.g. realizing the importance of and learning how to calculate statistical power). For me, statistics and probability continue to be a world of learning.

This book represents a stage in my journey through the world of statistics. It is born out of a frustration with how conventional statistical methods are misused in ecology on a routine basis, and a belief that Bayesian methods are relevant and useful. I hope this book convinces readers of the value of Bayesian methods and helps them learn Bayesian methods more quickly than me.



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Approximately five years ago I used null hypothesis significance testing to evaluate the predictions of some models of population viability. An astute reviewer questioned this approach because the models were surely known to be wrong a priori. The reviewer provided a glorious list of quotes that attacked null hypothesis significance testing (not unlike the quotes in Chapter 2). I started thinking about alternatives, leading me to Hilborn and Mangel's (1997) *The Ecological Detective*, and beyond.

*The Ecological Detective* (Hilborn and Mangel, 1997) is one of the best books available to ecologists for learning about Bayesian methods. However, ecologists wishing to use the suggested methods need at least some skills in computer programming. I intend my book to provide a bridge between a desire to conduct Bayesian analyses and the book by Hilborn and Mangel (1997). WinBUGS code for the analyses in this book is available from <http://arcue.botany.unimelb.edu.au/bayes.html>.

The bridge is built by using the freely available program WinBUGS (Spiegelhalter *et al.*, 2005; Appendix A) to conduct the vast majority of analyses in this book. I try to start gently, illustrating the most basic analyses, before giving some more complicated examples. More experienced users will find some analyses trivial, and novices may find some examples impenetrable. The aim is to provide a sufficient diversity of examples that the reader will be able to learn how to construct their own statistical models and conduct their own analyses.

This book is not necessarily designed to be read from cover to cover. Read Chapters 1 and 2 if you wish to know more about the differences between Bayesian and frequentist methods. If you just want to learn how to conduct Bayesian analyses, start with Chapter 1, Appendix A, and then move to Chapter 3 or whichever topic is most relevant. As you become more familiar with Bayesian methods, the entire content of the book will become more accessible.

I have many people to thank for their help while writing this book. Ralph Mac Nally and Alan Crowden's suggestion to write this book started the ball rolling. Brendan Wintle has been extremely important as a colleague, a source of advice and insights, and a sounding board for ideas. Kirsten Parris, David Lindenmayer, Jane Elith, Pip Masters, Linda Broome, Tara Martin, Mark McDonnell, Michael Harper, Brendan Wintle, Amy Hahs, Rodney van der Ree and many others have provided data for analysis over the years. I would have learnt very little without them.

This book owes much to the availability of WinBUGS, and I thank the team that developed the software. In particular, David Spiegelhalter,

Andrew Thomas and Bob O'Hara have answered questions and investigated software bugs from time to time.

Hugh Possingham, Mark Burgman, David Lindenmayer and Mark McDonnell have provided opportunities for me to conduct research into risk assessment, and the use of Bayesian methods. They have been influential, as have Fiona Fidler, Neil Thomason and my colleagues listed above. Various funding agencies have supported my research, with the Australian Research Council and The Baker Foundation being particularly generous.

I'd like to thank my parents David and Sue for fostering my interests in mathematics and ecology, and Dr John Gault for his enthusiastic interest in Bayesian issues of a medical nature.

Finally, thank you to everyone who has provided comments, in particular Mark Burgman, Geoff Cumming, Aaron Ellison, Ralph Mac Nally, Kirsten Parris, Gerry Quinn and Julia Stammers, who read most if not all of earlier drafts. Peter Baxter, Barry Brook, Ryan Chisholm, Gareth Davies, Lou Elliott, Fiona Fidler, Bill Langford, Terry Walshe and Nick Williams also provided helpful comments on various sections.