

# Contents

<i>List of contributors</i>	xiii
<b>Introduction</b> <i>Vinicio J. Sosa, Simoneta Negrete-Yankelevich, and Gordon A. Fox</i>	1
Why another book on statistics for ecologists?	1
Relating ecological questions to statistics	5
A conceptual foundation: the statistical linear model	7
What we need readers to know	12
How to get the most out of this book	13
<b>1 Approaches to statistical inference</b> <i>Michael A. McCarthy</i>	15
1.1 Introduction to statistical inference	15
1.2 A short overview of some probability and sampling theory	16
1.3 Approaches to statistical inference	19
1.3.1 Sample statistics and confidence intervals	20
1.3.2 Null hypothesis significance testing	21
1.3.3 Likelihood	27
1.3.4 Information-theoretic methods	30
1.3.5 Bayesian methods	33
1.3.6 Non-parametric methods	39
1.4 Appropriate use of statistical methods	39
<b>2 Having the right stuff: the effects of data constraints on ecological data analysis</b> <i>Earl D. McCoy</i>	44
2.1 Introduction to data constraints	44
2.2 Ecological data constraints	45
2.2.1 Values and biases	45
2.2.2 Biased behaviors in ecological research	47
2.3 Potential effects of ecological data constraints	48
2.3.1 Methodological underdetermination and cognitive biases	48
2.3.2 Cognitive biases in ecological research?	49
2.4 Ecological complexity, data constraints, flawed conclusions	50
2.4.1 Patterns and processes at different scales	51
2.4.2 Discrete and continuous patterns and processes	52
2.4.3 Patterns and processes at different hierarchical levels	54
2.5 Conclusions and suggestions	56
<b>3 Likelihood and model selection</b> <i>Shane A. Richards</i>	58
3.1 Introduction to likelihood and model selection	58
3.2 Likelihood functions	59

3.2.1	Incorporating mechanism into models	61
3.2.2	Random effects	63
3.3	Multiple hypotheses	65
3.3.1	Approaches to model selection	67
3.3.2	Null hypothesis testing	68
3.3.3	An information-theoretic approach	70
3.3.4	Using AIC to select models	73
3.3.5	Extending the AIC approach	74
3.3.6	A worked example	76
3.4	Discussion	78
<b>4 Missing data: mechanisms, methods, and messages</b>		
	<i>Shinichi Nakagawa</i>	81
4.1	Introduction to dealing with missing data	81
4.2	Mechanisms of missing data	83
4.2.1	Missing data theory, mechanisms, and patterns	83
4.2.2	Informal definitions of missing data mechanisms	83
4.2.3	Formal definitions of missing data mechanisms	84
4.2.4	Consequences of missing data mechanisms: an example	86
4.3	Diagnostics and prevention	88
4.3.1	Diagnosing missing data mechanisms	88
4.3.2	How to prevent MNAR missingness	90
4.4	Methods for missing data	92
4.4.1	Data deletion, imputation, and augmentation	92
4.4.2	Data deletion	92
4.4.3	Single imputation	92
4.4.4	Multiple imputation techniques	94
4.4.5	Multiple imputation steps	95
4.4.6	Multiple imputation with multilevel data	98
4.4.7	Data augmentation	101
4.4.8	Non-ignorable missing data and sensitivity analysis	101
4.5	Discussion	102
4.5.1	Practical issues	102
4.5.2	Reporting guidelines	103
4.5.3	Missing data in other contexts	104
4.5.4	Final messages	105
<b>5 What you don't know can hurt you: censored and truncated data in ecological research</b>		
	<i>Gordon A. Fox</i>	106
5.1	Censored data	106
5.1.1	Basic concepts	106
5.1.2	Some common methods you should not use	107
5.1.3	Types of censored data	109
5.1.4	Censoring in study designs	111
5.1.5	Format of data	113
5.1.6	Estimating means with censored data	113
5.1.7	Regression for censored data	116

5.2	Truncated data	124
5.2.1	Introduction to truncated data	124
5.2.2	Sweeping the issue under the rug	125
5.2.3	Estimation	125
5.2.4	Regression for truncated data	127
5.3	Discussion	129
<b>6</b>	<b>Generalized linear models</b> <i>Yvonne M. Buckley</i>	131
6.1	Introduction to generalized linear models	131
6.2	Structure of a GLM	135
6.2.1	The linear predictor	135
6.2.2	The error structure	136
6.2.3	The link function	136
6.3	Which error distribution and link function are suitable for my data?	137
6.3.1	Binomial distribution	138
6.3.2	Poisson distribution	141
6.3.3	Overdispersion	143
6.4	Model fit and inference	145
6.5	Computational methods and convergence	146
6.6	Discussion	147
<b>7</b>	<b>A statistical symphony: instrumental variables reveal causality and control measurement error</b> <i>Bruce E. Kendall</i>	149
7.1	Introduction to instrumental variables	149
7.2	Endogeneity and its consequences	151
7.2.1	Sources of endogeneity	152
7.2.2	Effects of endogeneity propagate to other variables	154
7.3	The solution: instrumental variable regression	154
7.3.1	Simultaneous equation models	158
7.4	Life-history trade-offs in Florida scrub-jays	158
7.5	Other issues with instrumental variable regression	161
7.6	Deciding to use instrumental variable regression	163
7.7	Choosing instrumental variables	165
7.8	Conclusion	167
<b>8</b>	<b>Structural equation modeling: building and evaluating causal models</b> <i>James B. Grace, Samuel M. Scheiner, and Donald R. Schoolmaster, Jr.</i>	168
8.1	Introduction to causal hypotheses	168
8.1.1	The need for SEM	168
8.1.2	An ecological example	169
8.1.3	A structural equation modeling perspective	171
8.2	Background to structural equation modeling	173
8.2.1	Causal modeling and causal hypotheses	173

8.2.2	Mediators, indirect effects, and conditional independence	174
8.2.3	A key causal assumption: lack of confounding	175
8.2.4	Statistical specifications	175
8.2.5	Estimation options: global and local approaches	176
8.2.6	Model evaluation, comparison, and selection	178
8.3	Illustration of structural equation modeling	179
8.3.1	Overview of the modeling process	179
8.3.2	Conceptual models and causal diagrams	180
8.3.3	Classic global-estimation modeling	181
8.3.4	A graph-theoretic approach using local-estimation methods	186
8.3.5	Making informed choices about model form and estimation method	190
8.3.6	Computing queries and making interpretations	193
8.3.7	Reporting results	196
8.4	Discussion	197
<b>9</b>	<b>Research synthesis methods in ecology</b> <i>Jessica Gurevitch</i> <i>and Shinichi Nakagawa</i>	200
9.1	Introduction to research synthesis	200
9.1.1	Generalizing from results	200
9.1.2	What is research synthesis?	201
9.1.3	What have ecologists investigated using research syntheses?	201
9.1.4	Introduction to worked examples	202
9.2	Systematic reviews: making reviewing a scientific process	203
9.2.1	Defining a research question	204
9.2.2	Identifying and selecting papers	204
9.3	Initial steps for meta-analysis in ecology	204
9.3.1	What not to do	205
9.3.2	Data: What do you need, and how do you get it?	205
9.3.3	Software for meta-analysis	207
9.3.4	Exploratory data analysis	207
9.4	Conceptual and computational tools for meta-analysis	210
9.4.1	Effect size metrics	210
9.4.2	Fixed, random and mixed models	210
9.4.3	Heterogeneity	211
9.4.4	Meta-regression	213
9.4.5	Statistical inference	213
9.5	Applying our tools: statistical analysis of data	214
9.5.1	Plant responses to elevated CO <sub>2</sub>	214
9.5.2	Plant growth responses to ectomycorrhizal (ECM) interactions	220
9.5.3	Is there publication bias, and how much does it affect the results?	221
9.5.4	Other sensitivity analyses	222
9.5.5	Reporting results of a meta-analysis	223
9.6	Discussion	224
9.6.1	Objections to meta-analysis	224
9.6.2	Limitations to current practice in ecological meta-analysis	226
9.6.3	More advanced issues and approaches	226

<b>10 Spatial variation and linear modeling of ecological data</b>	
<i>Simoneta Negrete-Yankelevich and Gordon A. Fox</i>	228
10.1 Introduction to spatial variation in ecological data	228
10.2 Background	232
10.2.1 Spatially explicit data	232
10.2.2 Spatial structure	232
10.2.3 Scales of ecological processes and scales of studies	236
10.3 Case study: spatial structure of soil properties in a <i>milpa</i> plot	237
10.4 Spatial exploratory data analysis	238
10.5 Measures and models of spatial autocorrelation	239
10.5.1 Moran's $I$ and correlograms	240
10.5.2 Semi-variance and the variogram	242
10.6 Adding spatial structures to linear models	246
10.6.1 Generalized least squares models	247
10.6.2 Spatial autoregressive models	250
10.7 Discussion	259
<b>11 Statistical approaches to the problem of phylogenetically correlated data</b>	
<i>Marc J. Lajeunesse and Gordon A. Fox</i>	261
11.1 Introduction to phylogenetically correlated data	261
11.2 Statistical assumptions and the comparative phylogenetic method	262
11.2.1 The assumptions of conventional linear regression	263
11.2.2 The assumption of independence and phylogenetic correlations	265
11.2.3 What are phylogenetic correlations and how do they affect data?	266
11.2.4 Why are phylogenetic correlations important for regression?	272
11.2.5 The assumption of homoscedasticity and evolutionary models	278
11.2.6 What happens when the incorrect model of evolution is assumed?	280
11.3 Establishing confidence with the comparative phylogenetic method	281
11.4 Conclusions	283
<b>12 Mixture models for overdispersed data</b>	
<i>Jonathan R. Rhodes</i>	284
12.1 Introduction to mixture models for overdispersed data	284
12.2 Overdispersion	286
12.2.1 What is overdispersion and what causes it?	286
12.2.2 Detecting overdispersion	288
12.3 Mixture models	289
12.3.1 What is a mixture model?	289
12.3.2 Mixture models used in ecology	292
12.4 Empirical examples	293
12.4.1 Using binomial mixtures to model dung decay	293
12.4.2 Using Poisson mixtures to model lemur abundance	299
12.5 Discussion	306
<b>13 Linear and generalized linear mixed models</b>	
<i>Benjamin M. Bolker</i>	309
13.1 Introduction to generalized linear mixed models	309
13.2 Running examples	310

13.3	Concepts	311
13.3.1	Model definition	311
13.3.2	Conditional, marginal, and restricted likelihood	319
13.4	Setting up a GLMM: practical considerations	322
13.4.1	Response distribution	322
13.4.2	Link function	323
13.4.3	Number and type of random effects	323
13.5	Estimation	323
13.5.1	Avoiding mixed models	324
13.5.2	Method of moments	324
13.5.3	Deterministic/frequentist algorithms	324
13.5.4	Stochastic/Bayesian algorithms	325
13.5.5	Model diagnostics and troubleshooting	326
13.5.6	Examples	327
13.6	Inference	328
13.6.1	Approximations for inference	328
13.6.2	Methods of inference	329
13.6.3	Reporting the GLMM results	331
13.7	Conclusions	333
	<i>Appendix</i>	335
	<i>Glossary</i>	345
	<i>References</i>	354
	<i>Index</i>	379