

2.4.2	Profile likelihood	25
2.4.3	Bootstrap	27
2.5	Summary	30
2.6	Exercises	31

II Simple Methods

3	Building blocks	37
3.1	State and observation models	37
3.1.1	State models	39
3.1.2	Survey design and observation models	43
3.2	Design and model	46
3.2.1	What is a survey design?	47
3.2.2	Design- vs. model-based inference	47
3.2.3	Can we tell if the model is wrong?	49
3.2.4	Design-based vs. Model-based: pros and cons	51
3.2.5	Relevance of design for likelihood-based inference	52
3.3	Summary	53
4	Plot sampling	55
4.1	Introduction	55
4.2	A simple plot survey	56
4.3	Estimation by design	57
4.3.1	Horvitz–Thompson estimator of abundance	57
4.4	Maximum likelihood estimation	59
4.4.1	Point estimation	60
4.4.2	Interval estimation	60
4.4.3	A more realistic example	63
4.5	Effect of violating assumptions	66
4.6	Summary	67
4.7	Exercises	67
5	Removal, catch-effort and change-in-ratio	72
5.1	Introduction	72
5.2	Removal method	74
5.2.1	Point estimation	74
5.2.2	Simple removal method MLE	76
5.2.3	Interval estimation	77
5.2.4	Heterogeneity	83
5.3	Catch-effort	88
5.3.1	Likelihood	90
5.3.2	Removal models and model selection	91
5.3.3	A word on CPUE as an index of abundance	93
5.4	Change-in-ratio	94

5.4.1	Full likelihood	96
5.4.2	Conditional likelihood	97
5.5	Effect of violating main assumptions	99
5.6	Summary	99
5.7	Exercises	101
6	Simple mark-recapture	104
6.1	Introduction	104
6.2	Single recapture and some notation	106
6.2.1	St Andrews data example	107
6.3	A two-sample mark-recapture likelihood	108
6.3.1	First capture occasion	109
6.3.2	Second capture occasion	109
6.3.3	Putting the two capture occasions together	111
6.3.4	Interval estimation	111
6.3.5	Heterogeneity	113
6.4	Related methods and models	116
6.4.1	Unknown marking process	116
6.4.2	Removal method likelihood	116
6.4.3	Hypergeometric models	117
6.4.4	Single mark, multiple captures	117
6.5	Multiple occasions: the "Schnabel census"	117
6.5.1	A likelihood for multiple capture occasions	118
6.5.2	Capture histories and individual identification	118
6.6	Types of mark-recapture model	119
6.6.1	Classification by observation model	119
6.6.2	Models M_0 , M_t , M_b , M_{tb}	121
6.6.3	Likelihoods for models M_0 , M_t , M_b , M_{tb}	121
6.7	Examples	123
6.7.1	St Andrews example data revisited	123
6.7.2	No animal heterogeneity; true model M_t	125
6.7.3	No heterogeneity; true model M_t ; small n	126
6.8	Effect of violating main assumptions	127
6.9	Summary	128
6.10	Exercises	128
7	Distance sampling	131
7.1	Introduction	131
7.2	Line transect sampling	132
7.2.1	A simple line transect survey	133
7.2.2	Maximum likelihood estimation	137
7.2.3	Horvitz-Thompson: estimation partly by design	143
7.2.4	Populations that occur in groups	145
7.2.5	Interval estimation	145
7.2.6	An example with heterogeneity	147

7.3	Point transect sampling	149
7.3.1	Maximum likelihood estimation	150
7.3.2	Horvitz-Thompson: estimation partly by design	154
7.3.3	Populations that occur in groups	155
7.3.4	Interval estimation	155
7.4	Other distance sampling methods	157
7.4.1	Cue counting	157
7.4.2	Trapping webs	158
7.4.3	Indirect distance sampling surveys	159
7.5	Effect of violating main assumptions	160
7.6	Summary	161
7.7	Exercises	162
8	Nearest neighbour and point-to-nearest-object	165
8.1	Introduction	165
8.2	Maximum likelihood estimation	167
8.3	Interval estimation	168
8.4	Example	169
8.5	Summary	171
8.6	Exercises	172
 III Advanced Methods		
9	Further building blocks	177
9.1	Introduction	177
9.2	State models	178
9.3	Observation models	180
10	Spatial/temporal models with certain detection	182
10.1	Introduction	182
10.2	Temporal modelling: migration counts	184
10.2.1	Estimation by design	184
10.2.2	Maximum likelihood estimation	185
10.2.3	Inference with "Unbinned" data	187
10.3	Spatial modelling: plot sampling	188
10.4	Spatio-temporal modelling	192
10.5	Other methods	193
10.6	Summary	196
10.7	Exercises	197
11	Dealing with heterogeneity	199
11.1	Introduction	199
11.1.1	Combining state and observation models	200
11.2	Distance sampling with covariates	201

11.2.1	Full likelihood: animal-level variables	202
11.2.2	Full likelihood: survey-level variables	204
11.2.3	Conditional likelihood: estimation partly by design	205
11.3	Mark-recapture	206
11.3.1	Notation	207
11.3.2	Animal-level stratification	208
11.3.3	Unobserved heterogeneity	209
11.3.4	Classification of models	212
11.3.5	Other methods	213
11.3.6	Observable heterogeneity: Horvitz–Thompson and con- ditional likelihood	214
11.3.7	Observable heterogeneity: full likelihood models . .	215
11.4	Removal methods	220
11.4.1	Animal-level stratification	220
11.4.2	Horvitz–Thompson and conditional likelihood . . .	221
11.4.3	Full likelihood methods	222
11.5	Summary	222
11.6	Exercises	223
12	Integrated models	227
12.1	Introduction	227
12.2	Distance sampling with a spatial model	228
12.2.1	Full likelihoods	228
12.2.2	GLM- and GAM-based methods	231
12.2.3	Confidence intervals	232
12.2.4	Example: Antarctic minke whales	232
12.3	Double-platform distance sampling	235
12.3.1	Full likelihood	235
12.3.2	Conditional likelihood	237
12.3.3	Example: North Sea harbour porpoise	239
12.4	Double-platform migration surveys	240
12.5	Other possibilities	243
12.6	Summary	243
12.7	Exercises	244
13	Dynamic and open population models	245
13.1	Introduction	246
13.2	Dynamic closed population example	247
13.2.1	State model	247
13.2.2	Observation model	249
13.2.3	Likelihood	250
13.3	Open population example	251
13.3.1	State model	252
13.3.2	Observation model	255
13.3.3	Likelihood	257

13.4 Model fitting	258
13.5 Extensions	260
13.5.1 A multiple-survey method example	260
13.5.2 Other extensions	261
13.6 Summary	262
13.7 Exercises	262

IV Overview

14 Which method?	269
14.1 Plot sampling	269
14.2 Removal, catch-effort and change-in-ratio	271
14.3 Mark-recapture	272
14.4 Distance sampling	273
14.4.1 Line transect sampling	273
14.4.2 Point transect sampling	274
14.4.3 Cue counting	274
14.4.4 Trapping webs	274
14.4.5 Indirect distance sampling surveys	275
14.5 Point-to-nearest-object and nearest neighbour methods	275
14.6 Migration counts	276
14.7 Spatial modelling and integrated models	276
A Notation and Glossary	278
A.1 Notation	278
A.2 Glossary	282
B Statistical formulation for observation models	284
B.1 Detection function	286
B.2 Multiple surveys	287
C The asymptotic variance of MLEs	289
C.1 Estimating the variance of an MLE	289
C.2 Estimating the variance of a function of an MLE	291
C.3 A one-parameter example	291
C.3.1 Fisher information version 1	292
C.3.2 Fisher information version 2	292
C.3.3 Observed information	292
C.3.4 Estimating the variance of $\hat{N}$	293
D State models for mark-recapture and removal methods	294
D.1 Static population	294
D.2 Independent dynamics	295
D.3 Markov dynamics	296

References 299

Index 307