Contents

Foreword v
Acknowledgements vii
List of Contributors xix

Introduction: From lions, to lion's manes, to dandelions: how different types of demographic data and methods are selected and why **1**
Roberto Salguero-Gómez and Marlène Gamelon

1 On the origins of this book 1
2 Origins of demographic analyses: from humans to nonhuman animals, plants, fungi, and microbes 2
3 Why use demographic methods across the Tree of Life? 2
4 From data acquisition to demographic analyses 3
5 Organisation of the book 6
6 Target audience 11
7 What next? A plea for a stronger, richer, broader, and more innovative demography 12
References 12

Part 1 Demographic Data Collection: From Genes to Environment **15**

1 Genetic data collection, pedigrees, and phylogenies **17**
Emily G. Simmonds, Alina K. Niskanen, Henrik Jensen, and Steven Smith

1.1 Introduction 17
1.2 Genetic pedigrees 19
1.3 Genetic phylogenies 19
1.4 Collection of genetic samples 21
1.5 Processing of samples (DNA extraction, amplification, and sequencing) 22
1.6 Preparation of data for analyses 23
1.7 Using the data to construct pedigrees and phylogenies 24
1.7.1 Pedigrees 24
1.7.2 Phylogenies 25
1.8 Conclusions 29
References 29

2 Biochemical and physiological data collection **35**
Oldřich Tomášek, Alan A. Cohen, Erola Fenollosa, Maurizio Mencuccini, Sergi Munné-Bosch, and Fanie Pelletier

2.1 Introduction 35
2.2 General criteria for selecting biomarkers in demographic studies 36
2.3 Designing the data collection 37
2.4 Physiological traits 37
2.4.1 Animal metabolism 37
2.4.2 Plant metabolism 39
2.4.3 Semen physiology 39
2.5 Biochemical traits 40
2.5.1 General biochemistry 40
2.5.2 Hormones 41
2.5.3 Oxidative stress 42
2.6 Telomeres 43
2.7 Immune markers 44
2.8 Epigenetic and omics data 45
2.9 Biologging 45
2.10 Combining biomarkers 46
2.11 Conclusions and perspectives 46
Acknowledgements 46
References 46

3 Social data collection and analyses **53**
Marie J. E. Charpentier, Marie Pelé, Julien P. Renoult, and Cédric Sueur

3.1 Introduction 53
3.2 Classic field-based methods for sampling social behaviours 54
3.2.1 A brief history of social studies, Jeanne Altmann, and the sampling of social behaviour 54
3.2.2 The interplay between field and lab studies 55
3.3 New technologies to sample social behaviour in the wild 55
3.3.1 A brief overview of animal's biologging 55
3.3.2 Biologging to determine individual social interactions and spatial associations 57
3.4 Analysing social behaviour 64
3.4.1 From data collection to social network analyses 64
3.4.2 Individual level: the roles of nodes 66
3.4.3 Intermediary levels 67
3.4.4 Group level and group comparison 67
3.4.5 Network dynamics 69
3.5 Conclusions 70
References 70

4 Growth rings across the Tree of Life: demographic insights from biogenic time series data **77**
Margaret E. K. Evans, Bryan A. Black, Donald A. Falk, Courtney L. Giebink, and Emily L. Schultz

4.1 Introduction 77
4.2 Tree and otolith growth rings—the basics 78

4.3 Growth rings in other organisms 81
4.4 Beyond growth rings and ring widths 82
4.5 Insights into demography 82
4.6 Ecosystem and macrosystem demography 86
4.7 A research agenda 87
4.8 Conclusions 89
References 90

5 Longitudinal demographic data collection 97
Marlène Gamelon, Josh A. Firth, Mathilde Le Moullec, William K. Petry, and Roberto Salguero-Gómez

5.1 Introduction: long-term field studies 97
5.2 Collection of longitudinal demographic data on mobile species 98
5.2.1 Procedures and type of data collected at the population level 98
5.2.2 Individual-level long-term field studies: concepts, methods, and data 101
5.3 Collection of longitudinal demographic data on sessile species 103
5.3.1 Procedures and type of data collected at the population level 104
5.3.2 Procedures and type of data collected at the individual level 104
5.4 The future of long-term studies: new aspects, current biases, and arising challenges 107
Acknowledgements 108
References 108

6 Drivers of demography: past challenges and a promise for a changed future 115
Pedro F. Quintana-Ascencio, Eric S. Menges, Geoffrey S. Cook, Johan Ehrlén, and Michelle E. Afkhami

6.1 Population dynamics and biotic and abiotic drivers 115
6.2 Challenges with incorporating drivers into structured population models 115
6.3 Quantifying drivers by observation and by experiments 117
6.4 Continuous drivers ('stress') 119
6.5 Episodic drivers ('disturbance') 120
6.6 Population dynamics in the landscape: influence of spatial habitat structure and heterogeneity 122
6.7 New and promising approaches 124
References 125

Part 2 Data- and Research Question-Driven Methods 131

7 Abundance-based approaches 133
Jonas Knape and Andreas Lindén

7.1 Aims of abundance analyses 133
7.2 Measures of abundance 134
7.2.1 Sampling abundance 134

7.3 Analytic approaches 135
7.3.1 Regression-type models 135
7.3.2 Dynamic abundance models 136
7.3.3 State-space models 143
7.4 Conclusions 145
References 147

8 Life tables: construction and interpretation 151
Owen R. Jones

8.1 Introduction 151
8.2 Cohort and period life tables 152
8.2.1 Cohort life tables 153
8.2.2 Period life tables 154
8.2.3 Fertility 156
8.3 The richness of life table information 157
8.4 Complications, correlations, and limitations 157
8.5 Conclusions 158
Data and code accessibility 158
References 159

9 Introduction to matrix population models 163
Yngvild Vindenes, Christie Le Coeur, and Hal Caswell

9.1 Introduction 163
9.2 An age-structured MPM 164
9.2.1 Life table for age structured population 164
9.2.2 Projecting growth of age structured population 165
9.2.3 Defining Leslie matrix elements for pre- and post-reproductive censuses 165
9.3 Stage-structured MPMs 166
9.4 Basic analytical results from MPMs 167
9.4.1 Asymptotic properties from the projection matrix 167
9.4.2 Sensitivity analysis of population growth rate 168
9.4.3 Life history characteristics 169
9.5 Case studies with different demographic structures 169
9.5.1 Case study 1: Age structure in Asian elephants 169
9.5.2 Case study 2: Life cycle stages in an isopod 171
9.5.3 Case study 3: Age and habitat structure in black-headed gulls 173
9.6 Conclusions 175
References 177

10 Integral projection models 181
Edgar J. González, Dylan Z. Childs, Pedro F. Quintana-Ascencio, and Roberto Salguero-Gómez

10.1 Introduction 181
10.2 Constructing a basic IPM 181
10.3 Modelling vital rates in terms of the state variable 185
10.3.1 Linear models 185
10.3.2 Generalised linear models 185

10.4 Combining the vital functions in the IPM 186
10.5 Perturbation analysis: sensitivity and elasticity 187
10.5.1 Perturbation on the kernel 187
10.5.2 Perturbation on the pre-existing and newborn sections of the kernel 187
10.5.3 Sensitivities on the vital rates 188
10.5.4 Sensitivities to vital rate parameters 188
10.6 Further considerations in the construction of vital-rate models 189
10.6.1 Extensions of the linear model 189
10.6.2 Model selection 189
10.7 Case studies 191
10.7.1 Case study 1: Soay sheep population structured by weight 191
10.7.2 Case study 2: Perennial herb population structured by height, elevation, and time since fire 191
References 193

11 Transient analyses of population dynamics using matrix projection models 197
David N. Koons, David T. Iles, and Iain Stott

11.1 Introduction 197
11.2 Examples 198
11.2.1 Example life cycle models 198
11.2.2 Transient analysis in constant environments 200
11.2.3 Transient perturbation analysis in constant environments 203
11.2.4 Population dynamics in time-varying environments 204
11.2.5 Transient perturbation analysis in time-varying environments 207
11.3 Conclusions 209
Acknowledgements 210
References 210

12 Individual-based models 213
Viktoriia Radchuk, Stephanie Kramer-Schadt, Uta Berger, Cédric Scherer, Pia Backmann, and Volker Grimm

12.1 Introduction 213
12.2 What are individual-based models and how do we document them? 213
12.3 Why individual-based models? 214
12.3.1 Emergent behaviour vs. imposed demographic rates 214
12.3.2 Local interactions and nonlinear feedbacks 215
12.4 The pros and cons of IBMs 216
12.5 Types of data used to build an IBM 217
12.6 Case studies 218
12.6.1 Vole–mustelid model 218
12.6.2 Wild boar–classical swine fever (CSF) virus model 220
12.6.3 Wild tobacco–insect model (TIMELY) 221
12.7 Conclusions 224
12.8 Note on Supplementary Comparison Supplementary list 225
References 226

13 Survival analyses **229**
Sarah Cubaynes, Simon Galas, Myriam Richaud, Ana Sanz Aguilar, Roger Pradel, Giacomo Tavecchia, Fernando Colchero, Sebastien Roques, Richard Shefferson, and Carlo Giovanni Camarda

13.1 Introduction 229
13.2 What is survival analysis and why do we need it? 229
13.2.1 Time matters 229
13.2.2 Censoring and missing data 230
13.2.3 Known fate data versus imperfect detection 230
13.3 Survival analyses in the lab: when it's (almost) all under control 230
13.3.1 Monitoring survival in the lab 230
13.3.2 Kaplan–Meier estimator and log-rank tests 230
13.3.3 Cox's proportional hazards to adjust for covariates 231
13.3.4 Example of a stress assay in an unconventional resistant organism: the tardigrade 231
13.4 Survival analyses in the wild: dealing with uncertainty and variable environments 232
13.4.1 Overview of CMR models 232
13.4.2 Environmental variability and individual heterogeneity in CMR models 234
13.4.3 Inference framework 234
13.4.5 Case studies in animal demography 235
13.4.6 Case studies in plant demography 236
13.5 Mortality analysis in human populations 237
13.5.1 Human data and assumptions 237
13.5.2 Parametric models over age 238
13.5.3 Overparametrised models: the example of the Lee–Carter model 239
13.5.4 Semiparametric models: the example of P-splines 239
13.5.5 Implementation example 239
13.6 Conclusions 239
References 240

14 Efficient use of demographic data: integrated population models **245**
Marlène Gamelon, Stefan J. G. Vriend, Marcel E. Visser, Caspar A. Hallmann, Suzanne T. E. Lommen, and Eelke Jongejans

14.1 Introduction: why use integrated population models? 245
14.2 How to build an IPM? 246
14.2.1 Population model 246
14.2.2 Individual likelihoods 246
14.2.3 Joint likelihood 246
14.3 Case studies 247
14.3.1 Blue tit 247
14.3.2 Common ragweed 251
Acknowledgements 253
References 254

Part 3 Applications 257

15 Spatial demography 259
Guillaume Péron

15.1 Introduction 259
15.2 Spatial variation in demographic rates 259
15.2.1 Statistical tools for nonparametric inference about spatial variation 259
15.2.2 Recent implementations in spatial demography 262
15.2.3 Discussion 263
15.3 Estimating dispersal fluxes 263
15.3.1 Integrated population models 264
15.3.2 Multisite capture–recapture models and integrated metapopulation models 264
15.3.3 Dispersal as a diffusion process along resistance surfaces 265
15.4 The feedback between space use and fitness 266
15.4.1 Principles of integral projection models as pertaining to spatial demography 266
15.4.2 Space use or resource selection? 266
15.4.3 Formal analysis of IPMs 267
15.4.4 Individual-based simulation approach 268
15.5 Conclusions 268
References 269

16 Evolutionary Demography 273
Shripad Tuljapurkar and Wenyun Zuo

16.1 Introduction 273
16.2 The early theory 273
16.3 Randomly varying environments 276
16.4 Post-reproductive life 279
16.5 Nonlinear models for mutation–selection 280
16.6 Density-dependent models 280
References 282

17 Reproductive value and analyses of population dynamics of age-structured populations 285
Bernt-Erik Sæther and Steinar Engen

17.1 Introduction 285
17.2 Stochastic theory 285
17.3 The concept of individual reproductive value 287
17.4 Temporal autocovariance in the environmental noise 289
17.5 Case studies 289
17.5.1 Moose on the island of Vega 289
17.5.2 A practical application: estimating risk of extinction in harvested Scandinavian lynx populations 290

17.6 Conclusions 293
Acknowledgements 294
References 294

18 Applying comparative methods to different databases: lessons from demographic analyses across mammal species 299
Jean-Michel Gaillard, Victor Ronget, Jean-François Lemaître, Christophe Bonenfant, Guillaume Péron, Pol Capdevila, Marlène Gamelon, and Roberto Salguero-Gómez

18.1 Introduction 299
18.2 Methods 301
18.2.1 Building databases and calculating demographic metrics 301
18.2.2 Statistical analyses accounting for phylogenetic inertia 302
18.3 Results 303
18.3.1 Allometric analyses 303
18.3.2 Assessing axes of variation among dimensionless demographic metrics 305
18.4 Conclusions 308
18.5 Prespectives 310
References 310

19 Adaptive management: making recurrent decisions in the face of uncertainty 313
James D. Nichols

19.1 Introduction 313
19.2 Structured decision-making 314
19.3 Adaptive management (AM) 314
19.3.1 Deliberative phase 315
19.3.2 Iterative phase 316
19.3.3 Double-loop learning phase 318
19.4 Demographic methods 318
19.4.1 Population size/abundance 318
19.4.2 Occupancy 319
19.4.3 Species richness 319
19.4.4 Landcover vegetative states 319
19.5 Case studies 320
19.5.1 Mallard (*Anas platyrhynchos*) duck harvest in North America 320
19.5.2 Management of vegetation states for Florida scrub jays (*Aphelocoma coerulescens*) 322
19.5.3 Disease control via AM 324
19.6 Conclusions 325
Acknowledgements 326
References 326

20 Heritability, polymorphism, and population dynamics: individual-based eco-evolutionary simulations 329
Anna Kuparinen

20.1 Introduction 329
20.2 Heritability and selection in the context of population dynamics 329

20.3 Generic ways to model the evolution of demographic rates 330
20.3.1 Parental trait values coupled with known heritability 330
20.3.2 Dummy genes coding the traits in a classic Mendelian manner 330
20.4 Case studies 332
20.4.1 Boreal forest adaptation to warming climate 332
20.4.2 Co-evolution of correlated traits in Atlantic cod 333
20.4.3 Evolution of a sexually polymorphic age at maturity in Atlantic salmon 336
20.5 Conclusions and future directions 337
References 339

21 Demographic processes in socially structured populations 341
Maria Paniw, Gabriele Cozzi, Stefan Sommer, and Arpat Ozgul

21.1 Introduction 341
21.2 A simulated, socially structured population 343
21.3 A socially structured matrix population model 344
21.4 A socially structured integral projection model 345
21.5 Explicitly accounting for group sizes in a population model 345
21.6 An individual-based model as a mechanistic approach to modelling sociality 345
21.7 Does increased model complexity improve inferences of population dynamics in a socially structured population? 346
21.8 Implications for life history models of socially structured populations 346
References 349

22 Demographic methods in epidemiology 351
Petra Klepac and C. Jessica E. Metcalf

22.1 Why demography is important to epidemic dynamics 351
22.2 Modelling the intersection between epidemiology and demography 352
22.3 Demographic underpinnings of a core parameter, R_0 355
22.4 A discrete-time multistate matrix approach 355
22.5 A specific example 356
22.6 Case study 358
22.7 Conclusions 359
References 360

Index 363