Amphibian Ecology and Conservation

A Handbook of Techniques

Edited by
C. Kenneth Dodd, Jr

OXFORD
UNIVERSITY PRESS

Techniques in Ecology and Conservation Series

Series Editor: William J. Sutherland

Bird Ecology and Conservation: A Handbook of Techniques
William J. Sutherland, Ian Newton, and Rhys E. Green

Conservation Education and Outreach Techniques
Susan K. Jacobson, Mallory D. McDuff, and Martha C. Monroe

Forest Ecology and Conservation: A Handbook of Techniques
Adrian C. Newton

Habitat Management for Conservation: A Handbook of Techniques
Malcolm Ausden

Conservation and Sustainable Use: A Handbook of Techniques
E.J. Milner-Gulland and J. Marcus Rowcliffe

Invasive Species Management: A Handbook of Techniques
Mick N. Clout and Peter A. Williams

Amphibian Ecology and Conservation: A Handbook of Techniques
C. Kenneth Dodd, Jr

Preface

As this volume is completed, more than 6400 amphibian species have been recognized, with new taxa being described nearly every day. The last few decades have seen an explosion in systematic research, particularly in the tropics. Long-recognized centers of diversity have been explored using increasingly sophisticated sampling techniques, yielding many new taxa. At the same time, new centers of speciation, such as Sri Lanka and the Western Ghats of India, have been discovered, while molecular techniques have yielded previously unsuspected diversity within some well-known taxa, such as the plethodontid salamanders of southeastern North America and the green toad (*Bufo viridis*) complex of Eurasia. For amphibian systematists, these are exciting times.

Unfortunately, amphibians are now at greater peril than at any time in recent geologic history, a situation chronicled in two recent data-rich books (Lannoo 2005; Stuart *et al.* 2008). Habitats are being lost at alarming rates because of expanding human populations and generally favorable economic conditions fostering development; emerging infectious diseases, particularly amphibian chytrid fungus (*Batrachochytrium dendrobatidis*), threaten worldwide impacts; non-indigenous species proliferate, affecting amphibians and their habitats; and amphibians, with their permeable skins, diverse life histories, and often biphasic life cycles requiring both terrestrial and aquatic habitats, are being saturated by a host of lethal and sublethal toxic substances. New threats, such as the effects of global climate change, further imperil amphibians, especially those with limited distributions and dispersal capabilities. Fully one-third of all amphibians are now considered threatened (Stuart *et al.* 2004), and 168 species have become extinct within the last two decades. Clearly, these are treacherous times for many frogs, salamanders, and caecilians.

Amphibians are, quite frankly, engaging animals. Despite Linnaeus' early characterization of amphibians in the context of "Terrible are thy works, O God", biologists have come to appreciate that their diverse life histories and shear numbers offer a wealth of material for research on basic ecological principles, such as trophic interactions, phenotypic plasticity, predator–prey interactions, community structure, mate choice and recognition, water balance, and many others. In response to threats, conservation biologists have probed these and other questions in hopes of understanding amphibian biology in order to prevent declines and extinctions. The basic and applied themes of biology merge

in these disciplines: understanding ecology leads to conservation options (see Gascon *et al.* 2007), and conservation-based research leads to a better appreciation of ecological principles.

To say that there are a great many techniques available in ecological and conservation-based research on amphibians is an understatement. The pages of journals such as *Herpetological Review* and *Applied Herpetology* contain techniques papers with every issue. Specialized books, such Heyer *et al.* (1994), Henle and Veith (1997), and Gent and Gibson (1998), offer additional summaries that are as applicable today as when they were published. No one volume can include all techniques. The current volume is meant not to supplant these earlier works, but to supplement them and add new areas not previously summarized, such as occupancy modeling, landscape ecology, genetics, telemetry, and disease biosecurity. Our objectives have been to delineate important new developments, to give an idea as to what the techniques tell or do not tell a researcher, to focus attention on biases and data inference, and to get readers to appreciate sampling as an integral part of their science, rather than just a means of capturing animals. The techniques used will set the boundaries within which results can or should be interpreted.

As noted earlier, amphibian systematics is a flourishing field, with many new opportunities made available by combining large datasets using molecular and morphological data with powerful computer analysis. The phylogeny of amphibians is undergoing increasingly sophisticated analysis. Some analyses, such as those of Frost *et al.* (2006), suggest relationships that differ substantially from "traditional" concepts. If accepted, extensive nomenclatural changes will be warranted. Although Frost *et al.* (2006) have advocated substantive changes in nomenclature, many of which will likely be accepted with further study, other amphibian biologists disagree with automatically accepting every change proposed by these authors. In this book, I have decided to retain the older nomenclature rather than make a taxonomic decision each time a name is mentioned. The intended audience of this volume (biologists starting their careers in ecology and conservation) likely will be more familiar with the older generic names of *Bufo*, *Rana*, and *Hyla*, and initially may be confused by the unfamiliar replacement names. Readers should be aware, however, that names such as *Lithobates* (= *Rana*, in part), *Anaxyrus* (= *Bufo*, in part), and others currently unfamiliar may soon be more commonplace.

I wish to thank the following for taking their valuable time to review manuscripts and offer suggestions for improving this volume: James Austin, Larissa Bailey, Bruce Bury, Dan Cogălniceanu, Sarah Converse, Steve Corn, Rafael Ernst, Alisa Gallant, Marian Griffey, Kerry Griffis-Kyle, Richard Griffiths,

Margaret Gunzburger, Tibor Hartel, Robert Jehle, Steve Johnson, Y.-C. Kam, Sarah Kupferberg, Frank Lemckert, Harvey Lillywhite, John Maerz, Joseph Mitchell, Clinton Moore, Erin Muths, James Petranka, Benedikt Schmidt, Ulrich Sinsch, Kevin Smith, Lora Smith, Joseph Travis, Susan Walls, and Matthew Whiles. I greatly appreciate the support from Ian Sherman and Helen Eaton at Oxford University Press and editorial help from freelance copy-editor Nik Prowse, and thank series editor, Bill Sutherland, for inviting me to edit the amphibian volume. This volume is dedicated to all the biologists who take up the challenge of amphibian ecology and conservation.

C. Kenneth Dodd, Jr

References

Frost, D. R., Grant, T., Faivovich, J., Bain, R. H., Haas, A., Haddad, C. F. B., de Sá, R. O., Channing, A.,Wilkinson, M., Donnellan, S. C. *et al*. (2006). The amphibian tree of life. *Bulletin of the American Museum of Natural History*, **297**, 1–370.

Gascon, C., Collins, J. P., Moore, R. D., Church, D. R., McKay, J. E., and Mendelson, III, J. R. (eds) (2007). *Amphibian Conservation Action Plan*. IUCN/SSC Amphibian Specialist Group, Gland and Cambridge.

Gent, T. and Gibson, S. (eds) (1998). *Herpetofauna Worker's Manual*. Joint Nature Conservation Committee, Peterborough.

Henle, K. and Veith, M. (eds) (1997). *Naturschutzrelevante Methoden der Feldherpetologie.* Mertensiella 7.

Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L.-A., and Foster, M. S. (eds). (1994). *Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians*. Smithsonian Institution Press, Washington DC.

Lannoo, M. J. (ed) (2005). *Amphibian Decline. The Conservation Status of United States Species.* University of California Press, Berkeley, CA.

Stuart, S., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fishman, D. L., and Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, **306**, 1783–6.

Stuart, S., Hoffman, M., Chanson, J. S., Cox, N. A., Berridge, R. J., Ramani, P., and Young, B. E. (eds) (2008). *Threatened Amphibians of the World*. Lynx Edicions, Barcelona; IUCN, Gland; Conservation International, Arlington, VA.

Contents

List of contributors xxv

Part 1 Introduction **1**

1 Amphibian diversity and life history **3**
Martha L. Crump

1.1 Introduction 3
1.2 Amphibian species richness and distribution 3
1.3 Amphibian lifestyles and life history diversity 5
1.3.1 *Caecilians* 6
1.3.1.1 Aquatic 7
1.3.1.2 Combination aquatic and terrestrial 7
1.3.1.3 Terrestrial and/or fossorial 7
1.3.2 Salamanders 7
1.3.2.1 Aquatic 8
1.3.2.2 Combination of aquatic and terrestrial 8
1.3.2.3 Terrestrial 9
1.3.2.4 Fossorial 10
1.3.2.5 Arboreal 10
1.3.3 Anurans 10
1.3.3.1 Aquatic/aquatic 10
1.3.3.2 Terrestrial/aquatic 11
1.3.3.3 Arboreal/aquatic 13
1.3.3.4 Fossorial/aquatic 14
1.3.3.5 Terrestrial/non-aquatic 14
1.3.3.6 Arboreal/non-aquatic 14
1.3.3.7 Fossorial/non-aquatic 15
1.4 Amphibian declines and why they matter 15
1.4.1 Economics 16
1.4.2 *Ecosystem function* 16
1.4.3 *Esthetics* 17
1.4.4 *Ethics* 17
1.5 References 17

2 Setting objectives in field studies **21**
Dan Cogălniceanu and Claude Miaud

2.1 Basic concepts for a good start 21

2.2 Steps required for a successful study 24
2.2.1 Temporal and spatial scales 24
2.2.2 *Choosing the model species* 25
2.2.3 *Pilot/desk study* 26
2.2.4 *Elaborate a conceptual model* 26
2.2.5 *The SMART approach* 27
2.2.6 *Applying the SMART approach to plan an amphibian inventory* 28
2.2.7 *Experimental versus field studies* 29
2.2.8 *Methods for sampling, data storage, and analysis* 29
2.3 Trade-offs and pitfalls 30
2.4 Ethical issues 31
2.5 Acknowledgments 32
2.6 References 32

Part 2 Larvae 37

3 Morphology of amphibian larvae 39
Roy W. McDiarmid and Ronald Altig

3.1 Background 39
3.2 Larval caecilians 40
3.2.1 Morphology and ontogeny 40
3.2.2 *Coloration* 42
3.2.3 *Diversity* 42
3.3 Larval and larviform salamanders 42
3.3.1 Morphology and ontogeny 42
3.3.2 *Coloration* 44
3.3.3 *Diversity* 44
3.4 Anuran tadpoles 45
3.4.1 Morphology and ontogeny 45
3.4.2 *Coloration* 49
3.4.3 *Diversity* 49
3.5 Summary 50
3.6 References 51

4 Larval sampling 55
David K. Skelly and Jonathan L. Richardson

4.1 Introduction 55
4.1.1 Why sample larvae? 55
4.1.2 *Target responses* 56
4.1.3 *Timing* 57
4.1.4 *Sampling effort* 57
4.2 Sampling techniques 58
4.2.1 Box/pipe sampler 58

4.2.1.1 Description 58
4.2.1.2 Application 60
4.2.1.3 Considerations 60
4.2.2 Dip net 60
4.2.2.1 Description 60
4.2.2.2 Application 61
4.2.2.3 Considerations 61
4.2.3 Seine 61
4.2.3.1 Description 61
4.2.3.2 Application 62
4.2.3.3 Considerations 62
4.2.4 Leaf litterbags 62
4.2.4.1 Description 62
4.2.4.2 Application 63
4.2.4.3 Considerations 63
4.2.5 Trapping 64
4.2.5.1 Description 64
4.2.5.2 Application 64
4.2.5.3 Considerations 64
4.2.6 Mark–recapture 65
4.2.6.1 Description 65
4.2.6.2 Application 66
4.2.6.3 Considerations 66
4.3 Other techniques 66
4.3.1 Bottom net *67*
4.3.2 *Electroshocking* 67
4.3.3 *Visual encounter survey* 67
4.4 Conclusions 67
4.5 Acknowledgments 68
4.6 References 68

5 Dietary assessments of larval amphibians 71
Matt R. Whiles and Ronald Altig

5.1 Background 71
5.2 Larval caecilians and salamanders 72
5.3 Anuran tadpoles 72
5.4 Assessing food sources and diets 73
5.4.1 Category I: preparatory studies 73
5.4.2 *Category II: gut contents* 74
5.4.3 *Procedures: anurans and small predators* 74
5.4.4 *Processing and analysis of gut contents* 75
5.5 Category III: assimilatory diet 78
5.5.1 Stable-isotope analysis 78
5.5.2 *Procedures* 80
5.5.3 *Fatty acid analyses* 81

5.6 Summary 82
5.7 References 83

6 Aquatic mesocosms 87

Raymond D. Semlitsch and Michelle D. Boone

6.1 Introduction 87
6.2 Historical background 88
6.3 Why use mesocosms? 90
6.4 Types of mesocosm 93
6.5 Setting up mesocosms 95
6.6 Common experimental designs 96
6.7 Case studies 98
6.7.1 Community ecology 98
6.7.2 *Evolutionary ecology* 99
6.7.3 *Ecotoxicology* 100
6.7.4 *Land use and management* 100
6.8 Conclusion 101
6.9 References 102

7 Water-quality criteria for amphibians 105

Donald W. Sparling

7.1 Introduction 105
7.2 Dissolved oxygen 105
7.3 Temperature 108
7.4 pH 110
7.5 Conductivity, hardness, and salinity 112
7.6 Total and dissolved organic carbon 113
7.7 Pollutants 114
7.7.1 Fertilizers and nitrogenous compounds 114
7.7.2 *Pesticides* 114
7.7.3 *Metals* 115
7.7.4 *Organic pollutants and halogenated hydrocarbons* 115
7.7.5 *Pharmaceuticals* 116
7.8 Summary and conclusions 116
7.9 References 117

Part 3 Juveniles and adults 121

8 Measuring and marking post-metamorphic amphibians 123

John W. Ferner

8.1 Introduction 123
8.2 Toe-clipping 125

8.2.1 *Anurans* 125
8.2.2 *Salamanders* 129
8.2.3 *Ethical issues related to toe-clipping of amphibians* 129
8.3 Branding 130
8.3.1 *Anurans* 130
8.3.2 *Salamanders* 131
8.4 Tagging and banding 131
8.4.1 *Anurans* 131
8.4.2 *Salamanders* 133
8.4.3 *Caecilians* 133
8.5 Trailing devices 133
8.6 Pattern mapping 134
8.6.1 *Anurans* 134
8.6.2 *Salamanders* 135
8.7 Passive integrated transponder (PIT) tags 136
8.7.1 *Anurans* 137
8.7.2 *Salamanders* 137
8.7.3 *Caecilians* 137
8.8 Taking measurements 138
8.9 Recommendations 138
8.10 References 139

9 Egg mass and nest counts 143

Peter W. C. Paton and Reid N. Harris

9.1 Background: using egg mass and nest counts to monitor populations 143
9.2 Oviposition strategies 144
9.3 Egg-mass counts 145
9.4 Amphibian nests and nest counts 147
9.5 Clutch characteristics 150
9.6 Spatial distribution of eggs 152
9.7 Breeding phenology 152
9.8 Number of surveys needed 153
9.9 Estimating egg-mass detection probabilities 154
9.10 Variation in counts among observers 154
9.11 Marking eggs 155
9.12 Situations in which nest counts are not practical 155
9.12.1 *Nest destruction* 155
9.12.2 *Desertion of attendant* 155
9.13 How to count eggs in a nest 156
9.14 Estimating hatching success 156
9.15 Analysis of egg-mass count data 157
9.16 Summary 157
9.17 References 158

10 Dietary assessments of adult amphibians 167

Mirco Solé and Dennis Rödder

10.1 Introduction 167
10.1.1 *Adult anurans* 167
10.1.2 *Adult caudata* 168
10.1.3 *Adult gymnophiona* 169
10.2 Methods to obtain prey items: historical overview 169
10.2.1 *Stomach flushing: materials* 170
10.2.2 *When should sampling be conducted?* 171
10.2.3 *How to perform the flush* 171
10.3 Data analysis 172
10.3.1 *Measuring prey availability and electivity* 174
10.3.2 *Comparing trophic niche structure* 176
10.3.3 *Fatty acid and stable-isotope analyses* 177
10.3.4 *Further biochemical analyses* 178
10.4 General considerations 178
10.4.1 *Ontogenetic changes* 179
10.4.2 *Seasonal changes* 179
10.5 Conclusions 180
10.6 Acknowledgments 180
10.7 References 180

11 Movement patterns and radiotelemetry 185

Dale M. Madison, Valorie R. Titus, and Victor S. Lamoureux

11.1 Introduction 185
11.2 Equipment 186
11.2.1 *Receivers and antennas* 186
11.2.2 *Transmitters* 186
11.2.2.1 External transmitters 187
11.2.2.2 Internal transmitters 188
11.3 Surgical techniques 189
11.3.1 *Surgery* 189
11.3.2 *Recovery and healing* 191
11.4 Tracking procedures 191
11.4.1 *Animal release* 191
11.4.2 *Locating signal source* 192
11.4.3 *Data collection* 193
11.5 Analysis of movement data 193
11.6 Validation of telemetry procedures 197
11.6.1 *Internal condition and mass* 197
11.6.2 *Movements* 198
11.6.3 *Reproduction* 198
11.6.4 *Injury and survivorship* 199

11.7 Conclusions 199
11.8 References 200

12 Field enclosures and terrestrial cages 203

Elizabeth B. Harper, Joseph H.K. Pechmann, and James W. Petranka

12.1 Introduction: amphibians in the terrestrial environment 203
12.2 What are the purposes of terrestrial enclosures? 204
12.3 Defining the research question 205
12.3.1 *Questions related to habitat types* 205
12.3.2 *Questions with treatments that can be assigned within enclosures* 207
12.4 Constructing enclosures 208
12.4.1 *Location of enclosures* 208
12.4.2 *Size and number of enclosures* 209
12.4.3 *Building enclosures that minimize escapes and trespasses* 216
12.4.4 *"Standardizing" conditions among enclosures* 218
12.5 Study species 218
12.5.1 *Choice of species* 218
12.5.2 *Source and age of animals* 219
12.6 Census techniques 219
12.6.1 *Individual marks* 219
12.6.2 *Methods of capture* 220
12.6.3 *Frequency of censuses* 220
12.7 Response metrics 221
12.7.1 *Vital rates: survival, growth, age at reproductive maturity, fecundity* 221
12.7.2 *Physiological responses* 222
12.7.3 *Behavioral responses* 222
12.8 Thinking outside the box 223
12.9 References 223

Part 4 Amphibian populations 227

13 Drift fences, coverboards, and other traps 229

John D. Willson and J. Whitfield Gibbons

13.1 Introduction 229
13.2 Drift fences, funnel traps, and other passive capture methods 229
13.2.1 *What are passive traps?* 229
13.2.2 *How are passive traps constructed, aligned, and monitored?* 231

13.2.3 *What can passive traps tell you? What can they not tell you?* 235
13.3 Coverboards and other traps that require active capture 236
13.3.1 *What are coverboards and other active traps?* 236
13.3.2 *How are active traps constructed, aligned, and monitored?* 237
13.3.3 *What can active traps tell you? What can they not tell you?* 240
13.4 References 241

14 Area-based surveys 247

David M. Marsh and Lillian M.B. Haywood

14.1 Introduction: what are area-based surveys? 247
14.1.2 *Why use area-based surveys?* 247
14.2 Kinds of area-based survey 249
14.3 Specific examples of area-based surveys 249
14.3.1 *Leaf-litter plots* 249
14.3.2 *Natural-cover surveys for terrestrial salamanders* 250
14.3.3 *Nocturnal transects* 251
14.3.4 *Quadrats for stream amphibians* 252
14.3.5 *Soil quadrats for caecilians* 252
14.4 Modifications 253
14.4.1 *Distance sampling* 253
14.4.2 *Adaptive cluster sampling* 253
14.5 Design issues: choice of sampling unit 254
14.5.1 *Design issues: how many replicates?* 255
14.5.2 *Reducing variation among replicates* 255
14.5.3 *How many times to survey each replicate?* 256
14.6 An example of study design 257
14.7 Assumptions of area-based surveys 259
14.8 Summary and recommendations 260
14.9 References 260

15 Rapid assessments of amphibian diversity 263

James R. Vonesh, Joseph C. Mitchell, Kim Howell, and Andrew J. Crawford

15.1 Background: rapid assessment of amphibian diversity 263
15.1.1 *When is an RA needed?* 264
15.2 Planning an RA 265
15.2.1 *Developing objectives* 265
15.2.2 *Costs and funding* 266
15.2.3 *Team selection and training* 266
15.2.4 *Permits* 267

15.2.5 *Data management* 267
15.2.6 *Developing the sampling plan* 268
15.2.6.1 Selecting sampling sites 268
15.2.6.2 Selecting sampling time 270
15.2.6.3 Selecting sampling techniques 270
15.2.6.3.1 *Visual encounter surveys (VESs)* 270
15.2.6.3.2 *Assumptions and limitations of VESs* 272
15.2.6.4 Determining what data to collect 273
15.2.6.5 Field logistics 274
15.3 In the field 274
15.4 Compiling data and interpreting results 274
15.5 Recommendations and reporting 275
15.6 Summary 275
15.7 References 276

16 Auditory monitoring of anuran populations 281

Michael E. Dorcas, Steven J. Price, Susan C. Walls, and William J. Barichivich

16.1 Introduction 281
16.2 MCS 281
16.2.1 *History and current status of MCS* 282
16.2.2 *Study objectives: what can MCS tell us?* 283
16.2.3 *Survey design* 283
16.2.4 *Other survey-design issues to consider: the efficiency of MCS* 284
16.2.5 *Limitations of MCS data* 287
16.3 ARS 288
16.3.1 *Sources for ARS* 289
16.3.2 *Construction, deployment, and retrieval of data* 289
16.3.3 *Monitoring environmental data* 292
16.3.4 *Answering questions using ARS* 292
16.3.5 *Limitation of ARS* 294
16.4 Conclusions 294
16.5 Acknowledgments 295
16.6 References 295

17 Measuring habitat 299

Kimberly J. Babbitt, Jessica S. Veysey, and George W. Tanner

17.1 Introduction 299
17.2 Habitat selection 299
17.3 Spatial and temporal scale 300
17.4 Approaches for examining habitat selection 300
17.5 Determining availability 301

17.6 What to measure 302
17.7 Weather variables 302
17.8 Aquatic habitat 304
17.9 Physical habitat variables 304
17.10 Chemical variables 307
17.11 Measuring vegetation 309
17.11.1 Tree (overstory) measurements 310
17.11.2 Shrub (midstory) measurements 312
17.11.3 Ground (understory) measurements 313
17.12 Edaphic features 314
17.13 Conclusion 314
17.14 References 315

Part 5 Amphibian communities 319

18 Diversity and similarity 321
C. Kenneth Dodd, Jr

18.1 Introduction 321
18.2 Data transformation 322
18.3 Species diversity 323
18.3.1 *Sampling considerations* 323
18.3.2 *Species richness* 324
18.3.3 *Species accumulation curves* 325
18.3.4 *Heterogeneity* 327
18.3.5 *Evenness and dominance* 329
18.4 Similarity 329
18.5 Software 331
18.6 Summary 334
18.7 References 334

19 Landscape ecology and GIS methods 339
Viorel D. Popescu and James P. Gibbs

19.1 Introduction 339
19.1.1 *Relevance of landscape ecology to amphibian biology and conservation* 339
19.1.2 *Defining a "landscape" from an amphibian's perspective* 341
19.1.3 *GIS* 342
19.2 Applications of spatial data for amphibian conservation 346
19.2.1 *Multiscale predictors of species occurrence and abundance* 346
19.2.2 *Landscape thresholds* 347
19.2.3 Connectivity/isolation in amphibian populations 349

19.2.4 *Landscape permeability* 351
19.2.5 *Landscape genetics* 352
19.3 Spatial statistics 353
19.4 Limitations and future directions 354
19.5 References 356

Part 6 Physiological ecology and genetics 361

20 Physiological ecology: field methods and perspective 363

Harvey B. Lillywhite

20.1 Introduction 363
20.1.1 *Important features of amphibians* 364
20.2 Heat exchange, body temperature, and thermoregulation 365
20.2.1 *Thermal acclimation of physiological function* 365
20.2.2 *Early methods in field studies of amphibian thermal relations* 366
20.2.3 *Precautions for temperature measurements* 367
20.2.4 *Telemetry* 371
20.3 Water relations 372
20.3.1 *Cutaneous water exchange: terrestrial environments* 372
20.3.2 *Cutaneous water exchange: aquatic environments* 374
20.4 Measuring water exchange 374
20.5 Energetics 375
20.6 Modeling amphibian–environment interactions 376
20.6.1 *Mathematical models* 376
20.6.2 *Physical models* 377
20.7 Other issues and future research directions 379
20.8 References 382

21 Models in field studies of temperature and moisture 387

Jodi J. L. Rowley and Ross A. Alford

21.1 Introduction 387
21.1.1 *The importance of understanding the temperature and moisture environments of amphibians* 387
21.1.2 *Physical models of amphibians* 389
21.2 Field models for investigating temperature and moisture 390
21.2.1 *Models with zero resistance to EWL* 390
21.2.2 *A system of models that allows for variable EWL* 390
21.2.2.1 Rationale 390
21.2.2.2 Model design and construction 391

21.2.2.3 Example of model construction and validation in the laboratory 392
21.2.2.4 Field validation of use of models to characterize available temperatures 395
21.2.2.5 The importance of matching the spectral properties of models to living animals 399
21.2.2.6 Models as indicators of relative moisture availability of microenvironments 399
21.3 Summary and future developments 402
21.4 References 403

22 Genetics in field ecology and conservation 407

Trevor J. C. Beebee

22.1 Background: the importance of genetics in ecology and conservation 407
22.2 Molecular methods for investigating amphibian populations 408
22.2.1 *Laboratory facilities* 408
22.2.2 *Sampling* 409
22.2.3 *DNA extraction* 409
22.2.3.1 Proteinase K/phenol/chloroform method 410
22.2.3.2 Kit-based DNA extraction 410
22.2.3.3 Chelex method 410
22.2.3.4 FTA cards 410
22.2.3.5 Summary of DNA-extraction methods 410
22.2.4 *Quantifying DNA recoveries* 411
22.2.5 *The basis of PCR analysis* 411
22.2.6 *Choice of analytical methods* 412
22.2.6.1 Mitochondrial DNA (mtDNA) 412
22.2.6.2 Random amplification of polymorphic DNA (RAPD) and amplified fragment length polymorphism (AFLP) analyses 413
22.2.6.2.1 *RAPD analysis* 413
22.2.6.2.2 *AFLP analysis* 414
22.2.6.2.3 *Microsatellite analysis* 414
22.3 Analysis of genetic data 417
22.3.1 *Cryptic species or life-stage identification* 417
22.3.2 *Genetic diversity, inbreeding, and bottlenecks* 417
22.3.3 *Identification of barriers to movement* 419
22.3.4 *Defining populations and population size* 420
22.3.5 *Historical issues* 421
22.3.6 *Behavior and sexual selection* 423
22.4 Future developments 423
22.5 References 425

Part 7 Monitoring, status, and trends 429

23 Selection of species and sampling areas: the importance to inference 431

Paul Stephen Corn

23.1 Introduction 431
23.2 Sampling 433
23.3 Study sites and consequences of convenience sampling 435
23.4 Abundance and inference 439
23.5 Conclusions 442
23.6 Acknowledgments 443
23.7 References 443

24 Capture–mark–recapture, removal sampling, and occupancy models 447

Larissa L. Bailey and James D. Nichols

24.1 Introduction 447
24.2 Estimating amphibian population size and vital rates 448
24.2.1 *Marking: tag type and subsequent encounter* 448
24.2.2 *Capture–mark–recapture* 449
24.2.3 *Removal sampling* 455
24.3 Estimating amphibian occupancy and vital rates 455
24.3.1 *Occupancy estimation* 456
24.3.2 *Estimation of occupancy vital rates: extinction and colonization* 457
24.4 Summary and general recommendations 458
24.5 Disclaimer 459
24.6 References 459

25 Quantifying abundance: counts, detection probabilities, and estimates 465

Benedikt R. Schmidt and Jérôme Pellet

25.1 Background: imperfect detection in amphibian ecology and conservation 465
25.2 Imperfect detection 466
25.2.1 *Counts underestimate abundance* 467
25.2.2 *Per-visit and cumulative detection probabilities* 468
25.2.3 *Temporal and spatial variation in detection probabilities* 469
25.3 Components of imperfect detection 470
25.4 How to deal with imperfect detection 471

25.4.1 *Estimation of abundance* 471
25.4.2 *Other approaches to dealing with imperfect detection* 473
25.5 Designing a sampling protocol 476
25.6 Software 476
25.7 Outlook 477
25.8 References 477

26 Disease monitoring and biosecurity 481
D. Earl Green, Matthew J. Gray, and Debra L. Miller

26.1 Introduction 481
26.2 Amphibian diseases of concern 482
26.2.1 *Infectious diseases* 482
26.2.2 *Parasitic diseases* 487
26.2.3 *Toxins* 487
26.3 Disease monitoring: detection and diagnosis 487
26.3.1 *Disease surveillance* 487
26.3.2 *Sample size* 490
26.3.3 *Sample collection and shipment* 490
26.3.4 *Diagnostics* 494
26.4 Biosecurity: preventing disease transmission 497
26.4.1 *Human and animal safety* 497
26.4.2 *Washing and disinfecting equipment* 498
26.4.3 *Movement of animals and disease management* 499
26.5 Conclusions 500
26.6 References 501

27 Conservation and management 507
C. Kenneth Dodd, Jr

27.1 Introduction 507
27.1.1 *Statutory protection* 508
27.1.2 *Protecting habitats* 508
27.2 Managing amphibian populations 509
27.3 Wetland breeding sites 510
27.3.1 *Wetland integrity and hydroperiod* 510
27.3.2 *Wetland creation and restoration* 512
27.3.3 *Core habitat and buffer zones* 514
27.3.4 *Vegetation structure, composition, and canopy cover* 516
27.3.5 *Water quality* 516
27.4 Terrestrial habitats 517
27.4.1 *Contiguous habitats and edge effects* 517
27.4.2 *Silviculture* 517

27.4.3 *Restoring degraded lands* 518
27.5 Migratory and dispersal routes 519
27.5.1 *Corridors between habitat fragments* 519
27.5.2 *Crossing transportation corridors* 519
27.6 Intensive manipulation of individuals 521
27.6.1 *Captive breeding* 521
27.6.2 *Relocation, repatriation, translocation (RRT)* 521
27.6.3 *Disease and biosecurity* 522
27.7 Conclusion 523
27.8 References 523

Index 529

Contributors

Ross A. Alford School of Marine and Tropical Biology, James Cook University, Townsville, Queensland 4811, Australia. E-mail: ross.alford@jcu.edu.au

Ronald Altig Department of Biological Sciences, Mississippi State University, Mississippi State, Mississippi 39762-5759, USA. E-mail: raltig@biology.msstate.edu

Kimberly J. Babbitt Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH 03824, USA. E-mail: kbabbitt@cisunix.unh.edu

Larissa L. Bailey Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA. E-mail: Larissa.Bailey@colostate.edu

William J. Barichivich Florida Integrated Science Center, US Geological Survey, 7920 NW 71st Street, Gainesville, FL 32653, USA. E-mail: wbarichivich@usgs.gov

Trevor J. C. Beebee School of Life Sciences, University of Sussex, Falmer, Brighton BN1 9QG, UK. E-mail: t.j.c.beebee@sussex.ac.uk

Michelle D. Boone Department of Zoology, 212 Pearson Hall, Miami University, Oxford, Ohio 45056, USA. E-mail: BooneMD@muohio.edu

Andrew J. Crawford Smithsonian Tropical Research Institute, Apartado Postal 0843-03092, Balboa, Ancón, Republic of Panama. E-mail: andrew@dna.ac

Dan Cogălniceanu University Ovidius Constanța, Faculty of Natural Sciences, Bvd. Mamaia 124, Constanța, Romania. E-mail: dcogalniceanu@univ-ovidius.ro

Paul Stephen Corn U.S. Geological Survey, Aldo Leopold Wilderness Research Institute, 790 E. Beckwith Ave., Missoula, MT 59801, USA. E-mail: scorn@usgs.gov

Martha L. Crump Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona 86011, USA. E-mail: marty.crump@ nau.edu

C. Kenneth Dodd, Jr Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA. E-mail: Terrapene600@gmail.com

Michael E. Dorcas Department of Biology, Davidson College, Davidson, NC 28035, USA. E-mail: midorcas@davidson.edu

John W. Ferner Department of Biology, Thomas More College, Crestview Hills, Kentucky 41017, USA. E-mail: john.ferner@thomasmore.edu

J. Whitfield Gibbons Savannah River Ecology Laboratory, P.O. Drawer E, Aiken, South Carolina 29802, USA. E-mail: wgibbons@uga.edu

James P. Gibbs Department of Environmental and Forest Biology, State University of New York, Syracuse, NY 13210, USA. E-mail: jpgibbs@esf.edu

Matthew J. Gray Center for Wildlife Health, Department of Forestry, Wildlife and Fisheries, University of Tennessee, 274 Ellington Plant Sciences Building, Knoxville, TN 37996, USA. E-mail: mgray11@utk.edu

D. Earl Green U.S. Geological Survey, National Wildlife Health Center, 6006 Schroeder Drive, Madison, WI 53711, USA. E-mail: david_green@usgs.gov
Elizabeth B. Harper State University of New York, College of Environmental Sciences and Forestry, 1 Forestry Drive, Syracuse, New York 13210, USA. E-mail: eharper@esf.edu
Reid N. Harris Department of Biology, James Madison University, Harrisonburg, Virginia 22807, USA. E-mail: harrisRN@jmu.edu
Lillian M. B. Haywood Department of Biology, Washington and Lee University, Lexington, VA 24450, USA. E-mail: haywoodl@wlu.edu
Kim Howell Department of Zoology and Wildlife Conservation, PO Box 35064, University of Dar es Salaam, Dar es Salaam, Tanzania. E-mail: kmhowell@udsm.ac.tz
Victor S. Lamoureux Binghamton University, PO Box 6000, Binghamton, New York 13902, USA. E-mail: vlamoureux@stny.rr.com
Harvey B. Lillywhite Department of Zoology, University of Florida, Gainesville, FL 32611, USA. E-mail: hbl@zoo.ufl.edu
Dale M. Madison Binghamton University, PO Box 6000, Binghamton, New York 13902, USA. E-mail: dmadison@binghamton.edu
David M. Marsh Department of Biology, Washington and Lee University, Lexington, VA 24450, USA. E-mail: marshd@wlu.edu
Roy W. McDiarmid Patuxent Wildlife Research Center, US Geological Survey, National Museum of Natural History, Washington DC 20036, USA. E-mail: mcdiarmidr@si.edu
Claude Miaud Laboratoire d' Alpine UMR CNRS 5553, Université de Savoie, 73376 Le Bourget-du-Lac, France. E-mail: claude.miaud@univ-savoie.fr
Debra L. Miller Veterinary Diagnostic and Investigational Laboratory, The University of Georgia, College of Veterinary Medicine, 43 Brighton Road, Tifton, GA 31793, USA. E-mail: millerdl@uga.edu
Joseph C. Mitchell Mitchell Ecological Research Service, LLC, PO Box 5638, Gainesville, FL 32627–5638, USA. E-mail: dr.joe.mitchell@gmail.com
James D. Nichols U.S. Geological Survey, Patuxent Wildlife Research Center, 12100 Beech Forest Road, Laurel, MD 20708, USA. E-mail: jnichols@usgs.gov
Peter W. C. Paton Department of Natural Resources, University of Rhode Island, Kingston, Rhode Island 02881, USA. E-mail: ppaton@uri.edu
Joseph H. K. Pechmann Department of Biology, 132 Natural Sciences Building, Western Carolina University, Cullowhee, North Carolina 28723, USA. E-mail: jpechmann@email.wcu.edu
Jérôme Pellet A. Mailbach Sàrl, CP 99, Ch. de la Poya 10, CH-1610 Oron-la-Ville, Switzerland. E-mail : jerome.pellet@amailbach.ch
James W. Petranka Department of Biology, University of North Carolina at Asheville, Asheville, North Carolina 28804, USA. E-mail: petranka@unca.edu

Viorel D. Popescu Department of Wildlife Ecology, University of Maine, Orono, ME 04469, USA. E-mail: dan.popescu@umit.maine.edu
Steven J. Price Department of Biology, Wake Forest University, Winston-Salem, NC 27109, USA. E-mail: sjprice@davidson.edu
Jonathan L. Richardson School of Forestry and Environmental Studies, Yale University, 370 Prospect Street, New Haven, Connecticut 06511, USA. E-mail: jonathan.richardson@yale.edu
Dennis Rödder Zoological Research Museum Alexander Koenig, Adenauerallee 160, D-53113, Bonn, Germany and Faculty of Geography/Geosciences, Trier University, Wissenschaftspark Trier-Petrisberg, Am Wissenschaftspark 25–27, D-54286 Trier, Germany. E-mail: d.roedder.zfmk@uni-bonn.de
Jodi J. L. Rowley School of Marine and Tropical Biology, James Cook University, Townsville, Queensland 4811, Australia. E-mail: Jodi.Rowley@austmus.gov.au
Benedikt R. Schmidt Zoologisches Institut, Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland. E-mail: bschmidt@zool.uzh.ch
Raymond D. Semlitsch Division of Biological Sciences, 105 Tucker Hall, University of Missouri, Columbia, Missouri 65211, USA. E-mail: SemlitschR@missouri.edu
David K. Skelly School of Forestry and Environmental Studies, Yale University, 370 Prospect Street, New Haven, Connecticut 06511, USA. E-mail: david.skelly@yale.edu
Mirco Solé Department of Biology, Universidade Estadual de Santa Cruz, Rodovia Ilhéus – Itabuna, km 16, Ilhéus, Bahia, Brazil. E-mail: mksole@uesc.br
Donald W. Sparling Cooperative Wildlife Research Laboratory, Life Science II, MS6504, Southern Illinois University, Carbondale, Illinois 62901, USA. E-mail: dsparl@siu.edu
George W. Tanner Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA. E-mail: tannerg@ufl.edu
Valorie R. Titus Binghamton University, PO Box 6000, Binghamton, New York 13902, USA. E-mail: vtitus1@binghamton.edu
Jessica S. Veysey Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH 03824, USA. E-mail: jss4@unh.edu
James R. Vonesh Department of Biology, Virginia Commonwealth University, 1000 West Cary Street, Richmond, VA 23284, USA. E-mail: jrvonesh@vcu.edu
Susan C. Walls Florida Integrated Science Center, US Geological Survey, 7920 NW 71st Street, Gainesville, FL 32653, USA. E-mail: swalls@usgs.gov
Matt R. Whiles Department of Zoology and Center for Ecology, Southern Illinois University, Carbondale, Illinois 62901-6501, USA. E-mail: mwhiles@zoology.siu.edu
John D. Willson Savannah River Ecology Laboratory, P.O. Drawer E, Aiken, South Carolina 29802, USA. E-mail: willson@uga.edu