

Index

Page numbers followed by *f* indicate figure, *t* indicate table

A

Abundance

- apparent, 14t
- covariate relationship with, 395, 395f
- estimation, 15, 384
 - analysis of real data, 396–409
 - covariates in, 390–396
 - ecological process in, 392f
 - generation and analysis of simulated data, 388–396
 - GLMM and, 383
 - introduction to, 383–388
 - N-mixture model with overdispersion in, 404–409
 - observation process in, 392f
 - open-population N-mixture model in, 396–409
 - posterior distributions in, 394f, 397, 401f
 - program R in, 396
 - p*-values in, 397
 - silver-washed fritillary example of, 396–409, 397f, 408f
 - simple Poisson model for, 398–401
 - simplest case of, 388–390
 - summary of, 409–410
 - WinBUGS and, 388–410
 - ZIP N-mixture model in, 401–404
- false negatives and, 384
- importance of, 20
- as key population descriptor, 409–410
- latent, 384
- modeled, 14t
- overdispersion in, 404–409
- parameters, 387
- Poisson distribution for, 385
- spatial variation in, 384
- in species–abundance distribution, 5
- as state variable, 410, 414
- study of, 1–6
- true, 14t

Additive fixed effects, 154

Age effects

- models with, 208–212
- time effects combined with, 212

Age-dependent models, multinomial

- likelihood and, 227–231, 252–255

Age-specific probability, of first breeding model

- analysis of, 290–294
- description of, 288–289
- generation of simulated data, 289–290
- survival and movement estimation with, 288–294

Akaike's information criterion (AIC), 42, 469, 470

Algebra

- BUGS language and, 50–51, 84
- modeling in, 25, 267
- multistate models and, 267

ANCOVA linear model

- GLM, 50, 52
- GLMM, 74–77, 106
- R code for, 50, 52
- random-effects, 75–76

Andrewartha, H. G., 1

ANOVA, 100–106

Apparent abundance, 14t

Apparent distribution, 14t, 415

Asp viper, 17–18, 18–19f, 74–77, 76f

Atlas, distribution, 4

B

Band-recovery models. *See* Mark-recovery models

Batched effects, pooling of, 81

Bayes rule

- exaggerated difficulty of, 36
- information combined with, 35
- learning formalized in, 34–35
- paraphrased, 34

- Bayes rule (*Cont.*)
 priors and, 35–37, 44
 quantities in, 33
- Bayesian computation, in Bayesian statistical modeling, 38
- Bayesian statistical modeling
 Bayesian computation in, 38
 challenges of, 41
 hierarchical, 43–44
 inference in, 44
 introduction to, 23–24, 28–38
 overview of, 464
 parameter nonidentifiability and, 217
 posterior sampling and, 41–43
 p-values in, 222–223, 226f
 role of, 24–27
 summary of, 44–45
 WinBUGS and, 38–40
- Begon, M., 2
- Behavioral effects
 defined, 136
 in generation and analysis of simulated data, 148–150
 importance of, 138
- Bernoulli distribution
 defined, 67
 site-occupancy models and, 417
- Bernoulli trials, 176, 244
- Beta-binomial distribution, 12
- Bias
 descriptor, 7
 estimation error and, 366
 simulations and, 16–20
 systematic, 121–126
- Binomial distribution
 beta-binomial, 12
 capture–recapture models and, 385
 negative, 12, 386
 observation process and, 9–13, 20
- Binomial GLM
 analysis of real data, 70–71
 generation and analysis of simulated data, 68–70
 for modeling-bounded counts or proportions, 67–71
 Poisson GLM compared to, 48
 summary of, 71–72
 WinBUGS and, 68–71
- Binomial mixture model
 abundance estimation and, 15, 384
 analysis of real data, 396–409
 covariates in, 390–396
 ecological process in, 392f
 generation and analysis of simulated data, 388–396
 GLMM and, 383
 introduction to, 383–388
 N-mixture model with overdispersion in, 404–409
 observation process in, 392f
 open-population N-mixture model in, 396–409
 posterior distributions in, 394f, 397, 401f
 program R in, 396
 p-values in, 397
 silver-washed fritillary example of, 396–409, 397f, 408f
 simple Poisson model for, 398–401
 simplest case, 388–390
 summary of, 409–410
 WinBUGS and, 388–410
 ZIP N-mixture model, 401–404
- assumptions, 387–388
 benefits, 385
 defined, 384
 detection probability in, 387
 for dynamic situations, 387
 false positives and, 388
 Poisson-binomial, 385–386
 for static situations, 387
- Binomial response, 15
- Biodiversity, 4–5
- Birch, L. C., 1
- Black grouse, 329, 329f, 334f
- Blue bug. *See* *Rosalia alpina* beetle
- Brooks–Gelman–Rubin statistic, 39
- BRT. *See* Bugs run time
- bugs function, 87
- BUGS language
 algebraic description in, 50–51, 84
 as hierarchical model translation, 25
 history of, 38
 latent suitability indicators defined in, 402
 likelihood defined in, 358
 logit stabilized in, 430
 value of, 25, 39, 41, 54–55
- Bugs run time (BRT), 93
- Burnin, 39

C

- Capture–recapture data
 for estimating closed population size
 analysis of real data, 157–162

- behavioral effects in, 148–150
- CJS model and, 135, 137–138
- combined effects in, 154–157
- generation and analysis of simulated data, 139–157
- individual effects in, 150–153
- introduction to, 134–139
- model $M_{t|bh}$ for, 157–162
- model M_{t+x} for, 162–168
- pen shell example of, 166–168, 167f
- summary of, 169–170
- time effects in, 145–147
- trap response example of, 136–137, 148–157
- in integrated population model example, 357–363
- joint analysis of
 - generation of simulated data, 296–297
 - model for, 295–300
 - survival and movement estimation from, 295–300
- likelihood of, 354
- mark-recovery data compared to, 295
- overdispersion and, 196
- for recruitment, survival, and
 - population size estimation using JS model
 - analysis of real data, 341–345
 - assumptions of, 316
 - black grouse example of, 329, 329f, 334f
 - connections between parameters in, 339–341
 - constant survival and time-dependent entry models in, 328–335
 - data augmentation in, 319–328, 338
 - GLM and, 328, 345
 - grey-headed woodpecker example of, 335–339, 336f
 - identifiability in, 339–341
 - introduction to, 316–317
 - Leisler's bats example of, 341–345, 344f
 - models with individual capture heterogeneity, 335–339
 - parameterizations of, 317, 325–328
 - priors in, 326
 - summary of, 345–346
 - WinBUGS and, 321–339, 341–345
- sampling of, 472
- for survival and movement estimation
 - using multistate models
 - age-specific probability of first breeding model, 288–294
 - fire salamanders example of, 282–284, 283f
 - introduction to, 264–268
 - little ringed plover example of, 270–274, 271f, 289–290, 302–303
 - model for joint analysis of capture–recapture and mark-recovery data, 295–300
 - movement among three sites, 300–306
 - movement between two sites, 268–281
 - real-data example, 307–311
 - showy lady's slipper example, 307f, 307–311
 - state-space likelihood and, 274
 - summary of, 311–312
 - temporal effects and, 280
 - temporary emigration model, 281–287
 - WinBUGS and, 270–287, 289–294, 296–300, 302–312
- for survival estimation using CJS model
 - age effect models and, 208–212
 - age-dependent models and, 227–231
 - analysis of real data, 231–237
 - constant parameters and, 177–183
 - fixed group and random time effect models in, 204–208
 - fixed group and time effect models in, 199–204
 - fixed group effect models in, 192–194
 - fixed time effect models in, 184
 - GLM and, 199, 211, 237
 - individual group effects in, 195–199
 - introduction to, 172–175
 - latent state variable in, 181–183
 - Leisler's bat example, 231–237, 232f, 235–236f
 - little owls example of, 177–183, 178f, 185, 189, 196, 209, 227–231
 - models with individual variation and, 192–199
 - multinomial likelihood and, 220–231, 237
 - parameter identifiability in, 216–220
 - R code and, 178
 - random group effects in, 194–195

- Capture–recapture data (*Cont.*)
- random time effect models in, 184–188
 - recapture probability and, 212–216
 - red-backed shrikes example, 213, 214f
 - summary of, 237–238
 - temporal covariates in, 188–192
 - temporal variability, 204
 - time and group effect models in, 199–208
 - time-dependent models and, 222–227
 - time-variation models and, 183–192
 - trap response models and, 212–216
 - WinBUGS and, 177–208, 212–237
 - understanding of, 465
- Capture–recapture models
- advantages of, 169
 - binomial distribution and, 385
 - classical, 135–136
 - data augmentation and, 139–140, 152
 - detection probability and, 136–137, 137t
 - GLM and, 138
 - with individual covariates, 162–168
 - introduction to, 134
 - SECR, 135, 475
 - simulations with, 139–157
 - behavioral effects, 148–150
 - combined effects, 154–157
 - individual effects, 150–153
 - introduction to, 139–145
 - time effects, 145–147
 - WinBUGS and, 138–169
- Chance, 27
- Cheap data, 385, 409–410
- CI. *See* Confidence interval
- CJS model. *See* Cormack–Jolly–Seber model
- Classical capture–recapture models, 135–136
- Cleaner thinking, hierarchical models for, 467
- Closed population size, capture–recapture
- data for estimating
 - analysis of real data, 157–162
 - behavioral effects in, 148–150
 - CJS model and, 135, 137–138
 - combined effects in, 154–157
 - generation and analysis of simulated data, 139–157
 - individual effects in, 150–153
 - introduction to, 134–139
 - model $M_{t,bh}$, 157–162
 - model M_{t+X} , 162–168
 - pen shell example of, 166–168, 167f
 - summary of, 169–170
 - time effects in, 145–147
 - trap response example of, 136–137, 148–157
- Closure assumption
- relaxing of, 475–476
 - temporary emigration and, 416
- Coal tit, 95f, 95–110, 97f
- Coefficient of variation (CV), 129
- Common terns, 244–246, 245f, 252–255
- Community
- models, for metapopulation designs, 474–475
 - as population, 5
- Confidence interval (CI), 37
- Conservation, population analysis for, 477–478
- Constant detection probability, 447, 472
- Constant parameters, 177–183, 246–252
- Constant survival and time-dependent entry models
- comparison of estimates, 333–335
 - multistate, 332
 - recruitment, survival, and population size estimation using, 328–335
 - restricted occupancy, 331
 - superpopulation formulation and, 333
- Conventional Poisson GLMM, for count data
- analysis of real data, 88–90, 95–110
 - fixed site and fixed year effects, 100–102
 - fixed site effects, 99–100
 - full model, 108–110
 - generation and analysis of simulated data, 84–88, 92–95
 - introduction to, 73–82
 - overdispersion in, 83
 - with random effects for variability among groups, 90–110
 - random site and random year effects, 103–105
 - random site effect, random year effect, and first-year fixed observer effect, 105–106
 - random site effect, random year effect, first-year fixed observer effect, and overall linear time trend, 106–108
 - random site effects, 102–103
 - uses of, 111
- Convergence, checking for, 62–63, 67, 70–71, 87, 89

- Cormack–Jolly–Seber (CJS) model
 assumptions, 173–174
 closed population size and, 135, 137–138
 emigration and, 371
 false negatives and, 173
 false positives and, 173
 in integrated population models, 371
 JS model compared to, 237, 345
 mark-recovery model compared to, 243–244, 248
 m-array and, 44, 220–231
 multinomial likelihood and, 173, 175, 220–231, 237
 multistate model compared to, 267, 278
 state-space models and, 173, 175–177, 181, 237, 465, 466
 survival estimation using
 age effect models and, 208–212
 age-dependent models and, 227–231
 analysis of real data, 231–237
 constant parameters and, 177–183
 fixed group and random time effect models in, 204–208
 fixed group and time effect models in, 199–204
 fixed group effect models in, 192–194
 fixed time effect models in, 184
 GLM and, 199, 211, 237
 individual group effects in, 195–199
 introduction to, 172–175
 latent state variable in, 181–183
 Leisler’s bat example, 231–237, 232f, 235–236f
 little owls example of, 177–183, 178f, 185, 189, 196, 209, 227–231
 models with individual variation and, 192–199
 multinomial likelihood and, 220–231, 237
 parameter identifiability in, 216–220
 R code and, 178
 random group effects in, 194–195
 random time effect models in, 184–188
 recapture probability and, 212–216
 red-backed shrikes example, 213, 214f
 summary of, 237–238
 temporal covariates in, 188–192
 temporal variability, 204
 time and group effect models in, 199–208
 time-dependent models and, 222–227
 time-variation models and, 183–192
 trap response models and, 212–216
 WinBUGS and, 177–208, 212–237
- Count data
 in integrated population model, 357–363
 likelihood of, 352–354
- Poisson GLMM for
 analysis of real data, 88–90, 95–110
 fixed site and fixed year effects, 100–102
 fixed site effects, 99–100
 full model, 108–110
 generation and analysis of simulated data, 84–88, 92–95
 introduction to, 73–82
 overdispersion in, 83
 with random effects for variability among groups, 90–110
 random site and random year effects, 103–105
 random site effect, random year effect, and first-year fixed observer effect, 105–106
 random site effect, random year effect, first-year fixed observer effect, and overall linear time trend, 106–108
 random site effects, 102–103
 uses of, 111
 replicated, 385, 409
- Covariates
 in abundance estimation, 390–396
 abundance’s relationship with, 395, 395f
 effects of, 79
 flexible modeling of, 476
 in individual covariate models
 capture–recapture models, 162–168
 for population size estimation, 166–168
 for species richness estimation, 163–166
 in N-mixture model, 390–396
 single-season occupancy model with, 422–427
 site, 390
 temporal, 188–192
- Credible interval (CRI)
 defined, 37
 increase in, 369
- CV. *See* coefficient of variation

D

DA. *See* Data augmentation

DAG. *See* Directed acyclic graph

Data augmentation (DA)

capture–recapture models and, 139, 140, 152

defined, 140

generation and analysis of simulated data with, 139–157

behavioral effects, 148–150

combined effects, 154–157

individual effects, 150–153

introduction to, 139–145

time effects, 145–147

introduction to, 139

JS model and, 319–328, 338

as multistate model, 322–325

as restricted dynamic occupancy model, 320–322

superpopulation parameterization and, 325–328

in random-effects models, 152

in recruitment, survival, and population size estimation, 319–328, 338

Data cloning, 36

Data dredging, 469–470

Dead-recovery matrix, 247

Dead-recovery models. *See* Mark-recovery models

Demographic parameters, temporal variability of, 373

Demographic rates

integrated population models estimating

analysis of, 358–363

CJS model in, 371

fecundity estimated with, 363–366, 377–378

hoopoe example of, 371f, 371–379, 378f

introduction to, 348–350

ortolan bunting example of, 349, 350–351f, 357–363, 366–370

for population viability analysis, 366–370

without productivity data, 363–366

real data example of, 371–379

simple example of, 357–363

summary of, 379–380

WinBUGS and, 357–379

population size and, 350–352

Descriptors, biased, 7

Detection. *See also* Detection/nondetection data

linear predictor for, 386

N-mixture model with overdispersion with, 404–409

probability, 6, 11

in binomial mixture models, 387

capture–recapture models and, 137t, 136–137

constant, 447, 472

date related to, 433

model selection view of, 473

state-space models and, 124–125, 131

time of day related to, 433

within-capture-history dependence of, 148

of silver-washed fritillary, 408f

Detection error. *See* False negatives

Detection/nondetection data

defined, 414

introduction to, 414–419

occurrence and species distribution

estimation from

analysis of real data, 427–436, 445–450

dynamic models for, 436–450, 459

generation and analysis of simulated data in, 420–427, 439–445

goodness of fit and, 418

introduction to, 414–418

long-eared owl example of, 439–445, 440f, 454, 456

multistate occupancy models, 450–458

p-values and, 419–420

Rosalia alpina example of, 427–436, 428–429f, 432f, 434f

single-season occupancy analysis, 420–427

six-spot burnet example of, 445–450, 445f, 450f

summary of, 459–460

WinBUGS in, 419–436, 439–450

Deterministic mechanisms, 6

Deviance information criterion (DIC), 42, 469

Directed acyclic graph (DAG), 356f, 467

Dirichlet distribution, 300, 302, 308, 454

Dispersion, extra-Poisson, 386, 405

Distance sampling, 135, 169

Distribution. *See also specific distributions*

apparent, 14t, 415

- atlas, 4
 - catalog, 49
 - importance of, 20
 - organism, 4
 - study of, 1–6
 - true, 14t, 415
 - The Distribution and Abundance of Animals* (Andrewartha and Birch), 1
 - Double-counting, 125
 - Dynamic multistate occupancy model, 458–459
 - Dynamic occupancy models, 436–450
 - Dynamic occurrence and species distribution models, 436–450, 459
- ## E
- Ecological process, 8, 392f
 - Ecology
 - definition of, 1–6
 - hierarchical view of, 6, 7f
 - metapopulation, 3–4
 - state changes in, 2, 2f
 - Ecology: Individuals, Populations, and Communities* (Begon), 2
 - Ecology: The Experimental Analysis of Distribution and Abundance* (Krebs), 1
 - Emigration. *See also* Temporary emigration
 - CJS model and, 371
 - permanent, 295
 - Entry probability, 317, 323, 329, 333, 340, 345
 - Errors. *See also* False negatives; False positives
 - estimation, 366
 - misclassification, 476
 - Monte Carlo, 144
 - nondetection, 7, 10
 - observation, 11
 - hierarchical models correcting, 11, 116–117, 117f, 384
 - Poisson distribution for, 352
 - standard, of estimator, 20
 - Estimated population size, 121–126
 - Estimation error, bias and, 366
 - Estimator, 17, 20
 - E-SURGE, 470–471
 - Exchangeability, assumption of, 77, 82
 - Expected count, 111, 134
 - Explanation, objective of, 26
 - Explicit models
 - defined, 26
 - hierarchical, 43, 111, 384, 472
 - of misclassification error, 476
 - not required, 473
 - SECR, 135, 475
 - Extra-Poisson dispersion, 386, 405
 - Extrinsic nonidentifiability, 216
- ## F
- False negatives
 - abundance and, 384
 - accounting for, 476
 - CJS model and, 173
 - false positives canceling out, 125
 - introduction to, 11–13, 20
 - multistate models and, 265
 - site-occupancy model and, 417
 - False positives
 - accounting for, 476
 - binomial mixture models and, 388
 - CJS model and, 173
 - false negatives canceling out, 125
 - introduction to, 12–13, 20
 - multistate models and, 265
 - sample size and, 13
 - site-occupancy model and, 416–417
 - Fecundity
 - integrated population models estimating, 363–366, 377–378
 - Poisson GLM modeling, 66–67
 - Fidelity, 295
 - Finite-population standard deviation, 79
 - Fire salamanders, 282–284, 283f
 - First breeding model, age-specific
 - probability of
 - analysis of, 290–294
 - description of, 288–289
 - generation of simulated data, 289–290
 - survival and movement estimation with, 288–294
 - First-year fixed observer effect, 105–108
 - Fisher Scoring, 58
 - Fixed effects
 - additive, 154
 - in fixed group and random time effect models, 204–208
 - in fixed group and time effect models, 199–204
 - in fixed group effect models in, 192–194
 - in fixed site and fixed year effects model, 100–102
 - in fixed site effects model, 99–100
 - in fixed time effect models, 184
 - random effects compared to, 76, 82

Fixed effects (*Cont.*)
 in random site effect, random year effect,
 and first-year fixed observer effect
 model, 105–106
 time effects, 184, 199–204
 in WinBUGS, 76
 Frailty, 208
 Freeman–Tukey statistic, 224
 Frequentist analysis, of statistical models,
 28–38
 Freuler, Reto, 126

G

GAM. *See* Generalized additive model
 Gamma prior, 120
 Generalized additive model (GAM)
 defined, 71
 development of, 476
 smoothing of, 131
 Generalized linear mixed model (GLMM)
 abundance estimation and, 383
 ANCOVA and, 74–77, 106
 ANOVA and, 100–106
 asp viper example, 17–18, 18–19f, 74–77,
 76f
 complex estimation in, 95
 conventional Poisson, for count data
 analysis of real data, 88–90,
 95–110
 fixed site and fixed year effects,
 100–102
 fixed site effects, 99–100
 full model, 108–110
 generation and analysis of simulated
 data, 84–88, 92–95
 introduction to, 73–82
 overdispersion in, 83
 with random effects for variability
 among groups, 90–110
 random site and random year
 effects, 103–105
 random site effect, random year
 effect, and first-year fixed observer
 effect, 105–106
 random site effect, random year
 effect, first-year fixed observer effect,
 and overall linear time trend,
 106–108
 random site effects, 102–103
 uses of, 111
 defined, 71
 GLM compared to, 88

 introduction to, 73–82
 latent effects and, 73
 null, 98–99
 peregrine falcon example of, 84–90, 86f,
 92–95
 summary of, 110–112
 Swiss coal tit example of, 95f, 95–110,
 97f
 Generalized linear models (GLM)
 advantages of, 54
 ANCOVA, 50, 52
 binomial
 analysis of real data, 70–71
 generation and analysis of simulated
 data, 68–70
 for modeling-bounded counts or
 proportions, 67–71
 Poisson GLM compared to, 48
 summary of, 71–72
 WinBUGS and, 68–71
 capture–recapture models and, 138
 effects formulation, 199
 GLMM compared to, 88
 introduction to, 48
 movement among three sites model
 and, 301
 peregrine falcon example of, 56–71,
 56–57f, 65f
 Poisson
 analysis of real data, 64–66
 binomial GLM compared to, 48
 fecundity modeling by, 66–67
 generation and analysis of
 simulated data, 56–64
 overdispersion in, 83
 in R, 55–66
 summary of, 71–72
 WinBUGS and, 55–66
 random effects in, 73
 in recruitment, survival, and population
 size estimation, 328, 345
 response components in
 link function and, 54–55
 noise, 48–55
 signal, 48–55
 summary of, 71–72
 in survival estimation using CJS model,
 199, 211, 237
 themes in, 15
 with WinBUGS, 48
 binomial GLM and, 68–71
 Poisson GLM and, 55–66

time series of counts modeled with, 55–66
 undefined real result trap in, 60–61
 Gibbs sampling, 38
 GLM. *See* Generalized linear models
 GLMM. *See* Generalized linear mixed model
 Goodness of fit (GOF)
 for integrated population models, 380
 m-array and, 222, 224
 in occurrence and species distribution estimation, 418
 Grey-headed woodpecker, 335–339, 336f
 Group effects, 138
 fixed
 in fixed group and random time effect models, 204–208
 in fixed group and time effect models, 199–204
 in fixed group effect models in, 192–194
 individual, 195–199
 models with, 199–208
 random, 194–195

H

Heterogeneity model, 150–153, 335–339
 Hierarchical models. *See also specific models*
 Bayesian statistical modeling and, 43–44
 BUGS language translation of, 25
 defined, 91
 explicit, 43, 111, 384, 472
 implicit, 43, 111, 384, 472
 importance of, 8
 N-mixture, 44
 observation error corrected by, 11, 116–117, 117f, 384
 partitioning in, 13
 power of, 464–472
 for cleaner thinking, 467
 for E-SURGE, 470–471
 for fitting of complex statistical models, 464–465
 for MARK, 470–471
 for PRESENCE, 470–471
 for primary model selection, 468–469
 for secondary model selection, 469–470
 for step-up approach to problems, 467
 for study design, 471–472

for synthetic understanding of models, 466t, 465–467
 for unmarked, 470–471
 random variables in, 43
 stochastic parts of, 27
 systematic parts of, 27
 variable selection and, 469–470
 Hierarchical scales of organization, 2
 ecology and, 6, 7f
 modeling of, 5
 Scale 1, 2, 3t
 Scale 2, 3, 3t
 Scale 3, 3t, 5
 Scale 4, 3t, 5
 Home range, 135
 Hoopoe, 371f, 371–379, 378f
 House martin, 126–130, 126f, 130f

I

Ibex population, 118–121, 118f, 121f, 124f
 Identifiability, 216–220, 339–341
 Immigration, 371, 377
 Implicit models
 defined, 26
 hierarchical, 43, 111, 384, 472
 Incidence. *See also* Occupancy
 defined, 437
 in metapopulation, 3
 Independence assumption, of integrated population models, 355
 Individual capture heterogeneity models, 335–339
 Individual covariate models
 capture–recapture, 162–168
 for population size estimation, 166–168
 for species richness estimation, 163–166
 Individual effects, 136, 138
 in generation and analysis of simulated data with data augmentation, 150–153
 group, 195–199
 Individual variation, models with
 with fixed group effects, 192–194
 with individual group effects, 195–199
 with random group effects, 194–195
 survival estimation and, 192–199
 Inference, scope of, 78–79
 Information combination
 with Bayes rule, 35
 development of, 474
 as motivation for random-effects model, 81

- Inits function, 128
 Integrated population models
 capture–recapture data in, 357–363
 count data in, 357–363
 defined, 348
 demographic rates, population size, and
 projection matrices estimation using
 analysis of, 358–363
 CJS model in, 371
 fecundity estimated with, 363–366,
 377–378
 hoopoe example of, 371f, 371–379,
 378f
 introduction to, 348–350
 ortolan bunting example of, 349,
 350–351f, 357–363, 366–370
 for population viability analysis,
 366–370
 without productivity data, 363–366
 real data example of, 371–379
 simple example of, 357–363
 summary of, 379–380
 WinBUGS and, 357–379
 development of, 349
 first step, 350–352
 second step, 352–354
 third step, 354–357
 fecundity estimated by, 363–366, 377–378
 goodness of fit and, 380
 independence assumption of, 355
 for population viability analysis, 366–370
 reproduction in, 357–363
 simulation with, 349
 state-space likelihood and, 354
 Intercept-only model. *See* Null model
 Intercepts
 random, 75, 78
 varying, 78
 Intrinsic nonidentifiability, 216
 Inverse Wishart distribution, 206–207
- as multistate model, 322–325
 as restricted dynamic occupancy
 model, 320–322
 superpopulation parameterization
 and, 325–328
 inferences of, 15
 as multistate model, 322–325, 332
 N-mixture, 475
 observation process in, 318, 318f
 recruitment, survival, and population size
 estimation using
 analysis of real data, 341–345
 assumptions of, 316
 black grouse example of, 329, 329f,
 334f
 connections between parameters in,
 339–341
 data augmentation in, 319–328, 338
 GLM and, 328, 345
 grey-headed woodpecker example
 of, 335–339, 336f
 identifiability in, 339–341
 introduction to, 316–317
 Leisler's bats example of, 341–345,
 344f
 models with constant survival and
 time-dependent entry, 328–335
 models with individual capture
 heterogeneity, 335–339
 parameterizations of, 317, 325–328
 priors in, 326
 summary of, 345–346
 WinBUGS and, 321–339, 341–345
 as restricted occupancy model, 331
 state process in, 318, 318f
 as state-space model, 317–319
 superpopulation formulation and, 333
 uses of, 170
 variants, 317
- JS model. *See* Jolly–Seber model

J

- Joint analysis, of capture–recapture and
 mark–recovery data
 generation of simulated data, 296–297
 model for, 295–300
 survival and movement estimation from,
 295–300
 Joint likelihood, formulation of, 354–357
 Jolly–Seber (JS) model
 CJS model compared to, 237, 345
 data augmentation and, 319–328, 338

K

- Kittiwakes, 414
 Krebs, C. J., 1

L

- Lack-of-fit ratio, 401
 Latent abundance, 384
 Latent effects, GLMMs and, 73
 Latent state variable, 181–183, 247, 276, 318
 Latent suitability indicators, 402
 Learning, formalized, 34–35

- Leisler's bats
 in recruitment, survival, and population size estimation using JS, 341–345, 344f
 in survival estimation using CJS model, 176f, 231–237, 232f, 235–236f
- Leslie-matrix modeling, 14t, 362, 379
- Levels, 78
- Likelihood. *See also* Maximum likelihood estimate; Multinomial likelihood
 BUGS language defining, 358
 of capture–recapture data, 354
 of count data, 352–354
 function, 29, 33, 36
 joint, 354–357
 principle, 223
 of reproductive success data, 354
 state-space
 integrated population models and, 354
 in survival and movement estimation using multistate models, 274
- Linear models. *See also specific models*
 mean structure described by, 49
 themes in, 15
- Linear predictor, for detection, 386
- Link function, 54–55, 422
- Little owls, 177–183, 178f, 185, 189, 196, 209, 227–231
- Little ringed plover, 270–274, 271f, 289–290, 302–303
- Log-function, 386, 394f
- Logistic normal, 150
- Logit, 148, 154, 186, 430
- Logit-link function, 386, 394f
- Long-eared owl, 439–445, 440f, 454, 456
- M**
- Magden, 126–130
- Marginal probability, 33
- MARK, 470–471
- Markov chain Monte Carlo (MCMC)
 benefits of, 358
 development of, 38
 mark-recovery data and, 261
 random effects and, 406
 in restricted occupancy model, 343
 sampling techniques, 38
 state-space models and, 120, 130
 WinBUGS blackbox of, 38–41, 44
- Mark-recovery data
 capture–recapture data compared to, 295
 joint analysis of
 generation of simulated data, 296–297
 model for, 295–300
 survival and movement estimation from, 295–300
 simulations with, 244–246, 296–297
 survival estimation using
 common terns example of, 244–246, 245f, 252–255
 introduction to, 241–242
 latent state variable in, 247
 m-array for, 249, 251–253, 255
 MCMC and, 261
 multinomial likelihood and, 248–255, 261
 priors in, 258, 260
 R code and, 249
 real-data example of, 255–261
 red kites example, 255–261, 256f, 259–260f
 sampling for, 242
 simulation of, 244–246
 state-space models and, 242–248, 261
 summary of, 261
 WinBUGS and, 244–261
- Mark-recovery models
 CJS model compared to, 243–244, 248
 multinomial likelihood fitting, 248–255
 model with age-dependent parameters, 252–255
 model with constant parameters, 248–252
 as state-space model
 advantages of, 242–248, 261
 analysis of model with constant parameters, 246–248
 simulation of mark-recovery data, 244–246
 state and observation processes, 243f, 243
- M-array
 CJS model fitted via, 44, 220–231
 goodness of fit and, 222–224
 mark-recovery data and, 249, 251–253, 255
- Maximum likelihood estimate (MLE)
 benefits of, 31
 from data cloning, 36

- Maximum likelihood estimate (MLE) (*Cont.*)
 defined, 29
 mode and, 28, 37
 posterior mean and, 28
 tadpole example of, 29, 30f, 33
- MCMC. *See* Markov chain Monte Carlo
- Mean effects, 78
- Memory, 160
- Metacommunity, 3t, 5
- Metapopulation, 15, 96
 ecology, 3–4
 extent of, 4
 incidence in, 3
- Metapopulation designs
 abundance estimation and, 15, 384
 analysis of real data, 396–409
 covariates in, 390–396
 ecological process in, 392f
 generation and analysis of simulated data, 388–396
 GLMM and, 383
 introduction to, 383–388
 N-mixture model with
 overdispersion in, 404–409
 observation process in, 392f
 open-population N-mixture model in, 396–409
 posterior distributions in, 394f, 397, 401f
 program R in, 396
p-values in, 397
 silver-washed fritillary example of, 396–409, 397f, 408f
 simple Poisson model for, 398–401
 simplest case, 388–390
 summary of, 409–410
 WinBUGS and, 388–410
 ZIP N-mixture model, 401–404
- community models for, 474–475
- in occurrence and species distribution
 estimation
 analysis of real data, 427–436, 445–450
 dynamic models for, 436–450, 459
 generation and analysis of simulated data in, 420–427, 439–445
 goodness of fit and, 418
 introduction to, 414–418
 long-eared owl example of, 439–445, 440f, 454, 456
 multistate occupancy models, 450–458
p-values and, 419–420
Rosalia alpina example of, 427–436, 428–429f, 432f, 434f
 single-season occupancy analysis, 420–427
 six-spot burnet example of, 445–450, 445f, 450f
 summary of, 459–460
 WinBUGS in, 419–436, 439–450
 population models for, 474–475
- Misclassification error, 476
- Mixed models. *See* Generalized linear mixed model
- MLE. *See* Maximum likelihood estimate
- Mode, 28, 37
- Modeling. *See also specific types of modeling*
 in algebra, 25, 26f
 flexible, of covariates, 476
 of hierarchical scales of organization, 5
 objectives, 26
 of parameter correlations, 79–80
 role of, 24–27
 sayings about, 24
 summary of, 44–45
 synthetic understanding of, 465–467, 466t
 themes, 15
- Modeling-bounded counts or proportions
 analysis of real data, 70–71
 binomial GLM for, 67–71
 generation and analysis of simulated data, 68–70
- Models. *See also specific models*
 M_b , 148–150
 M_h , 150–153
 M_t , 145–147
 M_{tblv} , 157–162
 M_{thv} , 154–157
 M_{t+x}
 capture–recapture data and, 162–168
 for population size estimation, 162–168
 for species richness, 163–166
 selection of, 37
 detection probability and, 473
 primary, 468–469
 secondary, 469–470
- Monte Carlo error, 144
- Movement among three sites, model of
 analysis of, 304–306
 description of, 300–302
 generation of simulated data, 302–303

- GLM and, 301
 - survival and movement estimation using, 300–306
 - Movement and survival estimation, from capture–recapture data using multistate models
 - age-specific probability of first breeding model, 288–294
 - fire salamanders example of, 282–284, 283f
 - introduction to, 264–268
 - little ringed plover example of, 270–274, 271f, 289–290, 302–303
 - model for joint analysis of capture–recapture and mark–recovery data, 295–300
 - movement among three sites, 300–306
 - movement between two sites, 268–281
 - real-data example, 307–311
 - showy lady’s slipper example, 307f, 307–311
 - state-space likelihood and, 274
 - summary of, 311–312
 - temporal effects and, 280
 - temporary emigration model, 281–287
 - WinBUGS and, 270–287, 289–294, 296–300, 302–312
 - Movement between two sites, estimated
 - analysis of, 274–281
 - described, 268–270
 - generation of simulated data, 270–274
 - using multistate models, 268–281
 - Movement probability, 14t
 - Multidimensional arrays, in WinBUGS, 396
 - Multievent models, 312
 - Multinomial likelihood
 - age-dependent models, 227–231, 252–255
 - CJS model fitted using, 173, 175, 220–231, 237
 - constant parameters and, 248–252
 - introduction to, 220–222
 - mark-recovery models fitted with, 248–255
 - with age-dependent parameters, 252–255
 - with constant parameters, 248–252
 - survival estimation and, 220–231, 237, 248–255, 261
 - time-dependent models, 222–227
 - Multiseason site-occupancy models, 436–450
 - Multistate models
 - algebraic description of, 267
 - applications of, 265
 - CJS models compared to, 267, 278
 - as constant survival and time-dependent entry models, 332
 - false negatives and, 265
 - false positives and, 265
 - JS model as, 322–325, 332
 - observation process and, 265, 266f
 - occupancy
 - dynamic, 458, 459
 - extensions of, 458, 459
 - importance of, 459
 - in occurrence and species distribution estimation, 450–458
 - parameterizations of, 453
 - uses of, 451
 - state process and, 265, 266f
 - in survival and movement estimation
 - from capture–recapture data
 - age-specific probability of first breeding model, 288–294
 - fire salamanders example of, 282–284, 283f
 - introduction to, 264–268
 - little ringed plover example of, 270–274, 271f, 289–290, 302–303
 - model for joint analysis of capture–recapture and mark–recovery data, 295–300
 - movement among three sites, 300–306
 - movement between two sites, 268–281
 - real-data example, 307–311
 - showy lady’s slipper example, 307f, 307–311
 - state-space likelihood and, 274
 - summary of, 311–312
 - temporal effects and, 280
 - temporary emigration model, 281–287
 - WinBUGS and, 270–287, 289–294, 296–300, 302–312
 - Mutually exclusive events, 32, 32t
- N**
- Negative binomial distribution, 12, 386
 - N-mixture model
 - basic, 387
 - covariates in, 390–396

N-mixture model (*Cont.*)

- generalization of, 410
- hierarchical, 44
- JS, 475
- open-population
 - in abundance estimation, 396–409
 - simple Poisson model, 398–401
- with overdispersion in abundance and detection, 404–409
- power of, 409
- simplest case of, 388–390
- ZIP, 401–404

Noise

- link function and, 54–55
- as response component, 48–55

Nondetection data. *See* Detection/
nondetection data

Nondetection error, 7, 10

Nonidentifiability, parameter, 216–217

Nonparametric assumptions, 476

Nuisance parameter, 320

Null model, 98–99

O

Observation

- equations, 116
 - error
 - hierarchical models correcting, 11, 116–117, 117f, 384
 - Poisson distribution for, 352
 - genesis of, 6–9
 - process, 7f
 - in abundance estimation, 392f
 - accounted for, 13
 - binomial distribution and, 9–13, 20
 - importance of, 472–474
 - in JS models, 318, 318f
 - in mark-recovery models, 243f, 243
 - in multistate models, 265, 266f
 - population analysis and, 8
 - systematic bias in, 121–126
 - true state and, 8
 - variance, 123
- Observed population size, 121–126
- Occam's razor, 24
- Occupancy. *See also* Site-occupancy models
- defined, 437
 - as state variable, 4
- Occurrence and species distribution
- estimation, using site-occupancy models
 - analysis of real data, 427–436, 445–450

- dynamic models for, 436–450, 459
- generation and analysis of simulated data
 - in, 420–427, 439–445
- goodness of fit and, 418
- introduction to, 414–418
- long-eared owl example of, 439–445, 440f, 454, 456
- multistate occupancy models, 450–458
- p*-values and, 419–420
- Rosalia alpina* example of, 427–436, 428–429f, 432f, 434f
- single-season occupancy analysis, 420–427
- six-spot burnet example of, 445–450, 445f, 450f
- summary of, 459–460
- WinBUGS in, 419–436, 439–450

OpenBUGS, 390, 439

Open-population model

N-mixture

- in abundance estimation, 396–409
- simple Poisson model, 398–401
- understanding of, 465

Organism distribution, 4

Ortolan buntings, 349, 350–351f, 357–363, 366–370

Overall linear time trend model, 106–108

Overdispersion

- capture–recapture data subject to, 196
- correction for, 386, 404
- defined, 82
- N-mixture model with, 404–409
- in Poisson GLM, 83
- in Poisson GLMM, 83
- in random-effects models, 82–90

Overparameterization, 100

P

Parameterization

- of JS recruitment, survival, and population size modeling, 317, 325–328
- of multistate occupancy models, 450–458
- overparameterization and, 100
- superpopulation, 325–328
- treatment contrast, 53

Parameters

- abundance, 387
- age-dependent, 252–255
- connections between, 339–341
- constant, 177–183, 246–252
- correlations, modeling of, 79–80

- defined, 20
- demographic, 373
- estimation and inference, 29
- fixed, 28–29
- identifiability, 216–220, 339–341
- nonidentifiability, 216–217
- nuisance, 320
- of Poisson distribution, 55
- variance, 37
- Pen shell, 166–168, 167f
- Peregrine falcons
 - GLM and, 56–71, 56–57f, 65f
 - GLMM and, 84–90, 86f, 92–95
- Permanent emigration, 295
- Poisson distribution, 12
 - for abundance, 385
 - for observation error, 352
 - parameter of, 55
 - zero-inflated, 386
- Poisson means, 63
- Poisson models
 - for abundance estimation, 398–401
 - GLM
 - analysis of real data, 64–66
 - binomial GLM compared to, 48
 - fecundity modeling by, 66–67
 - generation and analysis of simulated data, 56–64
 - overdispersion in, 83
 - in R, 55–66
 - summary of, 71–72
 - WinBUGS and, 55–66
 - GLMM
 - analysis of real data, 88–90, 95–110
 - fixed site and fixed year effects, 100–102
 - fixed site effects, 99–100
 - full model, 108–110
 - generation and analysis of simulated data, 84–88, 92–95
 - introduction to, 73–82
 - overdispersion in, 83
 - with random effects for variability among groups, 90–110
 - random site and random year effects, 103–105
 - random site effect, random year effect, and first-year fixed observer effect, 105–106
 - random site effect, random year effect, first-year fixed observer effect, and overall linear time trend, 106–108
 - random site effects, 102–103
 - uses of, 111
 - PLN, 83–84
 - Poisson-binomial mixture model, 385–386
 - Poisson random variable, 55
 - Poisson response, 15
 - Poisson–log-normal (PLN) model, 83–84
 - Population(s). *See also* Integrated
 - population models; Metapopulation; Open-population model; Population size; Superpopulation
 - abundance as key descriptor of, 409–410
 - analysis
 - for conservation, 477–478
 - defined, 6
 - methods for, 15
 - observation process and, 8
 - recurring themes in, 477
 - viability, 366–370
 - for wildlife management, 477–478
 - asp viper, 17–18, 18–19f, 74–77, 76f
 - black grouse, 329, 329f, 334f
 - classic, 4
 - common terns, 244–246, 245f, 252–255
 - community as, 5
 - counts, state-space models for
 - analysis of simulated data, 119
 - framework of, 117
 - house martin example, 126–130, 126f, 130f
 - ibex example, 118f, 118–121, 121f, 124f
 - introduction to, 115–118
 - MCMC and, 120, 130
 - observation equations in, 116
 - simple, 118–121, 131
 - state-process equations in, 116
 - systematic bias and, 121–126
 - WinBUGS and, 118–130
 - descriptors, 7
 - in finite-population standard deviation, 79
 - fire salamanders, 282–284, 283f
 - grey-headed woodpecker, 335–339, 336f
 - hoopoe, 371f, 371–379, 378f
 - kittiwakes, 414
 - Leisler's bats
 - in recruitment, survival, and population size estimation using JS model, 341–345, 344f
 - survival estimation using CJS model and, 231–237, 232f, 235–236f

Population(s) (*Cont.*)

- likelihood of count data, 352–354
 - little owls, 177–183, 178f, 185, 189, 196, 209, 227–231
 - little ringed plover, 270–274, 271f, 289–290, 302–303
 - long-eared owl, 439–445, 440f, 454, 456
 - models, for metapopulation designs, 474–475
 - ortolan bunting, 349, 350–351f, 357–363, 366–370
 - pen shell, 166–168, 167f
 - peregrine falcon
 - GLM model of, 56–71, 56–57f, 65f
 - GLMM model of, 84–90, 86f, 92–95
 - quantities, sample size and, 20
 - red kites, 255–261, 256f, 259–260f
 - Rosalia alpina* beetle, 427–436, 428–429f, 432f, 434f
 - silver-washed fritillary, 396–409, 397f, 408f
 - six-spot burnet, 445–450, 445f, 450f
 - sparrow, 9–11, 11f
 - spotted owl, 414
 - Swiss coal tit, 95f, 95–110, 97f
 - tadpole, 29, 30f, 33, 38
 - unobserved, 366
 - white storks, 252
 - wryneck, 156f
- Population size
- closed, capture–recapture data for
 - estimating
 - analysis of real data, 157–162
 - behavioral effects in, 148–150
 - CJS model and, 135, 137–138
 - combined effects in, 154–157
 - generation and analysis of simulated data, 139–157
 - individual effects in, 150–153
 - introduction to, 134–139
 - model M_{tth} for species richness estimation, 157–162
 - model M_{t+x} , 162–168
 - pen shell example of, 166–168, 167f
 - summary of, 169–170
 - time effects in, 145–147
 - trap response example of, 136–137, 148–157
 - demographic rates and, 350–352
 - individual covariate models estimating, 166–168
 - integrated population models estimating
 - analysis of, 358–363

- CJS model in, 371
- fecundity estimated with, 363–366, 377–378
- hoopoe example of, 371f, 371–379, 378f
- introduction to, 348–350
- ortolan bunting example of, 349, 350–351f, 357–363, 366–370
- for population viability analysis, 366–370
- without productivity data, 363–366
- real data example of, 371–379
- simple example of, 357–363
- summary of, 379–380
- WinBUGS and, 357–379

JS model estimating

- analysis of real data, 341–345
 - assumptions of, 316
 - black grouse example of, 329, 329f, 334f
 - connections between parameters in, 339–341
 - data augmentation in, 319–328, 338
 - GLM and, 328, 345
 - grey-headed woodpecker example of, 335–339, 336f
 - identifiability in, 339–341
 - introduction to, 316–317
 - Leisler's bats example of, 341–345, 344f
 - models with constant survival and time-dependent entry, 328–335
 - models with individual capture heterogeneity, 335–339
 - parameterizations of, 317, 325–328
 - priors in, 326
 - summary of, 345–346
 - WinBUGS and, 321–339, 341–345
 - observed, 121–126
 - of occupied patches, 13
 - as smoothed index, 380
 - true, 121–126
 - of unobserved populations, 366
- Positional matching, 87
- Posterior distributions
- in abundance estimation, 394f, 397, 401f
 - introduction to, 33–34, 36–37
- Posterior mean, MLE and, 28
- Posterior sampling, 41–43
- Postwork activity, 32
- Potential individuals, 141
- Precision, 16–20

- Predator control, 477
- Prediction, objective of, 26
- PRESENCE, 470–471
- Presence/absence data, 414, 416. *See also*
Detection/nondetection data
- Primary model selection, 468–469
- Priors
- Bayes rule and, 35–37, 44
 - Dirichlet distribution, 300, 302, 308, 454
 - gamma, 120
 - mark-recovery data and, 258, 260
 - random effects and, 77
 - in recruitment, survival, and population size estimation, 326
 - state-space models and, 127
 - uniform, 120
 - for variance parameters, 37
- Probability
- age-specific, of first breeding model analysis of, 290–294
 - description of, 288–289
 - generation of simulated data, 289–290
 - survival and movement estimation with, 288–294
- defined, 28
- detection, 6, 11
- in binomial mixture models, 387
 - capture–recapture models and, 137t, 136–137
 - constant, 447, 472
 - date related to, 433
 - model selection view of, 473
 - state-space models and, 124–125, 131
 - time of day related to, 433
 - within-capture-history dependence of, 148
- entry, 317, 323, 329, 333, 340, 345
- marginal, 33
- movement, 14t
- recapture, 212–216
- removal entry, 320, 323, 333
- survival, 14t, 15
- Process variance, 123
- Productivity data, estimation without, 363–366
- Program R. *See also* R code
- in abundance estimation, 396
 - distribution catalog in, 49
 - simulations with, 9, 10
- Projection matrices, integrated population models and
- analysis of, 358–363
 - CJS model in, 371
 - fecundity estimated with, 363–366, 377–378
 - hoopoe example of, 371f, 371–379, 378f
 - introduction to, 348–350
 - ortolan bunting example of, 349, 350–351f, 357–363, 366–370
 - for population viability analysis, 366–370
 - without productivity data, 363–366
 - real data example of, 371–379
 - reproduction and, 357–363
 - summary of, 379–380
 - WinBUGS and, 357–379
- Pseudo-individuals, 319, 331
- Pseudoreplication
- avoidance of, 80
 - in site-occupancy models, 437
- p*-values
- in abundance estimation, 397
 - in Bayesian statistical modeling, 222–223, 226f
 - criticisms of, 222–223
 - in site-occupancy model, 419–420
- ## Q
- Quantity
- defined, 33
 - sample size and, 20
- ## R
- R code
- for ANCOVA linear model, 50, 52
 - mark-recovery data and, 249
 - Poisson GLM in, 55–66
 - presentation of, 16
 - random-effects modeling in, 82–90
 - for survival estimation using CJS model, 178
 - treatment contrast parameterization and, 53
- R function, 63–64, 221
- Random effects
- annual rates as, 377
 - costs of, 82
 - defined, 73, 77–78
 - fixed effects compared to, 76, 82
 - flexibility from, 15
 - GLM and, 73
 - group, 194–195

- Random effects (*Cont.*)
- in linear predictor for detection, 386
 - MCMC and, 406
 - for overdispersion correction, 404
 - priors and, 77
 - time effects, 184–188, 204–208
 - for variability among groups, 90–110
 - in WinBUGS, 76, 82–90
- Random factor, 78
- Random processes, accounting for, 80
- Random site and random year effects model, 103–105
- Random site effect, random year effect, and first-year fixed observer effect model, 105–106
- Random site effect, random year effect, first-year fixed observer effect, and overall linear time trend model, 106–108
- Random site effects model, 102–103
- Random temporary emigration, 436
- Random time effect models, 184–188
- Random variables, 27
- in fitting of complex statistical models, 464–465
 - in hierarchical models, 43
 - Poisson, 55
- Random-coefficients models, 78
- Random-effects models
- ANCOVA, 75–76
 - data augmentation in, 152
 - difficulty fitting, 191
 - motivations, 78–81
 - accounting for all random processes, 80
 - borrowed strength, 80–81, 110
 - information combination, 81
 - modeling parameter correlations, 79–80
 - partitioning of variability, 79
 - pooling of batched effects, 81
 - pseudoreplication avoidance, 80
 - scope of inference, 78–79
 - variability assessment, 79
 - overdispersion accounted for in, 82–90
 - in R, 82–90
 - random site and random year effects model, 103–105
 - random site effect, random year effect, and first-year fixed observer effect model, 105–106
 - random site effect, random year effect, first-year fixed observer effect, and overall linear time trend model, 106–108
 - random site effects model, 102–103
 - random time effect model, 184–188
 - terminology, 78
 - in WinBUGS, 82–90
- Random-intercepts models, 75, 78
- Range, 4
- Recapture probability, survival estimation and, 212–216
- Recruitment, survival, and population size estimation using JS model
- analysis of real data, 341–345
 - assumptions of, 316
 - black grouse example of, 329, 329f, 334f
 - connections between parameters in, 339–341
 - data augmentation in, 319–328, 338
 - GLM and, 328, 345
 - grey-headed woodpecker example of, 335–339, 336f
 - identifiability in, 339–341
 - introduction to, 316–317
 - Leisler's bats example of, 341–345, 344f
 - models with constant survival and time-dependent entry, 328–335
 - models with individual capture heterogeneity, 335–339
 - parameterizations of, 317, 325–328
 - priors in, 326
 - summary of, 345–346
 - WinBUGS and, 321–339, 341–345
- Recruitment probability. *See* Entry probability
- Red kites, 255–261, 256f, 259–260f
- Red-backed shrikes, 213, 214f
- Regression model, 74
- Reif, Jiri, 157
- REML method, 75
- Removal entry probability, 320, 323, 333
- Replicated counts, 385, 409
- Reproduction, in integrated population model, 357–363
- Reproductive success data, 354
- Response components, in GLM
- link function and, 54–55
 - noise, 48–55
 - signal, 48–55
- Restricted occupancy model
- dynamic, 320–322
 - JS model as, 331

MCMC samples for, 343
 speed of, 341
 Rhat statistic, 39, 62, 63f, 87
 Robust design, 387, 472
Rosalia alpina beetle, 427–436, 428–429f, 432f, 434f

S

Sample size
 false positives and, 13
 population quantities and, 20
 Sampling
 of capture–recapture data, 472
 design, 468
 distance, 135, 169
 Gibbs, 38
 for mark–recovery data, 242
 MCMC, 38
 posterior, 41–43
 repeated, 17
 variation, 13, 19–20, 422
 Scale 1, 2, 3t
 Scale 2, 3, 3t
 Scale 3, 3t, 5
 Scale 4, 3t, 5
 Science, modeling’s role in, 24–27
 Seasons, as grouping factor, 437
 Secondary model selection, 469–470
 SECR models. *See* Spatially explicit capture–recapture models
 Showy lady’s slipper, 307f, 307–311
 Shrinkage, 80, 377
 Signal
 link function and, 54–55
 as response component, 48–55
 Silver-washed fritillary, 396–409, 397f, 408f
 Simulations
 abundance and covariate relationship in, 395f
 in abundance estimation, 388–396
 with age-specific probability of first breeding model, 289–290
 asp viper, 17–18, 18–19f, 74–77, 76f
 benefits of, 16–20
 bias and, 16–20
 binomial GLM and, 68–70
 with capture–recapture models, 139–157
 behavioral effects, 148–150
 combined effects, 154–157
 individual effects, 150–153
 introduction to, 139–145
 time effects, 145–147
 from inside out, 17
 with integrated population models, 349
 of mark–recovery data, 244–246, 296–297
 in model for joint analysis of capture–recapture and mark–recovery data, 296–297
 of movement among three sites, 302–303
 of movement between two sites, 270–274
 in occurrence and species distribution estimation, 420–427, 439–445
 Poisson GLM and, 56–64
 Poisson GLMM and, 84–88, 92–95
 with program R, 9–10
 state-space models and, 119
 in temporary emigration model, 282–284
 Single-season occupancy analysis
 model with covariates, 422–427
 in occurrence and species distribution estimation, 420–427
Rosalia alpina beetle example of, 427–436, 428–429f, 432f, 434f
 simplest model for, 420–422
 Site covariate, 390
 Site effects, 90–110
 Site-occupancy models
 assumptions of, 416
 Bernoulli distributions and, 417
 defined, 414
 dynamic, 436–450, 459
 false negatives and, 417
 false positives and, 416–417
 metapopulation designs and, 474–475
 multiseason, 436–450
 multistate
 dynamic, 458–459
 extensions of, 458–459
 importance of, 459
 in occurrence and species distribution estimation, 450–458
 parameterizations of, 453
 uses of, 451
 occurrence and species distribution estimation using
 analysis of real data, 427–436, 445–450
 dynamic models for, 436–450, 459
 generation and analysis of simulated data in, 420–427, 439–445
 goodness of fit and, 418
 introduction to, 414–418

Site-occupancy models (*Cont.*)

- long-eared owl example of, 439–445, 440f, 454, 456
 - multistate occupancy models, 450–458
 - p*-values and, 419–420
 - Rosalia alpina* example of, 427–436, 428–429f, 432f, 434f
 - single-season occupancy analysis, 420–427
 - six-spot burnet example of, 445–450, 445f, 450f
 - summary of, 459–460
 - WinBUGS in, 419–436, 439–450
 - p* not accounted for in, 419–420
 - pseudoreplication in, 437
 - simplest version of, 420–422
 - for single-season occupancy analysis
 - model with covariates, 422–427
 - in occurrence and species distribution estimation, 420–427
 - Rosalia alpina* beetle example of, 427–436, 428–429f, 432f, 434f
 - simplest model for, 420–422
 - for species distributions, 15, 419–420
 - state process of, 439
 - temporary emigration in, 436–437
- Six-spot burnet, 445–450, 445f, 450f
- Smoothed estimate, 131
- Sparrows, 9–11, 11f
- Spatial models
- development of, 475
 - SECR, 135, 475
 - for study design, 475
- Spatial variation, in abundance, 384
- Spatially explicit capture–recapture (SECR) models, 135, 475
- Species distribution estimation
- analysis of real data, 427–436, 445–450
 - dynamic models for, 436–450, 459
 - generation and analysis of simulated data in, 420–427, 439–445
 - goodness of fit and, 418
 - introduction to, 414–418
 - long-eared owl example of, 439–445, 440f, 454, 456
 - multistate occupancy models, 450–458
 - p*-values and, 419–420

- Rosalia alpina* example of, 427–436, 428–429f, 432f, 434f
 - single-season occupancy analysis, 420–427
 - six-spot burnet example of, 445–450, 445f, 450f
 - summary of, 459–460
 - WinBUGS in, 419–436, 439–450
 - site-occupancy model for, 15, 419–420
 - species–abundance, 5
- Species richness, 139
- biodiversity and, 5
 - model M_{tth} for estimating, 157–162
 - model M_{t+x} for estimating, 162–166
- Species–abundance distribution, 5
- Spline modeling, 476
- Spotted owl, 414
- Standard error, of estimator, 20
- State
- changes in, 2, 2f
 - defined, 264
 - observed, 8
 - process
 - equations, 116, 265
 - in JS model, 318, 318f
 - in mark-recovery model, 243f, 243
 - multistate models and, 265, 266f
 - in site-occupancy model, 439
 - true, 8
 - variables, 6
 - abundance, 410, 414
 - latent, 181–183, 247, 276, 318
 - occupancy, 4
- State-space likelihood
- integrated population models and, 354
 - in survival and movement estimation using multistate models, 274
- State-space models
- CJS models and, 173, 175–177, 181, 237, 465, 466t
 - defined, 111, 115
 - detection probability and, 124–125, 131
 - JS model as, 317–319
 - mark-recovery models as
 - advantages of, 242–248, 261
 - analysis of model with constant parameters, 246–248
 - simulation of mark-recovery data, 244–246
 - state and observation processes, 243, 243f

- for population counts
 - analysis of simulated data, 119
 - framework of, 117
 - house martin example, 126–130, 126f, 130f
 - ibex example, 118f, 118–121, 121f, 124f
 - introduction to, 115–118
 - MCMC and, 120, 130
 - observation equations in, 116
 - simple, 118–121, 131
 - state-process equations in, 116
 - systematic bias and, 121–126
 - WinBUGS and, 118–130
- priors and, 127
- summary of, 131
- survival estimation using mark-recovery data and, 242–248, 261
- Statistical models. *See also* Bayesian statistical modeling
 - complex, fitting of, 464–465
 - frequentist analysis of, 28–38
 - introduction to, 27
 - organic approach to, 469
 - response components in, 48–55
- Step-up approach, to problems, 467
- Strength, borrowed, 80–81, 110
- Study design
 - hierarchical models for, 471–472
 - spatial models for, 475
- Suitability indicators, latent, 402
- Superpopulation
 - in constant survival and time-dependent entry models, 333
 - parameterization, 325–328
- Survival estimation
 - using CJS model
 - age effect models and, 208–212
 - age-dependent models and, 227–231
 - analysis of real data, 231–237
 - constant parameters and, 177–183
 - fixed group and random time effect models in, 204–208
 - fixed group and time effect models in, 199–204
 - fixed group effect models in, 192–194
 - fixed time effect models in, 184
 - GLM and, 199, 211, 237
 - individual group effects in, 195–199
 - introduction to, 172–175
 - latent state variable in, 181–183
 - Leisler's bat example, 231–237, 232f, 235–236f
 - little owls example of, 177–183, 178f, 185, 189, 196, 209, 227–231
 - models with individual variation and, 192–199
 - multinomial likelihood and, 220–231, 237
 - parameter identifiability in, 216–220
 - R code and, 178
 - random group effects in, 194–195
 - random time effect models in, 184–188, 204–208
 - recapture probability and, 212–216
 - red-backed shrikes example, 213, 214f
 - summary of, 237–238
 - temporal covariates in, 188–192
 - temporal variability, 204
 - time and group effect models in, 199–208
 - time-dependent models and, 222–227
 - time-variation models and, 183–192
 - trap response models and, 212–216
 - WinBUGS and, 177–208, 212–237
 - using JS model
 - analysis of real data, 341–345
 - assumptions of, 316
 - black grouse example of, 329, 329f, 334f
 - connections between parameters in, 339–341
 - data augmentation in, 319–328, 338
 - GLM and, 328, 345
 - grey-headed woodpecker example of, 335–339, 336f
 - identifiability in, 339–341
 - introduction to, 316–317
 - Leisler's bats example of, 341–345, 344f
 - models with constant survival and time-dependent entry, 328–335
 - models with individual capture heterogeneity, 335–339
 - parameterizations of, 317, 325–328
 - priors in, 326
 - summary of, 345–346
 - WinBUGS and, 321–339, 341–345
- using mark-recovery data
 - common terns example of, 244–246, 245f, 252–255
 - introduction to, 241–242
 - latent state variable in, 247

Survival estimation (*Cont.*)

- m-array for, 249, 251–253, 255
- MCMC and, 261
- multinomial likelihood and, 248–255, 261
- priors in, 258, 260
- R code and, 249
- real-data example of, 255–261
- red kites example, 255–261, 256f, 259–260f
- sampling for, 242
- simulation of, 244–246
- state-space models and, 242–248, 261
- summary of, 261
- WinBUGS and, 244–261
- using multistate models
 - age-specific probability of first breeding model, 288–294
 - fire salamanders example of, 282–284, 283f
 - introduction to, 264–268
 - little ringed plover example of, 270–274, 271f, 289–290, 302–303
 - model for joint analysis of capture–recapture and mark–recovery data, 295–300
 - movement among three sites, 300–306
 - movement between two sites, 268–281
 - real-data example, 307–311
 - showy lady’s slipper example, 307f, 307–311
 - state-space likelihood and, 274
 - summary of, 311–312
 - temporal effects and, 280
 - temporary emigration model, 281–287
 - WinBUGS and, 270–287, 289–294, 296–300, 302–312
- Survival probability, modeled, 14t, 15
- Swiss coal tit, 95f, 95–110, 97f
- Swiss red kites, 255–261, 256f, 259–260f
- Synthetic understanding, of models, 466t, 465–467
- Systematic bias, state-space models and, 121–126

T

- Tadpole example, 29, 30f, 33, 38
- Temporal covariates, models with, 188–192
- Temporal effects, 280

Temporal variability

- of demographic parameters, 373
- in survival estimates, 204
- Temporary emigration
 - challenge of dealing with, 135
 - closure and, 416
 - model
 - analysis of, 284–287
 - description of, 281–282
 - generation of simulated data, 282–284
 - survival and movement estimation from, 281–287
 - random, 436
 - in site-occupancy models, 436–437
- Territory mapping method, 95
- Three sites, movement among
 - analysis of, 304–306
 - description of, 300–302
 - generation of simulated data, 302–303
 - GLM and, 301
 - survival and movement estimation using, 300–306
- Time and group effect models, 199–208
- Time effects, 136, 138
 - age effects combined with, 212
 - fixed, 184, 199–204
 - in generation and analysis of simulated data with data augmentation, 145–147
 - random, 184–188, 204–208
 - in time and group effect models, 199–208
- Time series, of counts, 55–66
- Time-dependent models, 223–227. *See also* Constant survival and time-dependent entry models
- Time-variation, models with
 - with fixed time effects, 184
 - with random time effects, 184–188
 - survival estimation with, 183–192
 - with temporal covariates, 188–192
- Trap response
 - closed population size estimation and, 136–137, 148–157
 - survival estimation and, 212–216
- Trap-happy effect, 137, 213
- Trap-shyness, 137
- Treatment contrast parameterization, 53
- Trend, 5
- True abundance, 14t
- True distribution, 14t, 415
- True population size, 121–126

True state, observed state compared to, 8
 Two sites, movement between
 analysis of, 274–281
 described, 268–270
 generation of simulated data, 270–274
 using multistate models, 268–281

U

Ultrastructural modeling, 189
 Unbiased estimate, 17
 Uncertainty, evaluation of, 28
 Uniform priors, 120
 Unmarked, 470–471
 Unobserved populations, estimates of, 366

V

Variability
 assessment, random-effects models and, 79
 among groups, 90–110
 partitioning of, 79
 temporal, 204, 373
 Variance
 decomposition, 8
 observation, 123
 parameters, 37
 process, 123
 Varying-intercepts models, 78
 Varying-slopes models, 78
 Viability analysis, 366–370
 Vital rates, 14t, 15

W

White storks, 252
 Wildlife management, population analysis for, 477–478
 WinBUGS. *See also* BUGS language
 in abundance estimation, 388–410
 Bayesian statistical modeling and, 38–40
 capture–recapture models and, 138–169
 cleaner thinking in, 467
 fixed effects in, 76
 flexibility of, 41

GLM with, 48
 binomial GLM and, 68–71
 Poisson GLM and, 55–66
 time series of counts modeled with, 55–66
 undefined real result trap in, 60–61
 idiosyncrasies of, 40
 integrated population models and, 357–379
 MARK compared to, 471
 as MCMC blackbox, 38–41, 44
 multidimensional arrays in, 396
 in occurrence and species distribution estimation, 419–436, 439–450
 presentation of, 16
 primary model selection in, 468–469
 random effects in, 76, 82–90
 in recruitment, survival, and population size estimation using JS model, 321–339, 341–345
 secondary model selection in, 469–470
 as standalone software, 40
 state-space models for population counts and, 118–130
 in step-up approach, 467
 for survival and movement estimation using multistate models, 270–287, 289–294, 296–300, 302–312
 in survival estimation using CJS model, 177–208, 212–237
 in survival estimation using mark–recovery data, 244–261
 Within-capture-history dependence, of detection probability, 148
 Wryneck, 158f

Y

Year effects, 90–110
 Yobs, 140

Z

Zero-inflated Poisson distribution, 386
 Zero-inflated Poisson (ZIP) N-mixture model, 401–404