Index

A

Abundance, estimation, 17
Acoustic sampling, 7, 275
  BUGS implementation, 278
  other types, 279
  secr implementation, 278
  signal strength model, 276
Activity center
  binomial point process model, 130
  in BUGS, 146
  concept, 16
  conditional intensity and, 135
  defined, 41, 128
  direct linkage to density, 17
  in distance sampling, 133
  individual location, 429
  initial values of, 143
  location of, 161, 163, 169
  in MCMC, 164
  in probability mass function, 135
  in SCR model, 134
  in space usage, 135
  in state space, 131, 140, 160
  multi-color spatial plot, 163
  non-uniformity of, 160
  two-dimensional spatial coordinate, 127
  uniform distribution, 165
  unobserved random variable., 128–129
  in **WinBUGS**, 159, 161
  of wolverine map, 166
Adaptive rejection sampling, 450
ArcGIS, 465–466
Akaike Information Criterion (AIC), 55, 184
  Bayesian model, 228
  likelihood methods, 223
  model selection in, 202, 218, 224
  secr package, 206, 220, 226
  sex specific density, 227
Alternative movement model, 396
American shad
  Cormack-Jolly-Seber (CJS) models, 419, 423
  SCR issues, 426
  stream flow, 430
Animal movement, 287
  see also Trap spacing
1 A protocol, 392
Area search, 385, 390, 392
Avian mist-netting example, 264

B

Basic capture-recapture method, 532
Bayesian analyses, 33, 50, 436, 511, 534–535
  Akaike Information Criterion (AIC), 228
  Bayes' rule, 50
  BUGS language for, 60
  checking, 80
  confidence intervals, 68
  indicator variable, 231
  inference principles, 52
  in JAGS, 204
  MCMC methods, 63
  posterior inference, 54
  prior distributions, 53
  selection, 80
  small sample inference, 55
Bayesian inference, 436
  sampling variance, 149
Behavioral response
  in animal studies, 102
  BUGS code for, 212
  contamination of, 139
  covariate effect, 207
  encounter probability, 209–210
  local or global, 212, 220
  probability changes in, 102
  to trapping, 102, 211
Bernoulli distributions, 29, 452
  encounter probability, 249
  M_0 model, 105
  observation model, 254
  Poisson model, 252
  prior distribution, 83
  probability distributions, 29
  Probability mass function (PMF), 29
  SCR0, 169
Binomial distributions, 452
  M_0 model, 103
  notation, 27
  Poisson integrated likelihood, 196
  probability mass function (PMF), 23, 28–29, 37
  R code, 25
Binomial GLMs
  parameter estimation, 77
Binomial integrated likelihood, 196
Binomial observation model, 127
  data augmentation, 145
Binomial point process model, 130

Binomial probability mass function, 23
Binomial regression
  waterfowl banding data, 79
Bivariate normal distribution, 33, 136
Black bears
  SCR + RSF model, study on, 360
  space usage, 362
  convex hell, 9
  standard approach, 12
  BUGS implementation
  Stratified populations, 373
Buffering, 9

C

Camera trapping, 5
  historical overview, 5
  ~~drumbear study, 8~~
  encounter probability, 8
  ~~non-spatial, inadequacy, 11~~
  ~~population studies in, 4~~
  for sampling methods, 13
~~Canada goose resightings, 511~~
Capture-recapture methods, 529
Categorical distributions, 30
Closed population models, 14
  data augmentation (DA), 92–93
Closed capture-recapture model M_h, *451*
Collared individuals, 521
C++, ~~computational speed using,~~ 470
Conditional distribution, 37, 455, 457
  constructing rules, 59
  M_0 model, 91
  Markov chain Monte Carlo (MCMC), 59
  Metropolis-Hastings algorithm, 59
Conditional likelihood, 183
  in closed population model, 91
  full likelihood, 183
  SCR model, 300
Convex hull
  buffering, 9
  density estimation, 9
  trapping array, 13
Cormack-Jolly-Seber (CJS) models, 418
Cost-weighted paths
  calculation, 338
  computation, 337–338
  defined, 335, 340
  R code, 338
  in SCR model, 336
Counter detector, in *secr* package, 258
Covariate effects
  in density, 311
  in encounter probability models, 207, 250
  landscape structure, 353
  in standard GLM or GLMM, 207
  see also Individual covariate model

D

Data augmentation, (DA)
  ~~in all zero rows, 94~~
  in closed population models, 92–93
  formal development, 97
  heuristic motivation, 94
  joint likelihood using, 110
  model-based analysis, 110
  M_h model, 105
  in M_0 model, 95
  occupancy parameter, 94
  posterior mass of, 120
  remarks on, 97
  sampling model, 118
  ~~under a Uniform(0, *M*), 121~~
  unknown *N*, 144
  in **WinBugs**, 146
  zero-inflated model, 95, 110
Data format
  ~~for number of traps, 155~~
  three-dimensional, 155
  two-dimensional, 141
Data structure
  formatting, 141
  manipulating, 141
  sampling design and, 126
~~Demographic composition, 500~~
  ~~survival, 413~~
Density estimation
  ~~Argentina jagur study, 326~~
  ~~canopy height, 324–325, 327~~
  covariate, using, 303, 311
  data simulation, 318
  intensity parameter, 327
  ~~of invariance, 116, 122~~
  in M_0 model, 102
  parameter estimation, 321
  posterior mean, 329
  ~~probability function, 316~~
  ~~**R** code, 328~~
  SCR definition of, 312
  ~~sex specificity, 329~~
  ~~value expectation, 316~~
Density maps
  effective sample area, 181

individual prediction, 169
Wolverine analysis, 166
DENSITY ~~Program~~, 173, 189
Detection function
behavioral response, 254
conditional probability, 251
in covariate influence, 109
data collection, 279
in distance sampling, 117–118
in indicator variable, 235
individual, 110
models, 191
~~non-~~, 276
probability, 276
proximity in, 275
signal strength, 277
time trend, 269
Detector dogs, 400
DIC model selection, 229
~~wolverian data, 229~~
Discrete habitat mask, 160
coarseness, evaluation, 161
Dispersal dynamics
~~individual location, 428~~
~~in population ecology, 430~~
Distance sampling, 30, 41, 44, 383, 386, 392
desert tortoise example, 120
in hierarchical model, 119–120
~~latent variability, 129~~
in SCR model, 117, 119, 122
DNA sampling, 6
Distribution of individuals, 531

E

Ecological distance
Bayesian analysis, 343
density covariate, 349
likelihood analysis, 342
SCR simulation, 339
~~stochastic, 22~~
Effective sample area, 199
density mapping, 181
Effective sample size, 460
~~Efford's formulation, 15~~
~~Efford's possum trapping data, 272~~
Encounter data file, 153
Encounter device types, 191
~~Encounter modeling~~
~~fisher study, 394~~
~~mountain lions, 393~~
Encounter probability
Bayesian analysis, 204
Bernoulli process, 249
binary observation, 252
~~cautionary note, 254~~
covariate model, 207, 250
~~date, impact on, 208~~
Gaussian model, 202, 253, 260
individual covariate, 213
multinomial model, 271
signal strength model, 276
space usage, 252
~~time, impact on, 208~~
trapping interval, 271
trap-specific covariate, 210
~~Envelope function, 450~~
Euclidean distance
in activity centers, 333
cost-weight distance, 338
encounter probability and, 334
~~estimate parameter, 347~~
in MLE model, 343
least-cost path model, 336, 342
mis-specified model, 343, 345, 349
in SCR model, 340
shortcomings, 334
Explicit movement models, 536

F

Fitness model
components, 237
in encounter probability, 219
individual trap frequencies, 241–242
occupancy dynamics, 245
Fixed search path
alternative movement models, 396
design 1, 384
encounter probability, 385
intensity model, 395

G

Gaussian kernel, 519
~~*G* bins, defined, 30~~
Gelman-Rubin ~~diagnostics~~, 463
Generalized linear (mixed) models (GL(M)Ms)
binomial, 84
~~in applied statistics, 48~~
in Bayesian framework, 63
Generalized linear models (GLMs)
binomial, 49, 77, 79
components, 48

in exponential family, 48
in SCR, 48
Poisson, 69, 71, 75
random effects, 49
~~Geographical analysis, 336, 345~~
Gibbs sampling, 57, 59, ~~438~~
in MCMC methods, 57
MH sampling *vs.*, 445
~~**R** code, 440~~
Goodness-of fit, 55, 80, 82
evaluation, 236
in SCR, 184
wolverine data, 243
~~Google Scholar citations, 532~~
~~Google Scholar search, 529~~
Gregarious species, 535
Group structure
in data augmentation, 376
mean model, 374
multi-catch model, 369–370
no encountered individuals, 373
single parameter, 374

H

Habitat mask, 187, 199–200
Habitat selection
space usage, 354
landscape simulation, 364, 367
non-uniform distribution, 311
spatial variation, 316
Hard plot boundaries, 390
~~Heterogeneity model, 103, 106~~
Hierarchical modeling
defined, 40
examples of, 41
random variables, 21
statistical analysis, 37
statistical inference and, 40
Home range center
definition, 128
~~exhibit behavior, 16~~
implied model, 149
space usage model, 135
see also Activity center
Homogeneous point process, 523
spatial randomness, 312

I

Imperfect identification, 534
Indicators variable
detection function, 235
wolverine data, 233
Individual covariate model
capture location, 110
data augmentation, 92
distance sampling, 87
extension, 114
~~Fort drum bear study, 111~~
heterogeneity model, 103
~~home range center, 115~~
in SCR, 109, 117
Individual heterogeneity
defined, 201
detection probability, 216
for home range size, 202
incorporation methods, 220
see also M_h model
Inhomogeneous point-process, 525
density model, 326
discrete space, 324
~~estimation parameters, 318~~
fitting model, 322
in SCR model, 314
intensity parameters, 315
Poisson model, 312
spatial variation, 311, 319
Integrated likelihood
construction, 177
marginal distribution, 174
MLE estimators, 173–174
Poisson method, 195–197
in SCR models, 179–180
~~simulated data, 175~~
under data augmentation, 183
Irregular patches, 345

J

JAGS, 467, 510
Bayesian analysis in, 60
ecological introduction to, 60
~~simulation analysis, 388~~
summary command for, 68
Joint distribution, 37
Jolly-Seber model, 406, 413
data augmentation, 409
spatial, 413

L

Landscape connectivity
geographical analysis, 345

in SCR models, 333–334, 339
Landscape structure
'A' protocol, 354–355
covariate model, 353
defined, 354
discrete model, 366
home range on, 361
resource selection, 364
simulated example, 356, 364
space configuration, 354, 367
Langevin algorithm, 444
Least-cost path
in **BUGS**, 343
computation, 347
covariate matrix, 340
defined, 333, 335
encounter probability, 334
home range, 335
in MLE model, 342
R code, 338
SCR example, 342
Lincoln-Petersen estimator, 502–503
of abundance, 534–535
Live-trapping study, 500

M

Marginal distribution, 37
Marginal likelihood
binomial form, 195
calculation, 187
conditional elements, 178
grid information on, 176
individual encounter and, 174
point process density, 196
Markov chain Monte Carlo (MCMC)
algorithm, 60, 72, 82, 508
in Bayesian analysis, 60, 63
binomial encounter process, 457
building own algorithm, 435
closed capture-recapture model M_h, *451*
in conditional distribution, 59
convergence analysis, 65
ecology application, 47
manipulating state-space, 463
parallel computing, 467
parameter estimation, 68
posterior distributions, 56, 436
R code, 65
in SCR models, 57, 454
using C++, 470
in **WinBUGS**, 64, 67
Marked individuals
homogeneous point process, 523
imperfect identification of, 514
information, 516
inhomogeneous point processes, 525
known number of, 501
known number of, 506
locations of home ranges of, 504
spatial distribution of, 505
unknown number of, 501–502
Markov random fields, 533
MARK program, 503
Mark-resight models, 499
M_b model
global trap response, 220
in non-spatial capture-recapture, 201
Mean maximum distance moved (MMDM)
home range radius, 101
Metropolis-Hastings algorithm
conditional distributions and, 59, 520
Metropolis-Hastings (MH) sampling, 443
vs. Gibbs sampling, 445
R code to run, 445
time series plots, 445
Metropolis-within-Gibbs, 446
M_h model
analysis, 105
Fort drum data, 106
as non-spatial capture-recapture, 201
random effect, 216
SCR, relevance to, 216
Misidentification, 534
MLE with known N, 173
MLE with unknown N, 179
M_0 model
binomial observation, 103
in black bear study, 98
in Bernoulli, 105
in **BUGS**, 95
capture-recapture assumptions, 90
closed population model, 88
conditional distribution, 91
occupancy type, 98
Modeling territoriality, 533
Model selection
in AIC, 218, 220
in Bayesian, 83
issues, 80
in prior distribution, 83
in SCR model, 84
statistical ecology, 55
variable indicators, 65
Modeling movement

population dynamics, 428
Model output
commands, 463
Gibbs sampling, 438
Metropolis-Hastings sampling, 443
Metropolis-within-Gibbs, 446
posterior density plots, 459
rejection and slice sampling, 450
serial autocorrelation and effective sample size, 460
summary results, 462
time series plots, 459
Movement model
alternatives, 396
auto-regression, 397
data simulation, 395
encounter frequency, 383
open population, 399
outcomes, 388
Moving activity centers, 526
Multi-catch device, 249, 258–259, 280
Multi-catch independent multinomial model, 535–536
Multi-session models
BUGS language, 382
data augmentation, 369–370
landscape variation, 382
multi-catch observation, 377
other approaches, 376
R code, 369–370
secr analysis, 377
sex effects on, 220, 369–370
Multi-state model
apparent survival, 420
issues, 423
random parameters, 421
spatial states, 403, 423
technical transition, 421
Multinomial abundance models
stratified populations, 371
Multinomial distributions, 30
Multinomial model
density estimators, 271
encounter devices, 258
in Gaussian methods, 260
JAGS using, 249
in single-catch trap, 271
resource selection, 260
in **WinBugs**, 260
Multiple
distinct sample group, 369
space sample, 381
M_x model
density invariance, 116

N

Non-spatial capture-recapture, 87, 534–535
Non-spatial mark-resight models, 503, 507 514–515
NOREMARK program, 503
Normal distribution, 436
Notation
binomial distribution, 27
BUGS language, 23
in hierarchical modeling, 21, 40
issues, 22
of R code, 21, 43
uniform point process, 32
Numerical integration
fitting parameters, 195
integration grid spacing, 186
R code, 182

O

Observation model
alternative methods, 249
in Bernoulli, 254
in Poisson, 250
JAGS, using, 249
multinomial distribution, 249, 271
single catch trap, 270
Observed point processes, 318
OpenBUGS, 435
Open populations
apparent survival, 405
dispersal, 399
issues, 409
model, 511
movements, 399
recruitment, 408
Optima design
calculation, 302
detector configuration, 293
issues, 294
in SCR model, 287, 297
swapping algorithm, 300–301
trap spacing, 289, 303, 307
Ordinary capture-recapture models
Efford's formulation, 11, 15
encounter probability
N, estimation, 109, 292, 364
non-spatial, 12

point process, 15
technical problems, 17–18
Ovenbird data
reanalysis, 378
Ovenbird mist-netting study, 410, 414

P

Parallel computing, 467
Parameter estimation
in maximum likelihood estimates (MLEs), 36
statistical inference, 34
Partial information designs, 399
Photographic survey, 533–534
Point process aggregation, 15
Point process model
binomial, 130
state-space, 131
for homogeneous point process, 523
for inhomogeneous point processes, 525
bin counts, 240
Poisson distribution, 31, 69
Poisson GLMs, 69
bird survey, example, 69
PoisGLMM(), 449
in **WinBugs**, 71
random effects, 75
Poisson integrated likelihood
binomial form of, 196
development, 195
Poisson model
in Bernoulli, 252
in BUGS, 254
data simulation, 255
encounter probability, 249, 507, 515
GLMM, 449
multinomial relationship, 263
regression, 452
in SCR, 250
in *secr*, 266
space usage, 251
trap specific, 263
wolverine camera, 257
zero-inflated, 255
Population dynamics
animal movement, 405
overview, 404
Posterior distribution, 438–439, 441
Bayesian inference, 52
conditionality, 57
defined, 52
density plots, 459
discrepancy measures, 82
inference of, 54, 55
mass of, 75
MCMC simulation, 56, 65, 68, 436
MH algorithm, 60
parameter estimation, 54, 83
plots of, 441
Prior distribution
Bayes' rule for, 52–53, 64, 83
choices, 63
conjugates, 58
in Bernoulli, 83
MCMC algorithm, 67
parameter estimation, 54
WinBUGS parameter, 73
Probability density function (PDF), 22
resource selection, 25
see also Probability mass function (PMF)
Probability distributions
Bernoulli, 29
binomial, 27
commonly used, 27
different notations for, 22
hierarchical model, 40
properties, 24 –25
random variable, 21, 22
Probability mass function (PMF)
Bernoulli distribution and, 29
binomial return, 23, 28–29, 37
defined, 23
issues, 22
parameters, 22, 37
properties, 24
random variable values, 23
Proposal distribution, 443
random walk, 443
Proximity detector
density estimators, 249
in signal strength, 275

R

Raccoons, 521
R code
beta distribution, 33
binomial distribution, 25
binomial pmf returns, 23
data analysis, using, 21
data simulation, 261
dbinom function., 28

declaration deat, 31
dnorm function, 33
joint distribution, 37
marginal distribution, 38–39
non-negligible probabilities, 23
normal distribution, 24
Poisson outcomes, 35
resource selection, 25
in SCR model, 43
uniform distribution, 32
uniform search model, 397
Radio-tagged individuals, 502–503
Random effect
in Bayesian analysis, 84
in GLM, 49
in GLMMs, 47, 49
in hierarchical models, 83
in MCMC, 47
in Poisson GLM, 75
in **WinBUGS** model, 61, 84
Random sample assumption, 504
Random variable
defined, 21, 25
Random walk proposal distribution, 443
readShapeSpatial(), 466
Recall Bayes' theorem, 436
Recruitment
data augmentation, 409
degenerate, 410
JS model, 406, 413, 416
in open population, 408
sampling perspectives, 404
time dependent, 412
Regular capture-recapture models, 501–502
Rejection sampling, 319, 450
Resighting techniques, 501
Resource selection
encounter probability, 354, 359
in Poisson model, 358
in SCR model, 353
mis-specification, 364
population estimate, 354
second-order scale, 361
telemetry data, 364, 366
Resource selection function (RSF)
independence assumption, 365

S

Sample size
encounter probability, 290
estimation parameters, 289, 307
generation techniques, 285
in conditional probability, 297
in SCR model, 292
spatial problems, 281
trap clusters, 302–303
Sampling design, 126
focal population *vs.* state-space, 284
model based, 282
population closure, 304
space vs individual, 283
Sampling methods
latent heterogeneity, 12
non-invasive, 13
Sampling techniques, 529
Scenario analysis, 281–282
SCR framework
assumptions of, 535
misidentification in, 535
SCR0
Bayesian analysis of, 131
Bernoulli model, 169
BUGS analysis, 125
fitting model, 156–157, 142
home range area, 149
multiple detections, 126
R function, 161
statistical assumptions, 151
in **WinBugs**, 146
SCR models
activity center, character, 298
applications, 376
Bayesian analysis, 149
binomial encounter process, 457
characterization, 41
conditional likelihood, 300
construct full conditionals, 455
continued development of, 532
core assumption, 151
data simulation, 262–263
distance sampling, 133
effective sample area, 169
encounter probability, 296
fixed array trap, 44
identify, 454–455
independence assumption, 365
integration, 359
model M_h, 133
optimal criteria for, 297
Poisson observation model, 299
population closure, 305
sex-specific encounter, 290
spacing aspect, 291
study design, 285
Search-encounter designs

fixed path, 384–385
methods, 7
total hazard, 386
uniform intensity, 385
secr package, 189
additional capabilities, 197
analysis, 192
covariate models, 199
density mapping, 199
encounter device, 191
in likelihood analysis, 195, 218
multi-session model, 196
ovenbird data, 266
population closure test, 199
sex specificity, 266
state-space buffer, 198
Serial autocorrelation, 460
Sex specificity
effects, 220
uncaptured individuals, 183
multi-session models, 369–370
secr package, 266
Single-catch trap, 535
~~inference system, 271~~
multiple sample session, 265
observation model, 270
Slice sampling, 450
Small sample inference
Bayesian analysis, 55
SMR model. *See* Spatial mark-resight model
Space usage model, 354
empirical analysis, 137
home range center, 135
Poisson distribution, 358
~~understanding, 139~~
Spatial capture-recapture (SCR) methods
in animal population, 5
~~in bears, 5~~
characterization, 9
construction of, 14
defined, 4
density estimation, 5
ecological theories and, 18
historical context, 12
inference formalization, 15
~~in lions, 5~~
non-spatial aspects, 8, 11
technical problems, resolving, 3–4
~~in tigers, 5~~
traditional, 18
~~Spatial Capture-Recapture Odyssey, 533~~
~~combining data from surveys, 533~~
~~explicit movement models, 536~~
~~gregarious species, 535~~
~~misidentification, 534~~
~~model fit and selection, 536~~
~~modeling territoriality, 533~~
~~single-catch traps, 535~~
Spatial design
construction, 307
formal analysis, 281
issues, 282, 294, 300
model-based, 293
optimization criteria, 300
temporal aspects, 303
Spatial distribution, 500
Spatial mark-resight (SMR) model, 500
~~for Canada geese in North Carolina, 514~~
~~hybrids of, 500~~
~~homogeneous point process, 523~~
imperfect identification of marked individuals, 514
~~implementing,~~ 507
~~individual capture histories, 503~~
inhomogeneous point processes, 525
~~information, marked and unmarked individuals, 516~~
~~known number of marked individuals~~
~~posterior distributions from, 522~~
~~raccoons on outer banks of North Carolina, 521~~
random sample assumption, 504
resighting techniques, 501
~~short history, 502~~
telemetry data, incorporating, 518
Spatial randomness, 311–312
homogeneous point process and, 312
observation model, 241
uniform distribution, 238
Spatial sampling
in SCR model, 283
issues, 281, 303
trap location, 283
State-space ~~concept~~, 16
~~camera trapping, 302~~
manipulating, ~~463~~
size sensitivity, 240
State-space model
invariance, 132
point process, 131
prescribing, 132
Stationary distribution, 441
Statistical inference
fundamentals of, 21
hierarchical models and, 40
parameter estimation and, 34
role in probability laws, 22

Stratified populations
BUGS implementation, 373
data simulation, 375
hierarchical model, 371
multinomial abundance models, 371
~~prototype, 370~~
in SCR model, 369
Strauss model, 532
Survival
~~affecting factors, 403~~
American shad, 419, 426
Cormack-Jolly-Seber (CJS) models, 418, 421
~~defined, 405~~
demographic parameters, 413
vs emigration, 405
in spatial model, 404
~~JS model~~, 406
~~non-spatial version, 426~~
in open population, 408
~~parameters, 408~~
~~posterior mean, 416~~
~~spatial multi-session model (S-MS), 410~~
~~week probability, 420~~

T

Telemetry data
activity centers, 355
~~on black bear study, 360~~
~~estimation parameters, 362, 364~~
~~raccoons on outer banks of North Carolina, 521~~
resource selection model, 353
RSF model, 366
SCR model, 354, 365
space sampling, 356, 359
Temporal dependence
multi-session formulation, 379
Temporary emigration, 13, 382
~~SCR models and, 13~~
Time series plots, 459
Total hazard,
encounter model, 386–387, 392
Trap arrangement, 293
Trap spacing
~~array size, 287~~
~~home range factors, 285–286~~
movement estimates, 286, 289
~~sensitivity analysis, 281~~
study design, 285, 291
Trap-specific covariate
encounter probability models, 210, 515

U

Uniform distribution, 32
Uniform intensity
design 2, 395
search-encounter designs, 385
Unmarked individuals
estimated number of, 507
information, 516
Unstructured spatial surveys, 392
~~UTM polygon, 467~~

W

WinBUGS, 435–436, 462–463, 467
fitting model, 156
in linear regression, 61
in markov chain Monte Carlo (MCMC), 64, 67
~~in prior distribution, 73~~
in random effect, 61, 84
Wolverine analysis
camera trapping, 162, 184
density map, 166
space usage, 159
~~summary, 158~~

Z

Zero-inflated, Poisson model, 255
~~Zero-truncated distribution, 511~~