THESIS

OCCUPANCY, ABUNDANCE, AND DENSITY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS

Submitted by

Heather C. Tipton

Department of Fish, Wildlife, and Conservation Biology

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2007

COLORADO STATE UNIVERSITY

October 24, 2006

WE HERBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY HEATHER C. TIPTON ENTITLED OCCUPANCY, ABUNDANCE, AND DENSITY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Advisor

Department Head

ABSTRACT OF THESIS

OCCUPANCY, ABUNDANCE, AND DENSITY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS

Concern over the decline of grassland birds has spurred the development of conservation plans focused on increasing our understanding of avian ecology and habitat relationships and developing better monitoring methods. While studies conducted in other states have suggested that black-tailed prairie dogs provide important habitat for grassland avifauna, this relationship has not been investigated across the shortgrass prairie of Colorado. In addition, most studies in the shortgrass ecosystem have not employed rigorous methods to monitor avian population parameters. My study addressed both of these issues, evaluating and employing novel monitoring methods to estimate grassland bird occupancy, abundance, and density on prairie dog colonies and in other shortgrass prairie habitats.

My results suggest that a novel probability-based sampling scheme (i.e., spatially balanced sampling) can be used effectively in large-scale studies. Patch occupancy methods appear feasible for monitoring most grassland bird species over large areas, but issues of closure should be addressed in future survey design. Double-observer methods also worked well and may result in improved estimates of grassland bird abundance. Results from these double-observer surveys provide unbiased population estimates for

Colorado's grassland avifauna and should be useful for assessing avian conservation needs.

My results suggest that prairie dog colonies provide valuable habitat for some shortgrass-associated birds. Both the mountain plover and burrowing owl appear highly associated with prairie dog colonies in eastern Colorado. Mountain plover occupancy and abundance were positively correlated with increasing amounts of prairie dog colony in the landscape. Burrowing owl occupancy was positively correlated with the presence of active prairie dogs on plots, but negatively correlated with increasing amounts of prairie dog colony in the surrounding landscape suggesting a preference for more structurally diverse landscapes. For some species, avian-habitat relationships varied with the population parameter measured. Cassin's sparrow occupancy was higher on prairie dog colony plots, although species abundance was greater on grassland plots. Lark sparrow and western meadowlark were more abundant on prairie dog colony plots than grassland and dryland agricultural plots, but species occupancy was not higher.

Grasshopper sparrows were the only species highly associated with dryland agriculture, with higher occupancy and abundance on plots in this stratum. This relationship may be caused by the increased homogeneity of native grasslands in eastern Colorado. In the absence of heterogeneity, species preferring taller vegetative conditions may rely on non-native habitats such as agricultural and Conservation Reserve Program lands.

In general, occupancy of most study species was influenced by a combination of plot- and landscape-level variables (rather than one or the other), corresponding with results of previous grassland bird studies conducted in mixed-grass and tallgrass prairies.

Large-scale habitat characteristics affected plot-level occupancy for many species, suggesting that species habitat selection may be constrained by broad-scale (landscape-level) requirements which act as a filter for local (plot-level) habitat requirements. Habitat variables did not explain much process variance in between-plot estimated species abundance suggesting that other variables including smaller-scale habitat factors should also be considered.

Conservation actions should incorporate land acquisition and management to benefit prairie dogs. Because managing for specific colony attributes may be difficult, I suggest managing to promote heterogeneity in the shortgrass ecosystem to ensure that suitable habitat is available for a variety of grassland inhabitants. To achieve successful results, partnerships with private landowners should also be pursued to meet land management goals over broad scales.

Heather Colleen Tipton

Department of Fish, Wildlife, and Conservation Biology

Colorado State University

Fort Collins, CO 80523

Spring 2007

ACKNOWLEDGMENTS

First, I would like to sincerely thank my co-advisors, Drs. Paul Doherty and Victoria Dreitz, for accepting me as their Master's student and allowing me to pursue this opportunity. They have both served as wonderful mentors and I will forever appreciate their thoughtful counsel and energetic support. I would also like to thank Dr. Jim Gammonley of the Colorado Division of Wildlife for helping me get my foot in the door. A big "thank you" also to my committee members, Drs. Barry Noon and David Theobald, for their guidance, especially in the design phase of my study.

I would like to thank my husband, David Tipton, for his loving support and his patience. I would also like to thank my family and especially my parents, Rich and Vicky Garrison, for their constant encouragement in this and every aspect of my life. I am where I am today because of them. I am also indebted to my friends, without whom this journey would not have been as enjoyable. In particular, Sharon Baruch-Mordo and Susan Shriner have provided unfailing support and invaluable advice, as well as the more-than-occasional sympathetic ear and shoulder to lean on.

I am truly grateful to the Colorado Division of Wildlife for funding this study. Additional funding was received from the Colorado Chapter of The Wildlife Society. In addition, this study would not have been possible without the cooperation of hundreds of private landowners throughout eastern Colorado. Their willingness to allow me on their lands was integral to the success of this project. Thanks also goes out to my field crews

who walked many miles and slept in many strange places to get the work done, and who kept my summers interesting.

I would also like to thank the Division Area and Wildlife Managers throughout eastern Colorado for indispensable logistical support, including the use of State Wildlife Area bunkhouses. Field lodging was also provided by the Shortgrass Steppe Long-term Ecological Research Center and the U.S. Forest Service at the Pawnee and Comanche National Grasslands. I am also grateful to those persons who provided the GIS data and tools instrumental to the design of this project – David Theobald (Colorado State University), Jon Kindler and Seth McClean (Colorado Division of Wildlife), Mary Hattis and Geri Mason (U.S. Forest Service), Michael Menefee (Colorado Natural Heritage Program), and Stu McFarland (Natural Resource Conservation Service).

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS vi

TABLE OF CONTENTS viii

LIST OF TABLES xi

LIST OF FIGURES xxvi

CHAPTER 1. ECOLOGY AND MONITORING OF COLORADO BREEDING GRASSLAND BIRDS: A REVIEW 1
INTRODUCTION 1
ESTIMATION METHODS USED FOR MONITORING GRASSLAND BIRDS 2
Sample Selection 3
Detection Error 5
THE SHORTGRASS PRAIRIE ECOSYSTEM 8
Black-tailed Prairie Dog (*Cynomys ludovicianus*) 11
Ecology of Grassland Birds 14
General background 14
Species of primary interest 17
Mountain plover (*Charadrius montanus*) 17
a) Natural history and conservation status 17
b) Current research and estimation methods 18
Western burrowing owl (*Athene cunicularia hypugaea*) 22
a) Natural history and conservation status 22
b) Current research and estimation methods 23
Other species 25
THESIS SUMMARY 28
LITERATURE CITED 31

CHAPTER 2. OCCUPANCY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS 48
INTRODUCTION 48
STUDY AREA 53
METHODS 53
Sampling Design 53

Field Data Collection 54
Covariate Data Collection 55
Model Set and Selection 56
Exploratory covariate analyses 56
Modeling detection probabilities 57
Modeling occupancy probabilities 59
Analysis 60
RESULTS 61
Mountain Plover 62
Burrowing Owl 63
Horned Lark 64
Cassin's Sparrow 64
Lark Sparrow 65
Lark Bunting 67
Grasshopper Sparrow 68
Western Meadowlark 69
DISCUSSION 70
Effects on Detection Probabilities 71
Effects on Occupancy Probabilities 72
Plot-level effects 72
Landscape-level effects 75
Limitations on Inference 79
LITERATURE CITED 81

CHAPTER 3. ABUNDANCE AND DENSITY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS 190
INTRODUCTION 190
STUDY AREA 194
METHODS 195
Sampling Design 195
Field Data Collection 196
Model Set and Selection 198
Habitat Factors Affecting Abundance 201
Estimating Latent Abundance from Occupancy Data 204
RESULTS 204
Mountain Plover 205
Burrowing Owl 207
Horned Lark 208
Cassin's Sparrow 210
Lark Sparrow 211
Lark Bunting 213
Grasshopper Sparrow 214
Western Meadowlark 216
DISCUSSION 217
Abundance and Density Estimation 219
Effects on Detection Probabilities 222

Effects on Abundance and Density 223
Plot-level effects 223
Landscape-level effects 226
Limitations on Inference 228
LITERATURE CITED 230

CHAPTER 4. IMPLICATIONS FOR GRASSLAND BIRD MONITORING AND CONSERVATION 295
INTRODUCTION 295
WHAT SHOULD WE MONITOR? – OCCUPANCY VERSUS ABUNDANCE.... 296
HOW SHOULD WE MONITOR? – APPLYING NEW METHODOLOGIES 297
Occupancy 298
Abundance 299
Sampling Frame 301
RECOMMENDATIONS FOR FUTURE STUDIES 302
CONSERVATION AND MANAGEMENT IMPLICATIONS 304
LITERATURE CITED 308

APPENDIX I. GEOGRAPHIC INFORMATION SYSTEM (GIS) PROCEDURES.... 310

COMPREHENSIVE LITERATURE CITED……..336

LIST OF TABLES

Table 1.1. North American prairie avifauna of the Great Plains. Shortgrass and short-mixed-grass associated species are listed in bold type and declining species (as indicated by analysis of Breeding Bird Survey data) are marked with an asterisk.. 43

Table 1.2. Species of conservation concern in Colorado's shortgrass prairie ecosystem. Each species' Partners in Flight (PIF) priority level is shown, along with corresponding Shortgrass Prairie Bird Conservation Region (BCR 18) ratings. Population trends are based on Breeding Bird Survey data within BCR 18 from 1966 to 1999. Shortgrass and short-mixed-grass associated species are listed in bold type. 44

Table 1.3. Selected natural history and conservation status of eight species of grassland birds in eastern Colorado. Species breeding distribution, observed habitat associations, and approximate timing of nest initiation, fledged young, and fall migration, as well as apparent population trends, are shown. Summarized from species accounts in *Colorado Breeding Bird Atlas* (Kingery 1998) and *The Birds of North America* series[a]. 46

Table 2.1. Correlation matrix for 10 visit-specific variables recorded during 1074 occupancy surveys of 282 plots in eastern Colorado in 2005. 'SurvPer' is the survey period (1-4) in which the visit occurred. 'Day' is an assigned value (1-59) representing date of visit within the survey season (2 May – 29 Jun), where 'Day' = 1 indicates 2 May 2005. 'StartTime' is the time of day at which the survey began. 'SurvDur' is the survey duration in minutes. 'AvgTemp' is the mean of recorded start and end temperatures, measured in °C. 'MaxTemp' is the higher of the recorded start or end temperatures. 'AvgWind' is the mean of recorded start and end wind speeds, measured in meters per second. 'MaxWind' is the greater of the recorded start or end wind speeds. 'AvgCloud' is the mean of recorded start and end cloud cover, estimated visually and coded as 1-4 representing 0-25%, 26-50%, 51-75% and >75% cover, respectively. 'MaxCloud' is the greater of the recorded start or end cloud cover..... 88

Table 2.2. Correlation matrix for 9 plot-level variables representing habitat characteristics of 282 occupancy plots in eastern Colorado in 2005. 'North' is the latitude of the plot center as represented by North American Datum 1927, Universal Transverse Mercator Zone 13 North. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony.

'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland……..89

Table 2.3. Correlation matrices for nine plot-level variables representing habitat characteristics of occupancy plots in three strata – (a) prairie dog colony, (b) grassland, and (c) dryland agriculture – in eastern Colorado in 2005. 'North' is the latitude of the plot center as represented by North American Datum 1927, Universal Transverse Mercator Zone 13 North. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS; 'pdP' equals zero for all grassland and dryland agriculture plots. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony. 'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland. 90

Table 2.4. Variables used as covariates in models estimating detection (*p*) and occupancy (ψ) probabilities of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown. Values of habitat variables are presented for all plots combined as well as for prairie dog colony (PD), grassland (Grass), and dryland agriculture (Ag) plots separately. In variable definitions, "landscape 1" refers to a plot plus its 500-m buffer, "landscape 2" refers to a plot plus its 1500-m buffer, and "landscape 3" refers to a plot plus its 2250-m buffer..... 92

Table 2.5. Predicted results of covariate-modeled detection probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific detection probabilities. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species detection probability. Explanation and coding of model parameters are provided in Table 2.4. 96

Table 2.6. Predicted results of covariate-modeled occupancy probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific occupancy probabilities. Other predicted results are represented as having either a

positive (+) or negative (−) effect, or no effect (NE), on species occupancy probability. Explanation and coding of model parameters are provided in Table 2.4. ……97

Table 2.7. Number of plots surveyed for grassland avifauna in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado during four survey periods in 2005. Survey periods were 1 May – 16 May (period 1), 17 May – 6 June (period 2), 7 June – 16 June (period 3), and 17 June – 30 June (period 4). ……..98

Table 2.8. Reasons and respective numbers of plots which I did not survey in 2005. Numbers are shown for three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado. "No contact" indicates plots for which I was unable to contact landowners or lessees. 99

Table 2.9. Results of goodness-of-fit tests using the parametric bootstrap procedure in program MARK for eight grassland bird species in eastern Colorado in 2005. Data were simulated under the most general (global) model, without individual covariates, for each species. Due to the low numbers of detections on grassland and dryland agriculture plots, the global model for burrowing owl was $p_t\,\psi_s$. For the remaining seven species, this was model $p_{s\times t}\,\psi_s$. The probability of observing a deviance larger than the observed value (p [deviance]) and estimates of the overdispersion parameter ($\hat{c}$) are shown. Values of $\hat{c}$ were calculated using both deviance (observed deviance ÷ mean of simulated deviances) and $\hat{c}$ (observed $\hat{c}$ ÷ mean of simulated $\hat{c}$) methods. 100

Table 2.10. Number (and %) of plots on which eight grassland bird species were detected in eastern Colorado in 2005. Raw detections are shown for three strata – prairie dog colony (90 plots surveyed), grassland (100 plots), and dryland agriculture (92 plots)..... 101

Table 2.11. Model selection results for 70 models of detection probability and occupancy for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 102

Table 2.12. Model selection results for 54 models of detection probability and occupancy for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative

to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 105

Table 2.13. Model selection results for 10 models of detection probability and occupancy for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 107

Table 2.14. Model selection results for 50 models of detection probability and occupancy for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 108

Table 2.15. Model selection results for 47 models of detection probability and occupancy for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 110

Table 2.16. Model selection results for 43 models of detection probability and occupancy for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4..... 112

Table 2.17. Model selection results for 44 models of detection probability and occupancy for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005.

Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4. 114

Table 2.18. Model selection results for 37 models of detection probability and occupancy for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4. 116

Table 2.19. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 118

Table 2.20. Covariate estimates ($\hat{\beta}_i$) under the top 21 occupancy models (AIC_c weight [w_i] ≥ 0.01) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.. 119

Table 2.21. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 126

Table 2.22. Covariate estimates ($\hat{\beta}_i$) under the top 26 occupancy models (AIC_c weight [w_i] ≥ 0.01) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.. 127

Table 2.23. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 134

Table 2.24. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4. 135

Table 2.25. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 141

Table 2.26. Covariate estimates ($\hat{\beta}_i$) under the top 25 occupancy models (AIC_c weight [w_i] ≥ 0.01) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4. 142

Table 2.27. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 152

Table 2.28. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.. 153

Table 2.29. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4..... 159

Table 2.30. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4. 160

Table 2.31. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4. 165

Table 2.32. Covariate estimates ($\hat{\beta}_i$) under the top 17 occupancy models (AIC_c weight [w_i] ≥ 0.01) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.. 166

Table 2.33. Estimated occupancy probabilities ($\hat{\psi}_i$) under the highest ranking model ($\Delta AIC_c = 0$) for eight grassland bird species in eastern Colorado in 2005. Each model's AIC_c weight (w_i) and number of parameters (*K*) are shown. Estimates with 95% confidence intervals are shown for three strata – prairie dog colony (pd), grassland (grs), and dryland agriculture (ag) – where appropriate. Occupancy estimates were calculated using stratum-specific means for individual covariates. Explanation, coding, and mean values of model parameters are provided in Table 2.4..... 171

Table 2.34. Estimated detection ($\hat{p}_i$) and occupancy ($\hat{\psi}_i$) probabilities for eight grassland bird species in three strata – prairie dog colony (pd), grassland (grs), and dryland agriculture (ag) – in eastern Colorado in 2005. Estimates were generated in program MARK under a general strata model ($p_s \psi_s$) and do not represent top model parameter estimates as indicated by ΔAIC_c and AIC_c weights (w_i). Standard errors (SE) and 95% confidence intervals of parameter estimates are also shown..... 173

Table 3.1. Correlation matrix for 9 visit-specific variables recorded during double-observer surveys of 278 plots in eastern Colorado in 2005. 'Day' is an assigned value representing date of visit within the survey season. 'StartTime' is the time of day at which the survey began. 'SurvDur' is the survey duration in minutes. 'AvgTemp' is the mean of recorded start and end temperatures, measured in °C. 'MaxTemp' is the higher of the recorded start or end temperatures. 'AvgWind' is the mean of recorded start and end wind speeds, measured in meters per second. 'MaxWind' is the greater of the recorded start or end wind speeds. 'AvgCloud' is the mean of recorded start and end cloud cover, estimated visually and coded as 1-4 representing 0-25%, 26-50%, 51-75% and >75% cover, respectively. 'MaxCloud' is the greater of the recorded start or end cloud cover..... 236

Table 3.2. Variables used as covariates in models estimating detection probabilities (*p)* of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown..... 237

Table 3.3. Predicted results of covariate-modeled detection probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005.

Predicted effects of plot stratum are represented as a ranking of stratum-specific detection probabilities. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species detection probability. Explanation and coding of model parameters are provided in Table 3.2. 238

Table 3.4. Area of extrapolation for estimates of grassland bird abundance under three scenarios – (a) conservative, (b) moderate, and (c) liberal – in eastern Colorado in 2005. Estimated total acreage of three habitat types – prairie dog colonies, grassland, and dryland agriculture –within the study area is shown. For each extrapolation scenario, the percent of this area that may be extrapolated to and the corresponding acreage are also shown. The conservative scenario adjusts for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. The moderate scenario adjusts only for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact" plots do not differ from surveyed plots). The liberal scenario includes no adjustment. 239

Table 3.5. Correlation matrix for 8 plot-level variables representing habitat characteristics of 278 mark-recapture plots in eastern Colorado in 2005. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony. 'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland. ... 240

Table 3.6. Habitat variables used in models examining underlying process variance of derived abundance estimates of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown. Values are presented for all plots combined as well as for prairie dog colony (PD), grassland (Grass), and dryland agriculture (Ag) plots separately. In variable definitions, "landscape 1" refers to a plot plus its 500-m buffer, "landscape 2" refers to a plot plus its 1500-m buffer, and "landscape 3" refers to a plot plus its 2250-m buffer. 241

Table 3.7. Predicted results of habitat covariate effects on underlying process variance of derived abundance estimates based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific mean abundance. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species abundance. Explanation and coding of model parameters are provided in Table 3.6. 243

Table 3.8. Number of adults (*N*) of 8 grassland bird species detected on 272 mark-recapture plots in 3 strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Number of plots where each species was detected is also shown. Species counts were recorded by double observers on a single plot visit……..244

Table 3.9. Model selection results for nine models of detection probability (*p*) and abundance (*N*) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (*L*), number of parameters (*K*), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 245

Table 3.10. Covariate estimates ($\hat{\beta}_i$) under nine models of detection probability (*p*) and abundance (*N*) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.. 246

Table 3.11. Summary statistics of derived abundance estimates ($\hat{N}$) for eight grassland bird species in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Abundance estimates were generated under the highest ranking model for detection probability for each species. Mean number of birds per 25 ha plot ($\overline{\hat{N}}$) ± standard deviation (SD) and value range of abundance estimates are shown for plots on which the species was detected. 247

Table 3.12. Extrapolated stratum-specific abundance estimates ($\hat{N}$) for eight grassland bird species under three scenarios – (a) conservative, (b) moderate, and (c) liberal – in eastern Colorado in 2005. Conservative estimates have been adjusted for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. Moderate estimates have only been adjusted for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact" plots do not differ from surveyed plots). Liberal estimates have not been adjusted. Extrapolated abundance estimates and 95% confidence intervals are presented for three strata – prairie dog colony, grassland, and dryland agriculture. Abundance estimates were extrapolated from density estimates calculated from derived abundance estimates generated under the highest ranking model for detection probability for each species……..248

Table 3.13. Extrapolated abundance estimates ($\hat{N}$) for eight grassland bird species under three scenarios – conservative, moderate, and liberal – for my study area in eastern

Colorado in 2005. Conservative estimates have been adjusted for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. Moderate estimates have only been adjusted for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact" plots do not differ from surveyed plots). Liberal estimates have not been adjusted. Extrapolated study-area abundance estimates and 95% confidence intervals were summed from extrapolated stratum-specific abundance estimates (Table 3.11). Abundance estimates were extrapolated from density estimates calculated from derived abundance estimates generated under the highest ranking model for detection probability for each species. 251

Table 3.14. Variance components analysis of nine habitat covariates of grassland bird mark-recapture plots and associated estimates of mountain plover (*Charadrius montanus*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability (p_{obs1} N_{plot}). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 1.06 (95% CI = 0.68, 1.90). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 252

Table 3.15. Comparison of abundance estimates ($\hat{N}$) of mountain plover (*Charadrius montanus*) and burrowing owl (*Athene cunicularia hypugaea*) obtained using direct (double-observer) and indirect (latent occupancy) estimation methods on 272 plots in eastern Colorado in 2005. The direct method used counts recorded by double observers on a single plot visit. The indirect method estimated latent abundance using occupancy data collected during 3-4 plot visits. Abundance estimates and 95% confidence intervals were generated under the highest ranking model for each species in program MARK (direct method) and under the Royle/Nichols heterogeneity model in program PRESENCE (indirect method). ……..253

Table 3.16. Model selection results for seven models of detection probability (p) and abundance (N) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. . 254

Table 3.17. Covariate estimates ($\hat{\beta}_i$) under seven models of detection probability (p) and abundance (N) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c

units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2. 255

Table 3.18. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of burrowing owl (*Athene cunicularia hypugaea*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{.}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 0.82 (95% CI = 0.39, 1.73). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 256

Table 3.19. Model selection results for 11 models of detection probability (p) and abundance (N) for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 257

Table 3.20. Covariate estimates ($\hat{\beta}_i$) under 11 models of detection probability (p) and abundance (N) for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2. . 258

Table 3.21. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of horned lark (*Eremophila alpestris*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 128.15 (95% CI = 108.73, 153.29). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 260

Table 3.22. Model selection results for nine models of detection probability (p) and abundance (N) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 261

Table 3.23. Covariate estimates ($\hat{\beta}_i$) under nine models of detection probability (p) and abundance (N) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.. 262

Table 3.24. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of Cassin's sparrow (*Aimophila cassinii*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_s N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 6.64 (95% CI = 4.86, 9.62). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 264

Table 3.25. Model selection results for eight models of detection probability (p) and abundance (N) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 265

Table 3.26. Covariate estimates ($\hat{\beta}_i$) under eight models of detection probability (p) and abundance (N) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.. 266

Table 3.27. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of lark sparrow (*Chondestes grammacus*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability (p_{wind} N_{plot}). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 19.09 (95% CI = 12.24, 33.60). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 267

Table 3.28. Model selection results for 13 models of detection probability (p) and abundance (N) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 268

Table 3.29. Covariate estimates ($\hat{\beta}_i$) under 13 models of detection probability (p) and abundance (N) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.. 269

Table 3.30. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of lark bunting (*Calamonspiza melanocorys*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}$ N_{plot}). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 110.71 (95% CI = 90.39, 138.74). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 272

Table 3.31. Model selection results for 15 models of detection probability (p) and abundance (N) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models are ranked by AICc. ΔAICc is the difference in AICc units from the highest ranking model. AICc weights (w_i), model likelihood (L),

number of parameters (K), and deviance are also shown. AICc weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2...273

Table 3.32. Covariate estimates ($\hat{\beta}_i$) under 15 models of detection probability (p) and abundance (N) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2. 274

Table 3.33. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of grasshopper sparrow (*Ammodramus savannarum*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 7.90 (95% CI = 5.36, 12.69). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 277

Table 3.34. Model selection results for 11 models of detection probability (p) and abundance (N) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2. 278

Table 3.35. Covariate estimates ($\hat{\beta}_i$) under 11 models of detection probability (p) and abundance (N) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.. 279

Table 3.36. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of western meadowlark (*Sturnella neglecta*) abundance in eastern Colorado in 2005. Analysis was conducted on

derived abundance estimates generated under the highest ranking model for detection probability (p_{obs} N_{plot}). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 5.13 (95% CI = 4.27, 6.27). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5. 282

Table 3.37. Estimated detection probabilities ($\hat{p}$) for eight grassland bird species in eastern Colorado in 2005. Estimates were generated in program MARK under a constant detection model ($p_{.}$) and do not typically represent top model parameter estimates as indicated by ΔAIC_c and AIC_c weights (w_i). Standard errors (SE) and 95% confidence intervals of parameter estimates are also shown. 283

LIST OF FIGURES

Figure 2.1. Study area and stratified sampling frame of a grassland avifauna study conducted in 2005 on three different habitat types in shortgrass prairie in eastern Colorado, USA. 175

Figure 2.2. Diagram of survey "transect" walked by observers during occupancy surveys conducted on randomly selected 500-m × 500-m plots in eastern Colorado in 2005. 176

Figure 2.3. Fates of plots selected in a grassland avifauna study conducted in 2005 in shortgrass prairie in eastern Colorado, USA. Locations are shown for surveyed plots in three strata – prairie dog colony, grassland, and dryland agriculture – and plots not surveyed due to inability to contact the landowner (no contact), access denied by the landowner or lessee, or if strata criteria were not met. 177

Figure 2.4. Effect of the landscape variable 'pdL1' on estimated mountain plover (*Charadrius montanus*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s \times grsL3+pdL1}$) and allowed to vary by the proportion of prairie dog colony in landscape 1 (pdL1) while holding the effect of the variable 'grsL3' constant at either: a) the overall variable mean (0.58), or b) the individual stratum means (pd = 0.57, grassland = 0.85, ag = 0.29). Landscape 1 was defined as the area of a plot and its 500 m buffer. The variable 'grsL3' was defined as the proportion of grassland in landscape 3, defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals..... 178

Figure 2.5. Effect of the landscape variable 'grsL3' on estimated mountain plover (*Charadrius montanus*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s \times grsL3+pdL1}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3) while holding the effect of the variable 'pdL1' constant at either: a) the overall variable mean (0.17), or b) the individual stratum means (pd = 0.53, grassland = 0.01, ag = 0.00). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'pdL1' was defined as the proportion of prairie dog colony in landscape 1, defined as the area of a plot and its 500 m buffer. Error bars represent 95% confidence intervals..... 180

Figure 2.6. Effect of the landscape variable 'pdL3' on estimated burrowing owl (*Athene cunicularia hypugaea*) occupancy probabilities in two strata – prairie dog colony

and grassland – in eastern Colorado in 2005. Prairie dog colony plots were further characterized as active or inactive. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s+act+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals. Because estimated occupancy probability of burrowing owl on dryland agriculture plots was 0.00 (95% CI = 0.00, 0.00), regardless of the amount of prairie dog colony in the surrounding landscape, these data are not shown. 182

Figure 2.7. Effect of the landscape variable 'grsL3' on estimated Cassin's sparrow (*Aimophila cassinii*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals. 183

Figure 2.8. Effect of the landscape variable 'grsL3' on estimated lark sparrow (*Chondestes grammacus*) occupancy probabilities in two strata – prairie dog colony and grassland – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+temp+wind}\ \psi_{s\times grsL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals. The low number of detections in dryland agriculture prevented modeling a covariate effect in addition to a stratum effect. 184

Figure 2.9. Effect of the landscape variable 'pdL3' on estimated lark bunting (*Calamonspiza melanocorys*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+\ day^2+eff+wind}\ \psi_{s+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals..... 185

Figure 2.10. Effect of the landscape variable 'pdL3' on estimated grasshopper sparrow (*Ammodramus savannarum*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3) while holding the effect of the variable 'grsL3' constant at either: a) the overall variable mean (0.58), or b) the individual stratum means (pd = 0.57, grassland = 0.85, ag = 0.29). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'grsL3' was defined as the proportion of grassland in landscape 3. Error bars represent 95% confidence intervals. 186

Figure 2.11. Effect of the landscape variable 'grsL3' on estimated grasshopper sparrow (*Ammodramus savannarum*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{day+\ day^2+temp}$ $\psi_{s\times grsL3+pdL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3) while holding the effect of the variable 'pdL3' constant at either: a) the overall variable mean (0.07), or b) the individual stratum means (pd = 0.19, grassland = 0.02, ag = 0.01). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'pdL3' was defined as the proportion of prairie dog colony in landscape 3. Error bars represent 95% confidence intervals. 188

Figure 3.1. Study area and stratified sampling frame of a grassland avifauna study conducted in 2005 on three different habitat types of shortgrass prairie in eastern Colorado, USA..... 284

Figure 3.2. Diagram of survey "transect" walked by observers during double-observer surveys conducted on randomly selected 500-m × 500-m plots in eastern Colorado in 2005. 285

Figure 3.3. Fates of plots selected in a grassland avifauna study conducted in 2005 in shortgrass prairie in eastern Colorado, USA. Locations are shown for surveyed plots in three strata – prairie dog colony, grassland, and dryland agriculture – and plots not surveyed due to inability to contact the landowner (no contact), access denied by the landowner or lessee, or if strata criteria were not met. 286

Figure 3.4. Calculated density of mountain plover (*Charadrius montanus*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs1}\ N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 287

Figure 3.5. Calculated density of burrowing owl (*Athene cunicularia hypugaea*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. No burrowing owls were detected on the 91 dryland agriculture plots surveyed in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{.}\ N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2..... 288

Figure 3.6. Calculated density of horned lark (*Eremophila alpestris*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 289

Figure 3.7. Calculated density of Cassin's sparrow (*Aimophila cassinii*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_s N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 290

Figure 3.8. Calculated density of lark sparrow (*Chondestes grammacus*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{wind} N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 291

Figure 3.9. Calculated density of lark bunting (*Calamonspiza melanocorys*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind} N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 292

Figure 3.10. Calculated density of grasshopper sparrow (*Ammodramus savannarum*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}$ N_{plot}). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 293

Figure 3.11. Calculated density of western meadowlark (*Sturnella neglecta*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs} N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2. 294

CHAPTER 1

ECOLOGY AND MONITORING OF COLORADO BREEDING GRASSLAND BIRDS: A REVIEW

INTRODUCTION

Over the last 40 years, shortgrass prairie birds have shown consistent, widespread declines. These declines may be a result of anthropogenic changes to the prairie landscape such as land conversion, fire suppression, and alteration of native grazing assemblages. As wildlife biologists have attempted to address these declines and better manage avian species of concern, they have focused on developing monitoring schemes and identifying avian-habitat associations. One potentially important habitat relationship is with one of the ecosystem's remaining native grazers, the black-tailed prairie dog (*Cynomys ludovicianus*, hereafter simply referred to as prairie dog). Studies have suggested that prairie dog colonies have higher avian densities and are more species rich than uncolonized areas. The objectives of my study were twofold. First, I evaluated recently developed monitoring methods which incorporate detection error to estimate occupancy, abundance, and density. Secondly, I used these methods to examine and compare the presence, abundance, and density of avian species across three strata (prairie dog colonies, native grassland without prairie dogs, and dryland agriculture) in the shortgrass prairie ecosystem of eastern Colorado. Below I present background

information on estimation methods and the shortgrass prairie ecosystem, further focusing on the role of prairie dogs in this ecosystem as well as the grassland avifauna.

ESTIMATION METHODS USED FOR MONITORING GRASSLAND BIRDS

To date, methodologies widely used to estimate grassland bird population parameters have lacked at least one of two important considerations – attention to a probability-based sampling scheme and incorporation of detection probability into population estimates (Nichols 1999, Pollock et al. 2002). In few instances are sufficient resources available to obtain a total count (i.e., census) of individuals over an entire area of interest. Due to resource limitations, biologists often employ sample surveys in which only a portion of the target area is surveyed. The data from such a survey is used to estimate parameters of interest and to extrapolate to the entire target area. Such estimates are desired to be both unbiased and precise (Lancia et al. 1994, W. Thompson 2002). Bias and variance may arise from the sampling unit selection process and from the counting process (S. Thompson 2002, W. Thompson 2002). To address issues of bias and maximize the precision of our estimate, a sample must be collected under a probability-based scheme and proper estimators, incorporating detection probabilities, used (Williams et al. 2002). Below I discuss both of these topics in relation to past survey efforts and more recent estimation techniques. Details specific to species of interest are discussed in species sections below.

Sample Selection

The sample selection process is of utmost importance if inference is to be made to larger areas of interest. To make proper inference to a target population, every individual in the population must be exposed to sampling with a known, non-zero probability. To be sampled, a target population needs to be separated into a list of sampling units, often referred to as a sampling frame (S. Thompson 2002). Sampling units from this frame then need to be chosen in a probabilistic manner.

Many previous surveys of grassland birds, such as the Breeding Bird Survey (BBS, Sauer et al. 2003), Northern Region Landbird Monitoring Program (NRLMP, Hutto and Young 2002), and others (Hanni 2002, Conway and Simon 2003, Hanni 2003), have employed a "convenience sampling" scheme, where samples are taken along existing roads or trails. This sampling design is often chosen due to accessibility issues and to ostensibly increase sample size. There is a serious cost to using such a scheme. There is no way to evaluate bias of the estimates, nor can such estimates be extrapolated to larger areas of interest. Estimates derived from these surveys may only provide inference to similar habitats (i.e., roads), which may be unrepresentative of the grassland community as a whole, unless calibration studies are conducted. Such surveys cannot be used as estimators of *relative* occupancy or abundance, as is sometimes claimed (Hanni 2002, Hutto and Young 2002, Conway and Simon 2003, Hanni 2003, Hutto and Young 2003), unless detection probabilities are constant across time and space (Williams et al. 2002).

The most widespread, generalized grassland bird surveys in Colorado have been conducted by Hanni (2002, 2003). Hanni (2002) compared road-based counts, interior

(≥161 m from a road) line transects, and random point transects in grassland across eastern Colorado. His results indicate that some grassland bird species select for or against roads, yielding different estimates of abundance and density based on the sampling locations used. Hanni's (2002) results further support the contention that relying on road-based samples is unwise. In 2003, Hanni conducted road-based section surveys plus a limited number of surveys of section interiors (≥322 m from a road) to further investigate potential response differences and to determine density correction factors. He concluded that a correction factor was indeed needed, but none has been developed to date.

I employed a three-stage, probability-based sampling plan. In the first stage, I stratified my study area on the three habitat types of interest – prairie dog colonies, native grassland without prairie dogs, and dryland agriculture. In the second stage, I used a recent development in sampling theory – a spatially balanced sampling scheme (Theobald et al. in press). Spatially balanced sampling (SBS) allows for improved coverage of a study area while avoiding some of the drawbacks associated with simple random or systematic sampling schemes. For example, a simple random sample can result in sample plots being clumped together, leading to uneven coverage of the study area. Systematic sampling guarantees even coverage but has the potential to produce biased estimates if the systematic sample coincides with an underlying periodicity in the response variable. Variance estimates from systematic samples are often derived using a SRS estimator, rather than a cluster sampling estimator, which often results in lower precision. This source of bias and loss of precision can be avoided using a SBS design.

A SBS design also maximizes spatial independence among sample locations, thereby reducing spatial autocorrelation (Theobald et al. in press).

I used a SBS tool implemented in a Geographic Information System (GIS) framework and employing a Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald 2004, Theobald et al. in press), similar to the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen 2004). Simply described, RRQRR achieves a spatially balanced sample through a five-step procedure in which two-dimensional space is converted into one dimension and each grid cell is ordered using Morton ordering (Theobald et al. in press). In the resulting design, every sample realization (i.e., any number of sequentially numbered plots) mimics the spatial pattern of the sample population (Theobald et al. in press).

I applied this tool to obtain a spatially balanced sample for each of my three strata. In the third stage of my probability-based sampling plan, I addressed the incorporation of detection probability to adjust my count statistics, as discussed below.

Detection Error

In addition to the use of a probability-based sampling scheme, bias may be reduced by minimizing errors in the counting process. One such error arises from failure to detect every individual within the sampling unit and the subsequent failure to adjust the count statistic accordingly (Lancia et al. 1994, Borchers et al. 2002, W. Thompson 2002, Williams et al. 2002). Under most field conditions, all individuals or species are unlikely to be detected with probability equal to 1. Therefore, appropriate survey methods need to be used to allow for corrections related to detection.

Many local and regional "indices" (e.g., NRLMP, Hutto and Young 2002, BBS, Sauer et al. 2003) are designed to obtain count statistics under standardized conditions in an effort to control variation in detection probability. However, success of these survey types is dependent on the ability to identify and control *all* factors influencing detection, thus keeping detection probability constant (Nichols 1992). This is usually difficult or impossible to accomplish. While standardization may improve detection probabilities and decrease variance, it is not adequate for dealing with the issue of detection. Failure to adjust estimates by incorporating detection rates generally invalidates use of such estimates for statistically meaningful population trend analysis or comparison.

Methods incorporating detection probabilities into demographic estimation, such as distance sampling (Burnham et al. 1980, Buckland et al. 2001) and those based on mark-recapture (Otis et al. 1978, Seber 1982, Borchers et al. 2002, Williams et al. 2002), have been available for many years, but have not been extensively used in the shortgrass prairie ecosystem. Distance sampling has been employed (Hanni 2002, 2003) but the transects have been laid out improperly (e.g., along roads). Distance sampling theory dictates that transects must be placed in a random fashion due to the influence underlying distributions of animals can have on modeled detection functions (Buckland et al. 2001). This is an important, but often overlooked, nuance of distance sampling. In addition, estimates obtained using distance sampling may be biased if assumptions are not met. Two important assumptions of distance sampling – namely that 1) all individuals on the line or point are detected with probability equal to 1, and 2) individuals do not move in response to the observer before being detected – can be difficult to assure in field

conditions (Rosenstock et al. 2002), especially with some grassland bird species that move secretively in response to observers.

Physical mark-recapture is generally impractical for monitoring over large areas due to the logistics involved in capturing and handling large numbers of grassland birds. A more recent, observation-based, estimation method is based on using "double observers" (Nichols et al. 2000), but is grounded in mark-recapture estimation techniques. By using two observers, an encounter history can be constructed for each individual (or individual species) with which mark-recapture estimators can be used. Additional methods focused on occupancy instead of abundance have also been recently developed (MacKenzie et al. 2002), especially for those species for which individuals are difficult to enumerate. Occupancy data (also called presence-absence, or more properly, presence-apparent absence data) record the number of sampling units occupied by animals, rather than the number of animals themselves. The methodology involves visiting each sampling unit multiple times within a time period for which occupancy is considered constant. During each visit, a species is detected with probability p, or not detected with probability $(1-p)$. Occupancy probability (ψ), or the proportion of sites that are occupied, is estimated from the resulting capture history using likelihood-based methodology (Mackenzie et al. 2002). A connection exists between occupancy and abundance, and occupancy data alone may also inform estimates of abundance (Royle and Nichols 2003). Neither the double-observer, nor the occupancy methods have yet been widely employed. I tested and used these promising methods (the protocols for which are fully described in Chapters 2 and 3) to examine and compare avian response to habitat structure in Colorado's shortgrass prairie ecosystem.

THE SHORTGRASS PRAIRIE ECOSYSTEM

Native grasslands have been altered to a greater extent than any other biome in North America (Samson et al. 2004). The native prairies of the Great Plains once stretched from Canada south to Mexico and from the foothills of the Rocky Mountains eastward into Indiana (Samson and Knopf 1996). These prairies – the tallgrass, mixed-grass, and shortgrass – evolved under varying gradients of temperature and seasonal precipitation, and were continually shaped by fire and grazing by endemic herbivores (Brockway et al. 2002). The shortgrass prairie, positioned in a moderately narrow (~320 km) band adjacent to the Rockies, was a heterogeneous landscape of open rolling plains and relatively treeless stream bottoms that provided habitat for a large variety of wildlife (Benedict et al. 1996, Corn and Peterson 1996, Knopf 1996b, Weaver et al. 1996, Fuhlendorf and Engle 2001). The shortgrass prairie, and many of the species which it harbors, is now imperiled by widespread cultivation and alteration of natural disturbance processes (Knopf 1994).

Native shortgrass prairie is primarily vegetated by low-growing, perennial grasses such as buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*), which flourish under intense grazing pressure and historically supported a diverse guild of herbivores. This guild was dominated by plains bison (*Bison bison*), pronghorn antelope (*Antilocapra americana*), and prairie dogs (Knopf 1994). Until the late 1800s, an estimated 30-60 million bison ranged across the Great Plains (Weaver et al. 1996). These bison sporadically grazed across the landscape in herds, leaving some areas almost denude of vegetation. Prairie dogs also created nearly bare areas in and around their ever-shifting colonies. In addition to native grazers, the landscape was also shaped by

both natural (lightening) and human-caused fires (Brockway et al. 2002). This combination of grazing and fire disturbances led to a shifting spatiotemporal mosaic, creating structural diversity essential to many grassland inhabitants (Fuhlendorf and Engle 2001, Brennan and Kuvlesky 2005).

During the late 19th century, Anglo-European settlers moved west into the Great Plains and brought about major ecological changes to the shortgrass prairie. Their systematic slaughter of bison was followed closely by intensive efforts to eradicate the prairie dog (Knopf 1994). Native herbivores were replaced by large herds of domestic cattle and sheep. Prairie was fenced into progressively smaller parcels which were then systematically grazed by the domestic livestock (Knopf 1994). In addition, increasingly large areas of native grassland were plowed and converted to farmland. Although the shortgrass prairie did not suffer as great a loss in this regard as the tall- and mixed-grass prairie ecosystems, approximately 24.4% was estimated to be in cropland by 1987 (Knopf 1994). Soil cultivation, road building, and the creation of other man-made structures also acted to reduce the effects of fires, a situation which was further exacerbated by the active suppression of wildfire initiated in the 1950s (Brockway et al. 2002). The cumulative result of these anthropogenic changes has been the conversion of the shortgrass prairie landscape into a collection of homogenous grassland fragments interspersed with agricultural fields and urban development (Lomolino et al. 2001).

In Colorado, the shortgrass prairie encompasses the eastern third of the state, spreading east from the foothills of the southern Rocky Mountains. The eastern plains are characterized by flat to gently rolling prairie, playas, intermittent streams, as well as irrigated and extensive dryland agricultural development. Urban development is low and

is primarily concentrated along the Front Range and riparian corridors (e.g., the South Platte and Arkansas Rivers). Yearly precipitation is low (25–40 cm) and summer temperatures high (up to 40° C). Climatic differences occurring along a north-south gradient create distinct floral and avifaunal associations north and south of the Palmer Divide, approximately aligned with Interstate 70 (National Drought Mitigation Center 2004).

The expanse of Colorado's shortgrass prairie ecosystem is principally threatened by the negative effects of homogeneous rangeland management and land conversion. On rangelands, standardized grazing regimes have been implemented to maximize available forage and increase livestock production at the expense of the land's former heterogeneity (Fuhlendorf and Engle 2001). Although conversion rates are relatively low, the eastern plains, primarily along Colorado's Front Range, continue to lose grassland and croplands to development (e.g., ~1.4 million acres [>5%] were converted between 1987 and 1997, Venner 2002). One possible result of these changes has been the reduction and elimination of some species from the ecosystem (Knopf 1994, Benedict et al. 1996).

In response to apparent declines in grassland species of concern, and to preclude listings under the Endangered Species Act (ESA), conservation initiatives have been developed to address conservation issues related to shortgrass prairie species. In Colorado, a plan was developed by the state Division of Wildlife (CDOW) in cooperation with the Colorado Grassland Species Working Group (Colorado Division of Wildlife 2003). This plan is designed to benefit a suite of shortgrass prairie species of concern including the prairie dog, mountain plover (*Charadrius montanus*), and burrowing owl

(*Athene cunicularia hypugaea*). The goals of CDOW's plan include 1) better understanding of grassland ecology, 2) support of ongoing efforts to evaluate potential monitoring methodologies and implementation of best available monitoring methodologies, and 3) increased conservation efforts through partnerships with private landowners. The plan recognizes the importance of using "best available science" to determine management and conservation actions, including the identification of high priority areas. Improving our understanding of shortgrass prairie ecology and species interactions is becoming increasingly important to make the most of conservation opportunities. The results of my study will inform such conservation opportunities. Below I discuss the ecology and conservation status of both the prairie dog and the grassland avifauna which are foci of my study.

Black-tailed Prairie Dog (*Cynomys ludovicianus*)

Prairie dogs have become emblematic of prairie conservation dilemmas due to polarized opinions about their inherent worth. Prairie dog colonies have been prominent features of the Great Plains landscape since the late Pleistocene (Goodwin 1995). Prairie dog colonies are thought to have covered over 40 million ha in North America prior to widespread European settlement (Knopf 1994, Miller et al. 1994, Benedict et al. 1996, Sidle et al. 2001b, Lomolino and Smith 2003, 2004, Lomolino et al. 2004). As the second most significant herbivore on the Great Plains (bison being the first, Samson and Knopf 1994), the prairie dog provided habitat for numerous grassland species through alteration of prairie vegetation, burrow construction, and soil improvement (Benedict et al. 1996, Stapp 1998, Winter et al. 2002).

Prairie dogs create large areas of grazed vegetation, bare soil, and burrows which are essential components of breeding habitat for grassland birds such as the mountain plover (Knopf 1996b) and burrowing owl (Haug et al. 1993). In addition, grasshoppers and beetles, the primary food items of grassland birds, require >10% of an area to be bare ground in order to lay eggs (Knopf 1996b) and thus benefit from prairie dog grazing and burrowing activities. Grazing activities by prairie dogs also stimulate fresh growth of vegetation and provide nutritious forage for prairie grazers such as cattle, bison, and pronghorn (Benedict et al. 1996, Kotliar et al. 1999, Lomolino and Smith 2004). Prairie dogs construct extensive underground tunnels which serve as nesting habitat and shelter for avian species such as burrowing owls (Desmond and Savidge 1996, Arrowood et al. 2001, Smith and Lomolino 2004). Prairie dogs also serve as prey for ferruginous hawks and other predators (Barko et al. 1999, Kotliar et al. 1999). Some researchers have suggested that the combination of these effects produces increased avian species occupancy, density, and richness observed on colonized versus uncolonized areas, as discussed below.

The prairie dog produces significant effects on shortgrass prairie structure and processes as well as overall biological diversity, influencing patch dynamics, contributing to grassland heterogeneity, and positively affecting many grassland bird species (Miller et al. 1994, Kotliar et al. 1999, Kretzer and Cully 2001, Winter et al. 2002, Lomolino and Smith 2004). However, prairie dogs are not considered a desirable member of the prairie community by all (Colorado Division of Wildlife 2003, Vermeire et al. 2004), and the role of prairie dogs in grasslands and their perceived level of decline have become central topics in the discussion of the state of the shortgrass prairie ecosystem. Prairie dog

numbers are suggested to have decreased by as much as 98% since the 19th century (Knopf 1994, Miller et al. 1994, Miller et al. 2000, Miller and Cully 2001, Sidle et al. 2001b), largely due to eradication efforts (e.g., poisoning, shooting), habitat destruction and fragmentation, and sylvatic plague (*Yersinia pestis*, Miller et al. 1994, Sidle et al. 2001b, Lomolino and Smith 2004). However, the rate of their decline is currently the subject of much debate. Recent efforts have been made to more accurately estimate the extent of prairie dog colonies in the Great Plains. Sidle et al. (2001b) reported the results of an aerial survey conducted during 1997-1998. Based on the resulting estimate (237,780 ha ± 18,640 SE) of occupied/active habitat in Nebraska, North Dakota, South Dakota, and Wyoming, this survey dispelled the popular belief that millions of hectares of prairie dog colonies exist in the northern Great Plains (Sidle et al. 2001b). In Colorado, an aerial survey of prairie dog colonies, completed in 2002 and based on methodology outlined by Sidle et al. (2001b), estimated 255,398 occupied ha (± 12,420 SE, White et al. 2005). This estimate represents a significant increase in occupied area over previous state estimates (<100,000 ha, Knowles 1998, EDAW Inc. 2000, U.S. Fish and Wildlife Service 2000). However, it also suggests that prairie dogs occupy only 5.3% of current potentially suitable habitat in Colorado and 2.6% of their historic state range based on a CDOW model (Colorado Division of Wildlife 2003).

Due to the possibility of continued declines, the National Wildlife Federation filed a petition to list prairie dogs as threatened under the ESA in 1998, although the petition was deemed unwarranted in 2004 (U.S. Fish and Wildlife Service 2004). In this interval, eleven states including Colorado had begun a multi-state conservation effort designed to provide long-term conservation and management of the species and eliminate the need

for ESA listing (Colorado Division of Wildlife 2003). The result of this effort was the *Multi-state Conservation Plan for the Black-tailed Prairie Dog,* Cynomys ludovicianus*, in the United States*, completed in February 2003. In Colorado, this plan complements the goals and objectives of CDOW's previously discussed grassland conservation plan. Given the concern over prairie dogs and the potential relationships between prairie dog colonies and grassland avian species, investigating the influence of prairie dog colonies on grassland bird species is of paramount importance.

Ecology of Grassland Birds

General background

Nine avian species, excluding sagebrush and wetland associates, are considered endemics of the Great Plains, and 20 other (secondary) species also show strong associations with grassland ecosystems at this regional level (Table 1.1, Knopf 1996b). These birds evolved within the shifting grassland mosaic created by natural disturbance regimes (Knopf 1994, Fuhlendorf and Engle 2001, Smith and Lomolino 2004, Brennan and Kuvlesky 2005). Of the nine endemic grassland birds, six may be considered associates of the shortgrass and/or short-mixed-grass ecosystems (Table 1.1, Knopf 1996b). Of the 20 "secondary" species, 5 are considered shortgrass or short-mixed-grass associates. Although more closely associated with taller grasslands or prairie-shrub ecotones, grasshopper sparrows (*Ammodramus savannarum*), western meadowlarks (*Sturnella neglecta*), and lark sparrows (*Chondestes grammacus*) are also commonly encountered in Colorado's shortgrass prairie (Knopf 1996b).

Extensive, systematic surveys of grassland birds began in 1966 with the Breeding Bird Survey (BBS), an annual inventory of birds in the U.S. and Canada (Sauer et al. 2003). Analyses of BBS data indicate that grassland birds as a group, and endemic species specifically, have exhibited steeper, more consistent, and more widespread declines than any other avian guild in North America (Knopf 1994, 1996b, Sauer et al. 2003, Smith and Lomolino 2004). Based on BBS data through 1996, 7 of the 9 endemic grassland species are declining, as are 14 of the 20 more widespread species (Table 1.1, Smith and Lomolino 2004). The *Conservation Plan for Grassland Species in Colorado* (Colorado Division of Wildlife 2003) identifies 24 species found within shortgrass prairie in the state which are currently in need of conservation efforts (Table 1.2, Colorado Division of Wildlife 2003).

Potential causes of declines among grassland birds are many, but may be generally defined as habitat loss, degradation, and fragmentation (Johnson and Igl 2001). Habitat-based effects may be localized or range-wide. For example, localized patterns have been detected for the lark bunting (*Calamospiza melanocorys*) and grasshopper sparrow indicating loss of local breeding habitat, while the mountain plover appears to be suffering range-wide habitat loss (Knopf 1994). Effects of fragmentation, such as those related to patch size, amount of edge, and patch isolation, may also negatively affect avian populations by reducing reproductive success and/or survival (Johnson and Igl 2001, Stephens et al. 2003). Determining causes of declines for grassland species is complicated by the potential combination of these factors as well as our limited knowledge regarding wintering habitats of migrants (Knopf 1994).

In response to these declines, wildlife researchers have undertaken studies to improve our understanding of grassland bird ecology. Studies specific to the effects of prairie dog colonies on avian assemblages have been conducted in mixed-grass and shortgrass prairie in areas primarily outside Colorado (Agnew et al. 1986, Barko et al. 1999, Smith and Lomolino 2004). These studies suggest avian densities and species richness are significantly higher on prairie dog colonies than uncolonized grasslands, and avian assemblages significantly vary between these habitats with greater breeding season richness on prairie dog colonies. Researchers have attributed these results to the structural diversity, concentrated prey species, increased seed production, and lower vegetation height (resulting in increased visibility of predators) provided by prairie dog colonies (Agnew et al. 1986, Barko et al. 1999). These colony attributes result from differences in vegetation between colonized and uncolonized areas which may be most dramatic during summer (i.e., breeding/growing season). Since vegetation is affected by seasonal precipitation, these effects would not be as great in drought years (Barko et al. 1999, Winter et al. 2003). Other research suggests that avian assemblages on prairie dog colonies are more similar to fallow cropland than native grassland, scrub/sandsage, and Conservation Reserve Program (CRP) lands (Smith and Lomolino 2004).

Based on apparent levels of decline, the focus of state conservation efforts, and the importance of potential habitat associations, I identified the mountain plover and burrowing owl as species of primary interest to my study for which the design of my study was most influenced. I also considered other avian species for which I was able to collect sufficient data and which are of conservation concern. Below I discuss the two primary species of interest as well as the group of other species I encountered in

sufficient numbers. I first summarize relevant information regarding species natural history and conservation status and then discuss current research and estimation methods.

Species of primary interest

Mountain plover (*Charadrius montanus*)

a) Natural history and conservation status

The mountain plover is distributed in western North American grasslands and is found in the eastern plains, South Park, and the San Luis Valley of Colorado (Kuenning and Kingery 1998). The plover is considered rare to fairly common during the breeding season, with major strongholds found on the Pawnee National Grassland (PNG) and in southeastern Colorado, where 10-20% and 40-50%, respectively, of the breeding population are thought to historically reside (Graul and Webster 1976, Knopf 1996a, Kuenning and Kingery 1998).

The mountain plover breeds in flat arid grasslands, characterized by short vegetation (e.g., grass <7.5 cm in height) and extensive (≥30%) bare ground, as well as in fallow cropland (Graul 1973, 1975, Knopf 1996a). Plovers arrive in Colorado in March to set up breeding territories, which average 16 ha for males (Knopf 1996a). Nesting occurs throughout April and May, and many breeding pairs produce two sets of young. Broods move an average of 300 m per day and range over an area averaging 56.6 ha (± 21.5 SE), with the minimum brood-rearing area believed to be approximately 28 ha (Knopf and Rupert 1996). Chicks begin flocking up with other young and adults in late June as they prepare to migrate to wintering areas by early August. Mountain plovers exhibit fidelity to their winter home range, as well as summer breeding sites (Knopf

1996a). The breeding biology of mountain plovers has been well studied, especially in northeastern Colorado, and additional information on their natural history may be found in Graul (1975), Miller and Knopf (1993), Knopf and Rupert (1995, 1999), Knopf (1996a), Kuenning and Kingery (1998), Dechant et al. (2003a), and Wunder and Knopf (2003).

The mountain plover is listed as a species of special concern in Colorado and four other states, and threatened in Nebraska, Canada, and Mexico (Colorado Division of Wildlife 2003). A petition to list the mountain plover as threatened under the ESA was found unwarranted in 2003 (U.S. Fish and Wildlife Service 2003). BBS trends (1966–1993) and other population surveys indicate a major decline (a decrease of two-thirds in 25 years, Knopf 1996a). This decline is thought to be acting on both breeding and wintering grounds and may be caused by habitat loss and degradation and pesticide use (Knopf 1996a).

b) Current research and estimation methods

Current and past research in Colorado focus on mountain plover use of shortgrass prairie and agricultural fields for nesting habitat (Knopf and Miller 1994, Shackford and Leslie 1994, Knopf and Rupert 1999, Shackford et al. 1999, Dreitz 2005) and on potential relationships with prairie dog colonies (Colorado Division of Wildlife 2003, Dreitz et al. 2006). Other studies have focused on plover reproduction and movement (Graul 1973, 1975, Graul and Webster 1976, Knopf and Rupert 1996, Dreitz et al. 2005).

Plovers in Colorado have been found to nest and raise broods in cultivated fields, and the most recent research in Colorado has found that nest success is comparable on

cropland and grassland (Dreitz 2005). Although there is some indication that brood-rearing plovers move to nearby prairie when crop vegetation grows taller than ~20 cm (Knopf and Rupert 1996), no such movement patterns were observed for plovers in a more recent study (Dreitz et al. 2005). Results of Dreitz et al. (2005) suggest that movements were similar between habitat types (dryland agriculture, grassland, and prairie dog colonies) and were not related to home-range or core area size (Dreitz et al. 2005). In addition, home-range size varied with the size of the prairie dog colony (or complex) used for nesting, and plovers nesting on prairie dog colonies did not move their broods to other habitat types (Dreitz et al. 2005).

In Montana, mountain plovers are known to be strongly associated with prairie dog colonies (Knowles et al. 1982, Olson and Edge 1985, Dinsmore et al. 2003), but the nature of this relationship in Colorado is not yet well understood (Knopf 1996a, Colorado Division of Wildlife 2003, Dreitz et al. 2005, Dreitz et al. 2006). While additional research is needed to determine the level of association between plovers and prairie dogs in Colorado, preliminary results indicate that prairie dogs maintain suitable plover habitat compared with surrounding grassland and that plovers may have higher nest success on colonized versus uncolonized grassland sites (U.S. Fish and Wildlife Service 1999). Few studies have looked at landscape effects, although Shackford (1996) and Shackford and Leslie (1994) identified potential preferences for large (>30 ha) agricultural fields and those near native shortgrass.

Demographic studies aimed at determining population estimates for the mountain plover have also been conducted. In Colorado, earlier estimation efforts by Graul and Webster (1976) used observed densities on PNG in conjunction with a survey of

grassland habitat conditions to estimate mountain plover abundance and density for the PNG area and the rest of the state. Their results indicated a rough estimate of ~20,800 plovers, with an average 6 birds/km^2, in and adjacent to PNG plus 105,000-210,000 plovers throughout the rest of the state, not including the South Park area (Graul and Webster 1976). More recent population estimates indicate much lower numbers, with ~78 breeding plovers estimated on PNG and ~7,000 throughout Colorado in 2002 (U.S. Fish and Wildlife Service 2003). However, interpreting these estimates is problematic due to the lack of a probability-based sampling scheme and adjustment for detection error, as discussed above.

More recent studies incorporating one or both of these features have been conducted in portions of the plover's range. These studies have used capture-recapture (Dinsmore et al. 2003), distance sampling (Wunder et al. 2003, Dreitz 2005, Plumb et al. 2005), and patch occupancy (Dreitz et al. 2006) to estimate mountain plover abundance and/or density. Dinsmore et al. (2003) successfully used capture-recapture methods to estimate annual population size at a Montana study site. High capture probabilities allowed them to precisely estimate numbers of breeding mountain plovers, which were found to be lower than were expected based on previous *ad hoc* estimates. They also found that changes in the annual plover population closely tracked changes in area occupied by prairie dogs (Dinsmore et al. 2003, Dinsmore et al. 2005).

Plumb et al. (2005) used distance sampling to estimate the abundance and density of mountain plover in grassland and desert-shrub landscapes, including areas of white-tailed prairie dog (*Cynomys leucurus*) colonies, in Wyoming. They estimated a minimum state population estimate of 3,393 birds, significantly higher than previous state estimates

(500-1,500 birds, Plumb et al. 2005). Surveys were conducted using ATVs and only in areas of high plover concentrations (average density of 4.47 ± 0.55 SE birds/km^2), allowing reasonable sample sizes. Wunder et al. (2003) used a combination of survey methods, including distance sampling, to estimate plover abundance and density in South Park, Colorado. They estimated the 2002 South Park population to be ~2,310 breeding adults at an average density of 7.9 birds/km^2 (± 0.9 SE, Wunder et al. 2003). The use of distance sampling was facilitated by Wunder et al. obtaining permission from most of the landowners to conduct surveys from a moving vehicle – an uncommon occurrence, especially on croplands. Dreitz (2005) attempted to use distance sampling to estimate densities of mountain plovers in eastern Colorado in 2001 and 2002. Because vehicles were usually constrained to field perimeters (i.e., transects not randomly placed) and walking transects would likely fail to detect plovers at their initial locations, she determined that distance sampling was not feasible given the low density of most populations and between-season distributional shifts of plovers in eastern Colorado.

Dreitz et al. (2006) investigated the feasibility of the latent-occupancy method (Royle and Nichols 2003) in eastern Colorado in 2003. Using occupancy data, Dreitz et al. estimated mountain plover latent abundance in three habitat types – agricultural fields, grassland, and prairie dog colonies. Although their results suggest that plovers were more abundant on prairie dog colonies than other habitats, inference is limited by the spatial extent and duration of their study (Dreitz et al. 2006). In addition, their abundance estimates cannot be extrapolated to all of eastern Colorado due to the sampling design used (i.e., only areas of high plover concentrations were surveyed) and potential closure

issues (Dreitz et al. 2006). However, their results suggest that estimating plover abundance from occupancy data is feasible.

The application of physical mark-recapture and distance sampling methods to large-scale areas is limited, especially in the presence of low-density populations. Therefore, it is important that alternative estimation methods be tested for their usefulness with estimation of mountain plover populations throughout the state.

Western burrowing owl (*Athene cunicularia hypugaea*)

a) Natural history and conservation status

The western burrowing owl is distributed in western North American grasslands and south into Central America. In Colorado, the owl is considered locally uncommon to fairly common and found almost exclusively in the eastern plains, although it was once more widely distributed across the state (Haug et al. 1993, Colorado Division of Wildlife 2003).

The burrowing owl breeds in open, well-drained grasslands, steppes, deserts, prairies, and agricultural lands. The owl is highly associated with burrowing mammals, whose holes are used for nesting (Haug et al. 1993). Little is known regarding owl migration. Burrowing owls breeding in Colorado are thought to migrate southward in September/October and return in March/April, with nesting initiated within a few weeks of arrival (Haug et al. 1993, Jones 1998). Burrowing owls are a semi-colonial species and exhibit intra-specific territoriality around nest burrows, with the intensity of this territoriality varying with owl density and colony size (Haug et al. 1993, Jones 1998). Territory size is not well known, with estimated nesting territory ranging from ~4-6 ha

(in Minnesota and North Dakota, Grant 1965) and diurnal foraging area averaging 3.5 ha (in eastern Wyoming, Thompson 1984). Nocturnal foraging area is considerably larger (averaging 35-241 ha in southern Saskatchewan, Haug and Oliphant 1990, Sissons et al. 2001) and may provide a better assessment of burrowing owl home range. Home-range/foraging-area size is likely to vary with prey density (Dechant et al. 2003b). Owls exhibit strong breeding site fidelity and are moderately site-specific (Plumpton and Lutz 1993, Desmond et al. 2000). For more details on the natural history aspects of burrowing owls refer to Grant (1965), Butts (1973), Thompson (1984), Haug et al. (1993), Jones (1998), Dechant et al. (2003b), and Gervais et al. (2003).

Burrowing owls are listed as threatened in Colorado and Mexico, endangered in two states and in Canada, and as a species of special concern in ten states (Colorado Division of Wildlife 2003). Apparent declines in burrowing owl populations (2.2% per year in the U.S. and 13.4% per year in Canada, 1966–2005 BBS data, Sauer et al. 2005) are thought to be primarily due to habitat loss and fragmentation (e.g., land conversion, extirpation of prairie dogs through eradication efforts or plague), pesticide use, and vehicle collisions (Haug et al. 1993, Gervais and Anthony 2003).

b) Current research and estimation methods

In Colorado, owls seem to be highly associated with shortgrass prairie (70% of sightings by Breeding Bird Atlasers, Jones 1998), and to favor prairie dog colonies (80% of sightings in one 1999 survey, VerCauteren et al. 2001). Prairie dog colonies probably provide nesting habitat with good visibility (i.e., mounds for perching and closely cropped vegetation), resulting in improved predator detection (Haug et al. 1993,

Desmond et al. 1995). This habitat preference has been corroborated in other states where researchers have found higher burrowing owl counts on prairie dog colonies than on other areas (South Dakota, Agnew et al. 1986, Nebraska, Desmond and Savidge 1996, Oklahoma, Barko et al. 1999, Smith and Lomolino 2004, New Mexico, Arrowood et al. 2001). In areas where prairie dogs have been extirpated, vegetation around burrows is thought to become too tall (i.e., >8 cm) for continued use by burrowing owls (Grant 1965, Butts 1973, Plumpton and Lutz 1993, Jones 1998, Desmond et al. 2000).

Numerous studies (Butts 1973, Thompson 1984, Hughes 1993, Plumpton and Lutz 1993, Desmond et al. 1995, Desmond and Savidge 1996, Toombs 1997, Restani et al. 2001) have been conducted examining potential relationships between prairie dog colony attributes (e.g., colony size, burrow density, and activity level) and owl density, burrow selection, site fidelity, nest predation rates, and nest success rates. In northeastern Colorado, Hughes (1993) found owl nesting density decreased as prairie dog colony size increased, while nesting density increased with an increase in percent active prairie dog burrows. In southeastern Colorado, Toombs (1997) found that the most important attribute of occupied prairie dog colonies was activity status (occupancy was significantly higher on active versus inactive colonies). A positive relationship between owl occupancy and active prairie dog colonies was also observed by Sidle et al. (2001a) in their surveys of National Grasslands throughout the Great Plains.

In other studies, potential relationships between owl occupancy and landscape composition and arrangement have been considered. In northeastern Colorado, Orth and Kennedy (2001) found the only predictor of owl occupancy was the number of shortgrass patches surrounding occupied colonies (occupancy increased with number of patches).

They reasoned that occupied colonies existing in fragmented landscapes may be preferred due to higher prey availability.

Currently, a standardized survey and monitoring program is not available to estimate burrowing owl occupancy, abundance, or changes therein (Holroyd et al. 2001). Local efforts to monitor owl populations use a variety of survey methods, the majority of which do not employ a probability-based sampling scheme. Statewide assessments have been conducted in Arizona (Brown 2001), New Mexico (Arrowood et al. 2001), North Dakota (Murphy et al. 2001), Oklahoma (Sheffield and Howery 2001), Texas (McIntyre 2004), and Wyoming (Korfanta et al. 2001), and have gathered data from numerous sources (e.g., historical records, including BBS data, questionnaires, and field observations) to discuss apparent trends. In most of these studies, field observations were limited to surveys of historic nesting sites or road-based surveys. In eastern Colorado, VerCauteren et al. (2001) conducted roadside surveys and incorporated additional location data from various sources to describe burrowing owl distribution. Conway and Simon (2003) evaluated two survey methods (roadside point counts and driving surveys) and the use of call-broadcast in Wyoming. Of these studies, only Conway and Simon (2003) adjusted count statistics for detection, and all studies relied on data obtained using convenience sampling. Thus, improvements in burrowing owl estimation efforts are needed to provide valid inference to larger populations of interest.

Other species

In addition to my focal species, I collected sufficient data to estimate occupancy, abundance, and density of six additional grassland bird species - horned lark (*Eremophila*

alpestris), Cassin's sparrow (*Aimophila cassinii*), lark sparrow (*Chondestes grammacus*), lark bunting (*Calamonspiza melanocorys*), grasshopper sparrow (*Ammodramus savannarum*), and western meadowlark (*Sturnella neglecta*). Below, I discuss results of previous studies conducted on these species in shortgrass and mixed-grass prairie. Aspects of each species' natural history pertinent to my study are summarized in Table 1.3.

Studies investigating avian community habitat associations in Colorado's shortgrass prairie have primarily been conducted in the northeastern portion of the state, most notably on PNG, and have focused on habitat correlations related to vegetation structure (e.g., grazing effects, Wiens 1973, Kantrud and Kologiski 1983). Although these studies did not investigate species associations with prairie dog colonies, their results do suggest potential relationships based on species preference for short, sparse vegetation in Colorado.

Additional studies, conducted in shortgrass and mixed-grass prairie, have compared the association of avifauna on prairie dog colonies with other uncolonized sites. In these studies, horned larks were found to positively associated with prairie dog colonies and were the most common birds on colonized sites (Agnew et al. 1986, Winter et al. 2003, Smith and Lomolino 2004). Cassin's sparrows, lark buntings, and grasshopper sparrows appeared to be associated with uncolonized sites (Agnew et al. 1986, Winter et al. 2003, Smith and Lomolino 2004). Mixed results were seen for other species (e.g., lark sparrows and western meadowlarks, Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004) and may be due to differences in study area, spatial extent, duration, climatic conditions, and methodologies.

Studies focusing on landscape effects on grassland bird communities have also been conducted. Hamer et al. (2006) investigated the effects of landscape structure, as described by several landscape metrics, and grasshopper density and richness on grassland bird species richness in the shortgrass/mixed-grass prairie of eastern Wyoming. They found that avian distributions were influenced by a complex mixture of landscape factors including grassland habitat area and prey availability. Valiulis (2003) also studied landscape structure in grasslands to explain variance in avian abundance and richness. She concluded that the relationship between landscape structure and bird communities may be stronger than previously thought (Valiulis 2003). In addition, these and other studies (Rotenberry and Knick 1999, Haire et al. 2000, Orth and Kennedy 2001, Fletcher and Koford 2002, Lueders 2002, Cunningham and Johnson 2006, Winter et al. 2006) highlight the need to quantify habitat factors and avian occupancy, abundance, density, and richness at larger and multiple spatial scales in consideration of species-specific perceptual/functional ranges. For many species, these ranges may be larger than typically considered and may be independent of body size. For example, results of Cunningham and Johnson (2006) from mixed-grass and tallgrass prairie in North Dakota suggest that grasshopper sparrow occupancy may be influenced by a combination of local and landscape (1600-m radius) habitat variables, while occupancy of western meadowlarks appeared unaffected by large-scale (>800 m) habitat factors. Studies of area requirements of grassland birds have also been conducted, and may shed light on the spatial extents which may be important to some grassland birds. Results from mixed-grass prairie and CRP fields in the northern Great Plains indicate that grasshopper sparrows may be considered area sensitive, while horned larks and western meadowlarks

appear to be insensitive to patch size, although other landscape metrics such as edge-to-area ratio may be important to patch use (Johnson and Igl 2001, Davis 2004).

As discussed above, most previous estimation efforts of grassland bird populations have not employed a probability-based sampling scheme or adjusted counts to correct for detection error. The importance of the former has been supported by Hanni's (2002) comparison of road-based surveys, interior line transects, and random point transects to estimate avian abundance and densities in Colorado. His results indicate that several species, including horned lark, lark sparrow, lark bunting, and western meadowlark, appear to be biased towards roads, while grasshopper sparrows appear to be biased away from roads. Calculated abundance and densities using road-based counts of these species, even though adjusted for detection, may grossly over- or under-estimate (respectively) avian populations when extrapolation occurs. Incorporation of detection probability into estimates of species occupancy, abundance, density, and species richness is also important, as addressed by both Lueders (2002) and Hamer et al. (2006).

THESIS SUMMARY

Previous studies have investigated habitat correlations of grassland birds, including levels of association with prairie dog colonies. However, most of these studies have not been conducted in Colorado and none have looked at avian response in shortgrass prairie across the entire state. Because prairie dogs do not modify the prairie ecosystem equally in all regions of the Great Plains and because dynamic processes

which affect avian species vary over space and time, regional differences are likely to exist (Winter et al. 2003, Smith and Lomolino 2004).

There is a need for studies specific to shortgrass prairie in Colorado to further test and generalize conclusions regarding habitat correlations, as well as to investigate other factors important in structuring the avian communities. In Chapter 2, I evaluated the patch occupancy method for monitoring grassland birds over large areas and used this method to compare presence of avian species between habitat types. Specifically, I tested predictions concerning variation in occupancy and detection of grassland birds across three strata – prairie dog colonies, native shortgrass, and dryland agriculture – as well as predictions concerning the surrounding landscape at multiple spatial scales. An analysis of occupancy data using maximum likelihood methods in program MARK (White and Burnham 1999) is presented, and potential habitat effects on species occupancy are discussed and compared with previous study results.

In Chapter 3, I evaluated double-observer methodologies to estimate grassland bird abundance and density in my three strata and the surrounding landscape, testing predictions concerning variation in species abundance and detection. Analyses of double-observer data using maximum likelihood and variance components methods in program MARK (White and Burnham 1999, White et al. 2002) are presented. A comparison of abundance estimates using the double-observer and latent-occupancy methods is also presented for my focal species. Species-habitat associations are discussed and results compared with those of previous studies.

In Chapter 4, I further discuss the feasibility of using these novel survey methods along with a new probabilistic sampling scheme across large-scale areas such as eastern

Colorado. I compare these avian population parameters (occupancy and abundance) and discuss the utility of each in grassland bird monitoring. In this chapter, I also discuss the implications of my study and recommendations for the conservation and management of grassland avifauna in Colorado's shortgrass prairie. Lastly, I provide a full description of GIS procedures used in my study in Appendix I, with step-by-step instructions for others who may wish to replicate my procedure.

LITERATURE CITED

Agnew, W., D. W. Uresk, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. Journal of Range Management 39:135-139.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Barko, V. A., J. H. Shaw, and D. M. Leslie. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwestern Naturalist 44:484-489.

Beason, R. C. 1995. Horned Lark (*Eremophila alpestris*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 195. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies - mammals. Pages 149-166 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Borchers, D. L., S. T. Buckland, and W. Zucchini. 2002. Estimating Animal Abundance - Closed Populations. Springer, New York, New York, USA.

Brennan, L. A., and W. P. Kuvlesky. 2005. North American grassland birds: An unfolding conservation crisis? Journal of Wildlife Management 69:1-13.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: Initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152.

Brown, N. L. 2001. The howdy owls of Arizona: A review of the status of *Athene cunicularia*. Journal of Raptor Research 35:344-350.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling - Estimating Abundance of Biological Populations. Oxford University Press, Oxford, UK.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1-202.

Butts, K. O. 1973. Life history and habitat requirements of burrowing owls in western Oklahoma. Thesis, Oklahoma State University, Stillwater, Oklahoma, USA.

Colorado Division of Wildlife. 2003. Conservation Plan for Grassland Species in Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Conway, C. J., and J. C. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501-511.

Corn, P. S., and C. R. Peterson. 1996. Prairie legacies - amphibians and reptiles. Pages 125-134 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Cunningham, M. A., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Applications 16:1062-1075.

Davis, S. K. 2004. Area sensitivity in grassland passerines: Effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. Auk 121:1130-1145.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, M. P. Nenneman, and B. R. Euliss. 2003a. Effects of management practices on grassland birds: Mountain Plover. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, P. A. Rabie, and B. R. Euliss. 2003b. Effects of management practices on grassland birds: Burrowing Owl. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: A 7 year analysis. Journal of Wildlife Management 64:1067-1075.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. Canadian Journal of Zoology-Revue Canadienne de Zoologie 73:1375-1379.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2003. Annual survival and population estimates of mountain plovers in southern Phillips County, Montana. Ecological Applications 13:1013-1026.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2005. Mountain plover population responses to black-tailed prairie dogs in Montana. Journal of Wildlife Management 69:1546-1553.

Dreitz, V. J. 2005. Resolving conflicts of Mountain Plovers (*Charadrius montanus*) breeding on agricultural lands in Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado, USA.

Dreitz, V. J., P. M. Lukacs, and F. L. Knopf. 2006. Monitoring low density avian populations: an example using Mountain Plover. Condor 108:700-706.

Dreitz, V. J., M. B. Wunder, and F. L. Knopf. 2005. Movements and home ranges of Mountain Plovers raising broods in three Colorado landscapes. Wilson Bulletin 117:128-132.

Dunning, J. B., Jr., R. K. Bowers, Jr., S. J. Suter, and C. E. Bock. 1999. Cassin's Sparrow (*Aimophila cassinii*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 471. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

EDAW Inc. 2000. Black-tailed prairie dog study of eastern Colorado. Prepared for the Colorado Department of Natural Resources, Denver, Colorado, USA.

Fletcher, R. J., and R. R. Koford. 2002. Habitat and landscape associations of breeding birds in native and restored grasslands. Journal of Wildlife Management 66:1011-1022.

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. Bioscience 51:625-632.

Gervais, J. A., and R. G. Anthony. 2003. Chronic organochlorine contaminants, environmental variability, and the demographics of a burrowing owl population. Ecological Applications 13:1250-1262.

Gervais, J. A., D. K. Rosenberg, and R. G. Anthony. 2003. Space use and pesticide exposure risk of male burrowing owls in an agricultural landscape. Journal of Wildlife Management 67:155-164.

Goodwin, H. T. 1995. Pliocene-Pleistocene biogeographic history of prairie dogs, Genus *Cynomys* (*Sciuridae*). Journal of Mammalogy 76:100-122.

Grant, R. A. 1965. The Burrowing Owl in Minnesota. Loon 37:2-17.

Graul, W. D. 1973. Breeding adaptations of the mountain plover (*Charadrius montanus*). Dissertation, University of Minnesota, St. Paul, Minnesota, USA.

Graul, W. D. 1975. Breeding biology of the Mountain Plover. Wilson Bulletin 87:6-31.

Graul, W. D., and L. E. Webster. 1976. Breeding status of Mountain Plover. Condor 78:265-267.

Haire, S. L., C. E. Bock, B. S. Cade, and B. C. Bennett. 2000. The role of landscape and habitat characteristics in limiting abundance of grassland nesting songbirds in an urban open space. Landscape and Urban Planning 48:65-82.

Hamer, T. L., C. H. Flather, and B. R. Noon. 2006. Factors associated with grassland bird species richness: the relative roles of grassland area, landscape structure, and prey. Landscape Ecology 21:569-583.

Hanni, D. 2002. A comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Hanni, D. 2003. Section-based monitoring of breeding birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington, D.C., USA.

Haug, E. A., and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of burrowing owls in Saskatchewan. Journal of Wildlife Management 54:27-35.

Holroyd, G. L., R. Rodriguez-Estrella, and S. R. Sheffield. 2001. Conservation of the Burrowing Owl in western North America: Issues, challenges, and recommendations. Journal of Raptor Research 35:399-407.

Hughes, A. J. 1993. Breeding density and habitat preference of the burrowing owl in northeastern Colorado. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Hutto, R. L., and J. S. Young. 2002. Regional landbird monitoring: Perspectives from the northern Rocky Mountains. Wildlife Society Bulletin 30:738-750.

Hutto, R. L., and J. S. Young. 2003. On the design of monitoring programs and the use of population indices: A reply to Ellingson and Lukacs. Wildlife Society Bulletin 31:903-910.

Johnson, D. H., and L. D. Igl. 2001. Area requirements of grassland birds: A regional perspective. Auk 118:24-34.

Jones, S. R. 1998. Burrowing Owl. Pages 220-221 *in* H. E. Kingery, editor. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership, Denver, Colorado, USA.

Kantrud, H. A., and R. L. Kologiski. 1983. Avian associations of the northern Great Plains grasslands. Journal of Biogeography 10:331-350.

Kingery, H. E., editor. 1998. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership, Denver, Colorado, USA.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

Knopf, F. L. 1996a. Mountain Plover (*Charadrius montanus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 211. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Knopf, F. L. 1996b. Prairie legacies - birds. Pages 135-148 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Knopf, F. L., and B. J. Miller. 1994. *Charadrius montanus* - montane, grassland, or bare-ground plover? Auk 111:504-506.

Knopf, F. L., and J. R. Rupert. 1995. Habits and habitats of Mountain Plovers in California. Condor 97:743-751.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

Knopf, F. L., and J. R. Rupert. 1999. The use of crop fields by breeding Mountain Plovers. Studies in Avian Biology 19:81-86.

Knowles, C. 1998. Availability of black-tailed prairie dog habitat for black-footed ferret recovery. Unpublished final report to U.S. Fish and Wildlife Service.

Knowles, C. J., C. J. Stoner, and S. P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

Korfanta, N. M., L. W. Ayers, S. H. Anderson, and D. B. McDonald. 2001. Preliminary assessment of Burrowing Owl population status in Wyoming. Journal of Raptor Research 35:337-343.

Kotliar, N. B., B. W. Baker, A. D. Whicker, and G. Plumb. 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental Management 24:177-192.

Kretzer, J. E., and J. F. Cully. 2001. Effects of black-tailed prairie dogs on reptiles and amphibians in Kansas shortgrass prairie. Southwestern Naturalist 46:171-177.

Kuenning, R. R., and H. E. Kingery. 1998. Mountain Plover. Pages 170-171 *in* H. E. Kingery, editor. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership and Colorado Division of Wildlife, Denver, Colorado, USA.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland, USA.

Lanyon, W. E. 1994. Western Meadowlark (*Sturnella neglecta*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 104. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Lomolino, M. V., R. Channell, D. R. Perault, and G. A. Smith. 2001. Downsizing nature: Anthropogenic dwarfing of species and ecosystems. Pages 223-243 *in* J. L. Lockwood and M. L. McKinney, editors. Biotic Homogenization. Kluwer, New York, New York, USA.

Lomolino, M. V., and G. A. Smith. 2003. Prairie dog towns as islands: Applications of island biogeography and landscape ecology for conserving nonvolant terrestrial vertebrates. Global Ecology and Biogeography 12:275-286.

Lomolino, M. V., and G. A. Smith. 2004. Terrestrial vertebrate communities at black-tailed prairie dog (*Cynomys ludovicianus*) towns. Biological Conservation 115:89-100.

Lomolino, M. V., G. A. Smith, and V. Vidal. 2004. Long-term persistence of prairie dog towns: Insights for designing networks of prairie reserves. Biological Conservation 115:111-120.

Lueders, A. S. 2002. Influences of vegetative structure on avian populations under grazing regimes in North Dakota mixed-grass prairie. Thesis, Colorado State University, Fort Collins, Colorado, USA.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

Martin, J. W., and J. R. Parrish. 2000. Lark Sparrow (*Chondestes grammacus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 488. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

McIntyre, N. E. 2004. Historical and current status of breeding and wintering Western Burrowing Owls (*Athene cunicularia hypugaea*) in Texas. Journal of Raptor Research 38:91-95.

Miller, B., G. Ceballos, and R. Reading. 1994. The prairie dog and biotic diversity. Conservation Biology 8:677-681.

Miller, B., R. Reading, J. Hoogland, T. Clark, G. Ceballos, R. List, S. Forrest, L. Hanebury, P. Manzano, J. Pacheco, and D. Uresk. 2000. The role of prairie dogs as a keystone species: Response to Stapp. Conservation Biology 14:318-321.

Miller, B. J., and F. L. Knopf. 1993. Growth and survival of Mountain Plovers. Journal of Field Ornithology 64:500-506.

Miller, S. D., and J. F. Cully. 2001. Conservation of black-tailed prairie dogs (*Cynomys ludovicianus*). Journal of Mammalogy 82:889-893.

Murphy, R. K., K. W. Hasselblad, C. D. Grondahl, J. G. Sidle, R. E. Martin, and D. W. Freed. 2001. Status of the Burrowing Owl in North Dakota. Journal of Raptor Research 35:322-330.

National Drought Mitigation Center. 2004. The Drought Monitor. University of Nebraska-Lincoln, Lincoln, Nebraska, USA. Online at <http://drought.unl.edu>.

Nichols, J. D. 1992. Capture-recapture models. Bioscience 42:94-102.

Nichols, J. D. 1999. Monitoring is not enough: On the need for a model-based approach to migratory bird management. *In* R. Bonney, D. N. Pashley, R. J. Cooper, and L. Niles, editors. Strategies for Bird Conservation: The Partners in Flight Planning Process. Cornell Lab of Ornithology, Cape May, New Jersey, USA. Online at <http://birds.cornell.edu/pifcapemay>

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393-408.

Olson, S. L., and D. Edge. 1985. Nest site selection by mountain plovers in northcentral Montana. Journal of Range Management 38:280-282.

Orth, P. B., and P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by burrowing owls (*Athene cunicularia hypugaea*) in northeastern Colorado? Canadian Journal of Zoology-Revue Canadienne de Zoologie 79:1038-1045.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical-inference from capture data on closed animal populations. Wildlife Monographs 62:1-135.

Plumb, R. E., F. L. Knopf, and S. H. Anderson. 2005. Minimum population size of Mountain Plovers breeding in Wyoming. Wilson Bulletin 117:15-22.

Plumpton, D. L., and R. S. Lutz. 1993. Nesting habitat use by Burrowing Owls in Colorado. Journal of Raptor Research 27:175-179.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105-119.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology of Burrowing Owls occupying black-tailed prairie dog towns in southeastern Montana. Journal of Raptor Research 35:296-303.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: Current practices and an alternative. Auk 119:46-53.

Rotenberry, J. T., and S. T. Knick. 1999. Multiscale habitat associations of the Sage Sparrow: Implications for conservation biology. Studies in Avian Biology 19:95-103.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Samson, F. B., and F. L. Knopf, editors. 1996. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin 32:6-15.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, Results and Analysis 1966-2005. Version 6.2.2006. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. Online at <http://www.mbr-pwrc.usgs.gov/bbs/>.

Sauer, J. R., J. E. Fallon, and R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for bird conservation regions. Journal of Wildlife Management 67:372-389.

Seber, G. A. F. 1982. The Estimation of Animal Abundance and Related Parameters. Second edition. Blackburn Press, Caldwell, New Jersey, USA.

Shackford, J. S. 1996. Studies and observations of Mountain Plover in the Great Plains. Page 27 *in* D. P. Coffin, editor. Summary report - shortgrass prairie/Mountain Plover workshop. Denver Audubon Society, Aurora, Colorado, USA.

Shackford, J. S., and D. M. Leslie. 1994. Mountain Plover breeding activity on cultivated fields. Federal aid project E-26-1. Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma, USA.

Shackford, J. S., D. M. Leslie, and W. D. Harden. 1999. Range-wide use of cultivated fields by Mountain Plovers during the breeding season. Journal of Field Ornithology 70:114-120.

Shane, T. G. 2000. Lark Bunting (*Calamospiza melanocorys*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 542. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Sheffield, S. R., and M. Howery. 2001. Current status, distribution, and conservation of the Burrowing Owl in Oklahoma. Journal of Raptor Research 35:351-356

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, D. N. Svingen. 2001a. Occurrence of Burrowing Owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research. 35:316-321.

Sidle, J. G., D. H. Johnson, and B. R. Euliss. 2001b. Estimated areal extent of colonies of black-tailed prairie dogs in the northern Great Plains. Journal of Mammalogy 82:928-936.

Sissons, R. A., K. L. Scalise, T. I. Wellicome. 2001. Nocturnal foraging and habitat use by male Burrowing Owls in a heavily-cultivated region of southern Saskatchewan. Journal of Raptor Research 35:304-309.

Smith, G. A., and M. V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138:592-602.

Stapp, P. 1998. A reevaluation of the role of prairie dogs in Great Plains grasslands. Conservation Biology 12:1253-1259.

Stephens, S. E., D. N. Koons, J. J. Rotella, and D. W. Willey. 2003. Effects of habitat fragmentation on avian nesting success: A review of the evidence at multiple spatial scales. Biological Conservation 115:101-110.

Theobald, D. T. 2004. GIS - GRTS: Spatially balanced sampling tool. ArcGIS v.9.0 extension. Language: Python. Operating System: Windows XP. Software Application ESRI ArcGIS v.9.0. Colorado State University, Fort Collins, Colorado, USA.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

Thompson, C. D. 1984. Selected aspects of burrowing owl ecology in central Wyoming. Thesis, University of Wyoming, Laramie, Wyoming, USA.

Thompson, S. K. 2002. Sampling. John Wiley and Sons, New York, New York, USA.

Thompson, W. L. 2002. Towards reliable bird surveys: Accounting for individuals present but not detected. Auk 119:18-25.

Toombs, T. P. 1997. Burrowing owl nest-site selection in relation to soil texture and prairie dog colony attributes. Thesis, Colorado State University, Fort Collins, Colorado, USA.

U.S. Fish and Wildlife Service. 1999. Proposed threatened status for the Mountain Plover. Pages 7587-7601 *in* Federal Register Volume 64, Number 30. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants: 12-month finding for a petition to list the black-tailed prairie dog as threatened. Pages 5476-5488 *in* Federal Register Volume 65, Number 24. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2003. Endangered and threatened wildlife and plants: Withdrawal of the proposed rule to list the Mountain Plover as threatened. Pages 53083-53101 *in* Federal Register Volume 68, Number 174. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2004. Endangered and threatened wildlife and plants: Finding for the resubmitted petition to list the black-tailed prairie dog as threatened. Pages 51217-51226 *in* Federal Register Volume 69, Number 159. Washington D.C., USA.

Valiulis, J. 2003. The use of continuous and categorical measures of landscape structure in predicting biotic response: An example using grassland birds. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Venner, M. 2002. Habitat approach to streamlining Section 7 - Colorado Department of Transportation's Shortgrass Prairie Initiative. Pages 109-117 *in* Sustainability and Environmental Concerns in Transportation 2002. Transportation Research Board National Research Council, Washington D.C., USA.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

Vermeire, L. T., R. K. Heitschmidt, P. S. Johnson, and B. F. Sowell. 2004. The prairie dog story: Do we have it right? BioScience 54:689-695.

Vickery, P. D. 1996. Grasshopper Sparrow (*Ammodramus savannarum*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 239. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Weaver, T., E. M. Payson, and D. L. Gustafson. 1996. Prairie ecology - the shortgrass prairie. Pages 67-75 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46, Supplement, 120-138.

White, G. C., K. P. Burnham, and D. R. Anderson. 2002. Advanced features of program MARK. Pages 368-377 *in* R. Fields, editor. Integrating People and Wildlife for a Sustainable Future, Proceedings of the Second International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA.

White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265-272.

Wiens, J. A. 1973. Pattern and process in grassland bird communities. Ecological Monographs 43:237-270.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Vertebrate Populations. Academic Press, San Diego, California, USA.

Winter, M., D. H. Johnson, J. A. Shaffer, T. M. Donovan, and W. D. Svedarsky. 2006. Patch size and landscape effects on density and nesting success of grassland birds. Journal of Wildlife Management 70:158-172.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2002. Vegetation of prairie dog colonies and non-colonized shortgrass prairie. Journal of Range Management 55:502-508.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2003. Breeding season avifauna of prairie dog colonies and non-colonized areas in shortgrass prairie. Transactions of the Kansas Academy of Science 106:129-138.

Wunder, M. B., and F. L. Knopf. 2003. The Imperial Valley of California is critical to wintering Mountain Plovers. Journal of Field Ornithology 74:74-80.

Wunder, M. B., F. L. Knopf, and C. A. Pague. 2003. The high-elevation population of Mountain Plovers in Colorado. Condor 105:654-662.

Table 1.1. North American prairie avifauna of the Great Plains. Shortgrass and short-mixed-grass associated species are listed in bold type and declining species (as indicated by analysis of Breeding Bird Survey data) are marked with an asterisk.

Primary (endemic) species	Genus species
Ferruginous hawk	*Buteo regalis*
Mountain plover*	*Charadrius montanus*
Long-billed curlew*	*Numenius americanus*
Spraque's pipit*	*Anthus spragueii*
Cassin's sparrow*	*Aimophila cassinii*
Baird's sparrow*	*Ammodramus bairdii*
Lark bunting*	*Calamospiza melanocorys*
McCown's longspur	*Calcarius mccownii*
Chestnut-collared longspur*	*Calcarius ornatus*
Secondary species	**Genus species**
Mississippi kite	*Ictinia mississippiensis*
Swainson's hawk	*Buteo swainsoni*
Northern harrier*	*Circus cyaneus*
Prairie falcon	*Falco mexicanus*
Greater prairie chicken*	*Tympanuchus cupido*
Lesser prairie chicken	*Tympanuchus pallidicinctus*
Sharp-tailed grouse	*Tympanuchus phasianellus*
Upland sandpiper	*Bartramia longicauda*
Burrowing owl*	*Athene cunicularia*
Short-eared owl*	*Asio flammeus*
Horned lark*	*Eremophila alpestris*
Eastern meadowlark*	*Sturnella magna*
Western meadowlark*	*Sturnella neglecta*
Dickcissel*	*Spiza americana*
Savannah sparrow*	*Passerculus sandwichensis*
Grasshopper sparrow*	*Ammodramus savannarum*
Henslow's sparrow*	*Ammodramus henslowii*
Vesper sparrow*	*Pooecetes gramineus*
Lark sparrow*	*Chondestes grammacus*
Clay-colored sparrow*	*Spizella pallida*

Source: Adapted from Knopf (1996b) and Smith and Lomolino (2004).

Table 1.2. Species of conservation concern in Colorado's shortgrass prairie ecosystem. Each species' Partners in Flight (PIF) priority level is shown, along with corresponding Shortgrass Prairie Bird Conservation Region (BCR 18) ratings. Population trends are based on Breeding Bird Survey data within BCR 18 from 1966 to 1999. Shortgrass and short-mixed-grass associated species are listed in bold type.

Species	*Genus species*	PIF priority level[a]	% of breeding population in BCR 18	BCR trend	P-value
Northern harrier	*Circus cyaneus*	II	4.37	-2.8	0.25
Swainson's hawk	*Buteo swainsoni*	I	20.94	-0.7	0.69
Ferruginous hawk	*Buteo regalis*	I	21.11	1.46	0.37
Prairie falcon	*Falco mexicanus*	I	10.17	5.72	0.08
Greater prairie chicken	*Tympanuchus cupido*	I	7.58	54.96	0.16
Lesser prairie chicken	*Tympanuchus pallidicinctus*	I	No Data	No Data	
Scaled quail	*Callipepla squamata*	I	8.37	-2.95	0.05
Mountain plover	*Charadrius montanus*	I	73.6	-1.06	0.78
Upland sandpiper	*Bartramia longicauda*	II	1.37	-5.46	0.22
Long-billed curlew	*Numenius americanus*	I	14.08	-3.32	0.15
Burrowing owl	*Athene cunicularia*	I	34.95	-3.37	0.15
Say's phoebe	*Sayornis saya*	II	10.44	0.79	0.63
Chihuahuan raven	*Corvus cryptoleucus*	II	24.42	-1.33	0.26
Loggerhead shrike	*Lanius ludovicianus*	-	7.82	-0.18	0.93
Horned lark	*Eremophila alpestris*	III	21.49	-1.89	<0.01
Cassin's sparrow	*Aimophila cassinii*	I	38.55	-1.68	0.01
Brewer's sparrow	*Spizella breweri*	III	1.09	-5.99	0.12
Lark sparrow	*Chondestes grammacus*	II	17.73	-1.48	0.06
Lark bunting	*Calamospiza melanocorys*	II	36.44	-1.97	0.01

…table continued

…table continued

Species	*Genus species*	PIF priority level[a]	% of breeding population in BCR 18	BCR trend	P-value
Grasshopper sparrow	*Ammodramus savannarum*	II	19.65	-1.53	0.17
McCown's longspur	*Calcarius mccownii*	I	18.42	2.5	0.69
Chestnut-collared longspur	*Calcarius ornatus*	I	2.66	9.4	0.26
Dickcissel	*Spiza americana*	II	1.85	4.26	0.11
Western meadowlark	*Sturnella neglecta*	III	18.44	-0.64	0.06

[a] Partners in Flight (PIF): Tier I - High overall priority (species typically of conservation concern throughout their range); Tier II - High regional priority (species of moderate overall priority but of higher regional priority); Tier III - U.S. watch list species.

Source: From PIF Species Assessment Database - RMBO 2003; conservation ratings compiled from PIF database within BCR 18 and rated species selected according to use of shortgrass prairie and shrubland habitats during breeding season and greater then 1% breeding population in BCR.

Table 1.3. Selected natural history and conservation status of eight species of grassland birds in eastern Colorado. Species breeding distribution, observed habitat associations, and approximate timing of nest initiation, fledged young, and fall migration, as well as apparent population trends, are shown. Summarized from species accounts in *Colorado Breeding Bird Atlas* (Kingery 1998) and *The Birds of North America* series[a].

Species	Breeding distribution	Habitat	Territory size	Nesting	Fledging	Migration	Trends
Mountain plover	portions of MT, WY, eastern CO, NM, and OK/TX panhandles	heavily grazed areas in shortgrass prairie, cultivated fields	male = 16 ha; brood = avg. 56 ha, min. 28 ha	April - May	June	July	declining throughout
Burrowing owl	western North America	heavily grazed prairie dog towns	nesting = avg. 4-6 ha; forage = avg. 35-241 ha	April - May	June	Sept. - Oct.	declining throughout
Horned lark	throughout North America, except portions of southeast U.S., Canadian interior, and northwest Pacific coast	heavily grazed areas in prairie, cultivated fields; tend to move into croplands in late June/July	avg 0.7-1.5 ha	April - May	May - June	NA (resident)	generally declining
Cassin's sparrow	from southern High Plains into southwestern U.S. and northern Mexico	open prairie w/scattered shrubs, cacti, or yucca	1.7 – 3.3 ha	May - July	June - July	Aug. - Sept.	declining throughout

…table continued

…table continued

Species	Breeding distribution	Habitat	Territory size	Nesting	Fledging	Migration	Trends
Lark sparrow	central and western North America	open prairie w/ varied structure	up to 6 ha	June	July	Aug.-Oct.	declining throughout
Lark bunting	adjacent to Rocky Mtns. from southern Canada south into NM & TX panhandle	lightly-moderately grazed areas in shortgrass w/ some shrubs	0.5 - 1.0 ha	May - June	June - July	July - Aug.	declining, but variable
Grasshopper sparrow	across U.S. & southern Canada, primarily east of Rocky Mtns.; scattered in Mexico and S. America	lightly grazed prairie, CRP fields	< 2 ha	May - June	June - July	Sept./Oct. (but not well documented)	declining throughout
Western meadowlark	western North America	lightly-moderately grazed areas in short- and mixed-grass prairie and croplands	2-7 ha	May - June	June - July	NA (resident)	declining slightly throughout

[a] *Birds of North America* species accounts: mountain plover (Knopf 1996a), burrowing owl (Haug et al 1993), horned lark (Beason 1995), Cassin's sparrow (Dunning et al. 1999), lark sparrow (Martin and Parrish 2000), lark bunting (Shane 2000), grasshopper sparrow (Vickery 1996), and western meadowlark (Lanyon 1994).

CHAPTER 2

OCCUPANCY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS

INTRODUCTION

Native grasslands have been altered to a greater extent than any other biome in North America (Samson et al. 2004), resulting in the conversion of the once diverse prairie landscape into a collection of homogenous grassland fragments interspersed with agricultural fields (Lomolino et al. 2001, Brockway et al. 2002, Brennan and Kuvlesky 2005). Part of this alteration has been caused by the attempted eradication of the black-tailed prairie dog (*Cynomys ludovicianus*, hereafter simply referred to as prairie dog) which has resulted in extensive declines in both prairie dog numbers and colony acreage (Knopf 1994, Benedict et al. 1996, Miller and Cully 2001, Sidle et al. 2001b). A recent survey of Colorado's shortgrass prairie indicates that prairie dogs occupy approximately 2,554 km^2 (1.94%) of the eastern plains (White et al. 2005) – only 5.3% of current potentially suitable habitat and 2.6% of the species' historic state range (Colorado Division of Wildlife 2003b).

The prairie dog creates large areas of grazed vegetation, bare soil, and burrows which are essential components of breeding habitat for grassland birds such as the mountain plover (*Charadrius montanus,* Knopf 1996b) and the western burrowing owl (*Athene cunicularia hypugaea,* Haug et al. 1993). In addition, grasshoppers and beetles,

the primary food items of grassland birds, require >10% of an area to be bare ground in order to lay eggs (Knopf 1996b), and thus benefit from prairie dog grazing and burrowing activities. Some researchers have suggested that the combination of these effects produces increased avian species occupancy, density, and richness observed on colonized versus uncolonized areas (Agnew et al. 1986, Barko et al. 1999, Smith and Lomolino 2004). The decline of prairie dogs, together with land conversion and grassland homogenization, has possibly resulted in the reduction of some species from the shortgrass prairie ecosystem as suggested by Breeding Bird Survey (BBS) analyses (Knopf 1994, 1996b, Sauer et al. 2003, Smith and Lomolino 2004). Concerns over declines in mountain plover and burrowing owl specifically, and grassland birds as a whole, have spurred the development of conservation plans, such as the *Conservation Plan for Grassland Species in Colorado* (Colorado Division of Wildlife 2003b), which focus on improving our knowledge of the ecology and status of grassland species.

Current and past research of mountain plover in Colorado focus on the species' use of shortgrass prairie habitats, including agricultural fields and prairie dog colonies, for nesting (Knopf and Miller 1994, Shackford and Leslie 1994, Knopf and Rupert 1999, Shackford et al. 1999, Dreitz 2005, Dreitz et al. 2005). While mountain plovers are strongly associated with prairie dog colonies in Montana (Knowles et al. 1982, Olson and Edge 1985, Dinsmore et al. 2003, Dinsmore et al. 2005), the nature of this relationship in Colorado is not yet well understood (Knopf 1996a, Colorado Division of Wildlife 2003b, Dreitz et al. 2005, Dreitz et al. 2006). Preliminary results indicate that prairie dogs maintain suitable plover habitat as compared with surrounding grassland (U.S. Fish and Wildlife Service 1999, Dreitz et al. 2005, Dreitz et al. 2006).

Burrowing owls in Colorado also appear to favor prairie dog colonies (80% of sightings in one 1999 survey, VerCauteren et al. 2001). This habitat preference has been corroborated in other states where researchers have found higher burrowing owl counts on prairie dog colonies than other areas (South Dakota, Agnew et al. 1986, Nebraska, Desmond and Savidge 1996, Oklahoma, Barko et al. 1999, Smith and Lomolino 2004, New Mexico, Arrowood et al. 2001). Burrowing owls have also been highly associated with active prairie dog colonies as compared with inactive colonies (Toombs 1997, Desmond et al. 2000, Sidle et al. 2001a).

Studies have also been conducted investigating the effects of prairie dog colonies on avian assemblages as a whole in shortgrass and mixed-grass prairie (Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004). While some species (e.g., horned larks, *Eremophila alpestris*) were found to be positively associated with prairie dog colonies, others (e.g., Cassin's sparrows, *Aimophila cassinii*, lark buntings, *Calamospiza melanocorys*, and grasshopper sparrows, *Ammodramus savannarum*) appeared to be associated with uncolonized sites (Agnew et al. 1986, Winter et al. 2003, Smith and Lomolino 2004). Mixed results for some species (e.g., response of lark sparrows, *Chondestes grammacus*, and western meadowlarks, *Sturnella neglecta*; Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004) may be due to differences in study area, spatial extent, duration, climatic conditions, and methodologies. Additionally, landscape factors (e.g., grassland habitat area) likely influence avian distributions, and the effect of both small- and large-scale habitat factors should be considered in conjunction with species-specific

perceptual/functional ranges (Orth and Kennedy 2001, Lueders 2002, Valiulis 2003, Cunningham and Johnson 2006, Hamer et al. 2006).

To rigorously investigate habitat and landscape effects on grassland birds, and to inform conservation actions of agencies, attention needs to be paid to the statistical methods employed. Obtaining unbiased estimates of occupancy is important to effectively monitor resource selection, including shifts in habitat use, and extinction and colonization of patches, as well as address issues of species co-occurrence (MacKenzie 2006, MacKenzie et al. 2006). Reliable information is vital if land managers are to make sound management decisions and evaluations, and so that policy makers can make informed decisions on species conservation issues.

Methodologies widely used to estimate grassland bird population parameters have lacked at least one of two important considerations – attention to a probability-based sampling scheme and incorporation of detection probability into population estimates (Nichols 1999, Pollock et al. 2002). Previous surveys of grassland birds, such as the BBS (Sauer et al. 2003), Northern Region Landbird Monitoring Program (NRLMP, Hutto and Young 2002), and others (Hanni 2002, Conway and Simon 2003, Hanni 2003), have employed a "convenience sampling" scheme, where data are collected along roads or trails. Evaluating bias of such estimates is difficult, and problems arise when extrapolating these estimates to larger areas of interest (other than roads). Methods incorporating a probability-based approach, and applicable to large-scale survey projects, have been recently developed. Specifically, a spatially balanced sampling design (Theobald et al. in press) allows for improved coverage of a study area while avoiding some of the drawbacks associated with simple random or systematic sampling schemes.

Bias also arises from failure to detect occupied sampling units and the subsequent failure to adjust the count statistic accordingly (Lancia et al. 1994, Borchers et al. 2002, Thompson 2002, Williams et al. 2002). Recently, methods focused on incorporating detection probability into occupancy estimation have been developed (MacKenzie et al. 2005). Occupancy data indicate the number of sampling units occupied by animals, rather than the number of animals themselves. Occupancy methodology involves visiting each sampling unit multiple times within a time period for which occupancy is considered constant. During each visit, a species is detected with probability p, or not detected with probability $(1-p)$. Occupancy probability (ψ), or the proportion of sites that are occupied, is estimated from the resulting capture history using likelihood-based methodology (Mackenzie et al. 2002).

My objectives were to employ and evaluate spatially balanced sampling and occupancy methodologies for monitoring grassland bird species over large areas and to increase understanding of grassland bird ecology in the shortgrass prairie ecosystem of eastern Colorado. Specifically, I tested predictions concerning variation in occupancy and detection of grassland birds across three habitat strata – prairie dog colonies, native grassland not occupied by prairie dogs (hereafter simply referred to as grassland), and dryland agriculture – as well as predictions concerning the surrounding landscape at multiple spatial scales. I identified the mountain plover and burrowing owl as species of primary interest, for which the design of this study was most influenced. In addition, data were available to estimate occupancy for the following six grassland species: horned lark, Cassin's sparrow, lark sparrow, lark bunting, grasshopper sparrow, and western meadowlark.

STUDY AREA

In Colorado, shortgrass prairie spreads east from the foothills of the southern Rocky Mountains. The study area consisted of all areas (privately and publicly owned) in Colorado located ~48 km east of Interstate 25, excluding lands owned by the Department of Defense (Figure 2.1). This area encompasses approximately 81,200 km^2 in 20 counties and was defined to include most of the shortgrass prairie in Colorado while avoiding urban and ex-urban areas, and high-security areas which could not be accessed.

METHODS

Sampling Design

I determined land cover types within the study area using 30-m vegetation classification data (Colorado Division of Wildlife 2003a) into which I incorporated all available Conservation Reserve Program (CRP), road, and prairie dog colony data using the Geographic Information System (GIS), ArcGIS 9.0. A detailed explanation of all GIS procedures is provided in Appendix I.

The sampling frame consisted of 500-m × 500-m (25 ha) grid cells categorized as prairie dog colony, grassland, or dryland agriculture (Figure 2.1). For each stratum, I chose sample plots from the frame using a spatially balanced sampling tool (Theobald 2004) employing a Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. in press), similar to the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen 2004). Based on the randomly assigned survey order, my field crew and I contacted land owners and lessees by phone or in person in order to obtain access. For those plots where we obtained access, I based final

plot selection and stratum designation on qualitative vegetative assessments, determined in the field, according to the following criteria: 1) surveyed grassland and dryland agricultural plots had 100% coverage of the appropriate cover type, and 2) surveyed prairie dog colony plots had a minimum of 25% coverage by an active or recently inactive prairie dog colony. If the observed vegetative cover did not meet strata criteria, the plot was not surveyed. Plots which included portions of major (paved or graded) roads or active structures were also not surveyed (186 plots).

Field Data Collection

We conducted up to four occupancy surveys of each plot, once in each of four survey periods: 1 May – 16 May, 17 May – 6 June, 7 June – 16 June, and 17 June – 30 June. The distance from the southern border of Colorado to the northern border is approximately 445 km. Because the phenology of avian breeding activity is believed to begin earlier in the south, I chose to survey plots from south to north during each survey period. Morning and evening surveys were primarily conducted between the hours of sunrise and 1100 and between 1830 and sunset, respectively. Surveys were generally not conducted under unacceptable weather conditions which included temperatures above 27° C (~80° F), wind speeds above 6.0 mps (~13.5 mph), and fog or precipitation which reduced visibility to less than 125 m.

Surveys of each plot began at the plot's southeast corner; field observers marked this point with a small flag at the time of the first visit. When navigating to this point, care was taken not to cross or disturb the study plot prior to beginning the survey. All surveys were conducted by either one or two observers using binoculars, Garmin 12

Global Positioning System (GPS) unit, Bushnell rangefinder, declinated compass, field guide, Brunton digital temperature and wind meter, and datasheets. At the start of the survey, time and weather conditions were recorded. Beginning from the southeast corner, the observer walked west along the plot's south boundary approximately 125 m, turned north and walked approximately 375 m, turned west and walked approximately 250 m, and finally turned south and walked approximately 375 m to the plot's south boundary (Figure 2.2). Walking this "transect" ensured the observer was no more than ~125 m from any location in the study plot, an assumed maximum distance for positive species identification. If terrain or other environmental factors required, the observer altered this transect in order to see the entire plot or positively identify birds. Transects were walked slowly with occasional stops such that each survey typically lasted 20-50 minutes. Species observed within the plot boundary were recorded by detection type (visual or auditory observation), and at the end of each survey, time and weather conditions were again recorded.

Covariate Data Collection

During the field season, observers recorded data to characterize each plot, including whether prairie dogs were currently active at colonies. I later identified prairie dog colonies within 2250 m of surveyed plot boundaries using digital aerial photography taken during the field season. I digitized these data in ArcGIS 9.0 and combined the resulting prairie dog colony layer with the baseline 30-m vegetation classification data (Colorado Division of Wildlife 2003a) to obtain percent cover of prairie dog colony and grassland at three spatial scales - a plot plus its 500-m, 1500-m, or 2250-m buffer,

hereafter referred to as landscape 1, landscape 2, and landscape 3, respectively (Appendix I).

Model Set and Selection

I developed *a priori* hypotheses for detection and occupancy probabilities based on existing literature regarding individual species' breeding ecology and vegetation preferences, preliminary results from my pilot study conducted in 2004, and personal communications with biologists familiar with the study area and species, as well as my own personal observations. Detection-related hypotheses examined the effect of plot stratum and time-specific variables (e.g., survey weather conditions, survey effort) on species detection probabilities. Occupancy-related hypotheses examined the effect of plot- and landscape-level habitat variables on species occupancy probabilities.

Exploratory covariate analyses

For all variables of interest, I first examined the available variance and correlation. Initially, I chose 10 visit-specific variables which I thought would have the greatest effect on detection probability: survey date (represented by survey period and day), start time, survey duration, temperature (measured as a survey average and a maximum), wind speed (average and maximum), and cloud cover (average and maximum). Survey duration was similar for the majority of surveys and therefore I did not use it as a covariate. As expected, survey period and day, and average and maximum values of temperature, wind, and cloud cover, were highly correlated (Table 2.1), so only

survey day and average values of weather variables were used as individual covariates in my analyses.

To investigate avian-habitat associations, I wanted to test the effect of the amount of prairie dog colony and grassland in the surrounding landscape on species occupancy probabilities at the three spatial scales defined above. I examined the correlation of the resulting six landscape variables plus three additional plot-level variables: plot northing, prairie dog activity status, and the amount of prairie dog colony inside plot boundaries. As expected, nested variables (e.g., amount of prairie dog colony in the plot and landscapes 1, 2, and 3) were highly correlated (Tables 2.2). Because I expected to model these variables in combination with plot stratum designation, I also examined available variance and correlation of plot- and landscape-level variables in each stratum (Table 2.3). Due to the high correlation of nested variables, I decided to model landscape habitat measures at a single scale within individual models (i.e., no model would include effects of the amount of prairie dog colony in both landscapes 2 and 3). Based on these exploratory results (Tables 2.1-2.3), I selected four visit-specific, four plot-level, and six landscape-level covariates to model detection and occupancy probabilities (Table 2.4).

Modeling detection probabilities

I developed candidate model sets for detection probabilities based on my *a priori* hypotheses for each species (Table 2.5). I modeled *p* as either constant (.), or as a function of survey period (time, t), selected visit-specific covariates (Table 2.4), plot stratum (s), plot northing (north), or an additive or multiplicative combination of these variables.

Because avian behavior differs by breeding activity (e.g., birds are generally less detectable when nesting compared with breeding displays and brood-rearing periods), I predicted that survey date (day) would affect detection probability for all but the most common species (horned lark and western meadowlark). In addition, although a number of species (residents and early migrants) had already begun breeding activities when surveys began in May, several species with later migration schedules were just beginning to arrive. For these species, I hypothesized that day in season may have a nonlinear effect on detection probability and modeled a quadratic term (day + day^2). When modeling mountain plover detection probability, I also modeled a multiplicative interaction of 'day' and the plot-level covariate 'north' (i.e., day × north) to test for an effect of differences in the timing of breeding activity within the study area on detection probability.

For all species, I hypothesized that an increase in survey effort (number of observers) would positively affect detection probability. I was not able to investigate individual observer effect on detection probability due to the large numbers of observers relative to the number of detections per species, yet this is another possible source of variation and should be accounted for whenever possible. I predicted that increases in average survey temperature and wind speed would both negatively affect detection for all species due to a decrease in bird activity and, in the case of wind, the opportunity for auditory detections, especially for smaller sparrow species. In contrast, I predicted that the effect of plot stratum on detection probability would vary by species (Table 2.5). Stratum may affect detection due to visibility differences created by vegetation height and structure coupled with species behavior, the abundance of the species (e.g., fewer

individuals on a plot may lead to lower detection probabilities), or observer expectations (e.g., the expectation that mountain plovers are rarely found in grassland may lead to lower detection probabilities there).

Modeling occupancy probabilities

I developed candidate model sets for occupancy probabilities based on my *a priori* hypotheses for each species (Table 2.6). I modeled ψ as either constant, or as a function of survey period (time), selected plot- and landscape-level covariates including plot stratum (Table 2.4), or an additive or multiplicative combination of these variables. For all species except horned lark (which was detected on virtually all surveyed plots), I predicted that plot stratum would have the greatest effect on species occupancy probabilities, with species' responses based on their respective habitat/vegetation preferences (Chapter 1, Table 1.3). In addition, because climatic differences produce changes in vegetative structure (e.g., grass height) along a north-south gradient in Colorado's shortgrass prairie (National Drought Mitigation Center 2004), I hypothesized that stratum-specific occupancy probabilities, especially on grassland plots, may also differ by plot northing (Table 2.6). This effect would be greatest for species with strong preferences for extremes in grass height including the mountain plover (prefers grass <7.5 cm in height) and grasshopper sparrow (often associated with tallgrass prairie).

For all species, I hypothesized that grassland birds preferentially select breeding grounds (plots) found within landscapes containing more native grassland (Hamer et al. 2006). Thus, I predicted a positive effect of grassland landscape variables on occupancy probabilities for all species (Table 2.6). Hypotheses related to the effect of prairie dog

colony area on occupancy probability were species-specific based on individual species' breeding ecology. For the mountain plover and burrowing owl, I predicted a positive effect of increasing amounts of prairie dog colony in the landscape (at all spatial scales) on occupancy probabilities. This hypothesis was based on species' habitat preferences, including association with prairie dog complexes, suggested from previous research (Dechant et al. 2003, Dreitz et al. 2005). In contrast, a number of grassland birds, sparrow species in particular, often utilize areas of taller grasses within the shortgrass prairie as well as landscapes with varied structure. Additionally, I considered the relationship between species' home-range/breeding territory size and my plot area (25 ha). Based on these factors, I predicted a negative effect of increasing amounts of prairie dog colony, both within plot boundaries and the surrounding landscape, on occupancy probabilities of Cassin's sparrow, lark sparrow, lark bunting, and grasshopper sparrow (Table 2.6).

For burrowing owls, I hypothesized that the presence of prairie dogs would also have a strong positive effect on occupancy probability (Table 2.6). I did not consider activity status as an important covariate for other study species.

Analysis

I estimated plot-level detection (p) and occupancy (ψ) probabilities from models as defined above using the occupancy estimation data type in program MARK (White and Burnham 1999). Before running the models, I tested for goodness-of–fit using the parametric bootstrap procedure in program MARK (White and Burnham 1999). Data were simulated under the most general (global) model, without individual covariates, for

each species. Due to the low numbers of detections on grassland and dryland agriculture plots, the global model for burrowing owl was $p_t \psi_s$. For the remaining seven species, this was model $p_{s \times t} \psi_s$.

I proceeded to run candidate model sets which incorporated selected variables of interest into detection and occupancy probabilities for individual species. The number of models among species model sets varied according to species-specific hypotheses (Tables 2.5 and 2.6) as well as the degree of model uncertainty, with greater uncertainty necessitating a larger number of models. I used Akaike's Information Criterion with small sample size correction (AIC_c) to rank models (Burnham and Anderson 2002).

RESULTS

I surveyed a total of 282 plots, consisting of 90 in prairie dog colonies, 100 in grassland, and 92 in dryland agriculture (Table 2.7 and Figure 2.3). Reasons that plots were not surveyed are summarized in Table 2.8 and Figure 2.3. The results of the goodness-of-fit simulations indicated no evidence of overdispersion for any of the species (Table 2.9). For some species, the effect of plot stratum on p and/or the effect of stratum-specific covariates on ψ could not be estimated due to low numbers of detections in certain stratum (Table 2.10). Model selection results provide ranking of detection and occupancy probabilities in final candidate model sets (Tables 2.11 - 2.18). Below I detail results for each species.

Mountain Plover

Throughout the survey season, mountain plovers were detected on a total of 59 plots – 40 prairie dog colony plots, 7 grassland, and 12 dryland agriculture (Table 2.10). Models in which detection probability (p) was modeled as constant (.) consistently ranked higher than models where p was allowed to vary by stratum (s), survey effort (eff), average survey temperature (temp), or day of visit (day, Table 2.11).

Models incorporating stratum, the proportion of landscape 1 covered by prairie dog colony (pdL1), and the proportion of landscape 3 covered by grassland (grsL3) into occupancy (ψ) estimates consistently ranked high ($\Delta AIC_c < 2.50$, Table 2.11). These three covariates had the highest cumulative AIC_c weights ($\Sigma\, w_i$), totaling 1.00, 0.80, and 0.87, respectively (Table 2.19). In addition, modeling a stratum-specific effect of the variable 'grsL3' (i.e., s × grsL3) on ψ was always selected over models assuming a common effect (s + grsL3). Other top models (those with $w_i \geq 0.01$) included an effect of the proportion of landscape 2 covered by prairie dog colony (pdL2) as well as grassland (grsL2) on ψ, although cumulative AIC_c weights for these model parameters were low (0.19 and 0.10, respectively, Tables 2.11 and 2.19).

Based on minimum AIC_c, model $p_{.}\ \psi_{s \times grsL3+pdL1}$ ($w_i = 0.11$) was selected as the best approximating model of mountain plover detection and occupancy probabilities (Table 2.11). The covariate point estimate ($\hat{\beta}$) from the top model suggested a positive relationship ($\hat{\beta}$ = 3.89, 95% confidence interval [CI] = 1.32, 6.46) between mountain plover occupancy and the variable 'pdL1', regardless of plot strata (Table 2.20 and Figure 2.4). However, the effect of the variable 'grsL3' on mountain plover occupancy varied by stratum, showing a positive effect for prairie dog colony ($\hat{\beta}$ = 4.25, 95% CI =

1.20, 7.30) and dryland agriculture plots ($\hat{\beta}$ = 2.73, 95% CI = -0.81, 6.26) and some evidence for a negative effect for grassland plots ($\hat{\beta}$ = -2.35, 95% CI = -7.13, 2.42; Table 2.20 and Figure 2.5).

Burrowing Owl

Throughout the survey season, burrowing owls were detected on a total of 59 plots – 58 prairie dog colony plots, 1 grassland, and 0 dryland agriculture (Table 2.10). Due to low numbers of detections on grassland and agriculture plots, models in which *p* varied by stratum were not possible. Models in which *p* was modeled as constant (.) consistently ranked higher than models where *p* was allowed to vary by survey period (time, t) or by time-varying covariates such as survey effort (eff), day of visit (day and day^2), or average survey temperature (temp, Table 2.12).

Models incorporating stratum (s), presence of active prairie dogs on the plot (act), and proportion of prairie dog colony in the surrounding landscapes (pdL1, pdL2, and pdL3) into occupancy estimates consistently ranked high ($\Delta AIC_c \leq 3.00$, Table 2.12). Both ψ_s and ψ_{act} had cumulative AIC_c weights of 1.00 (Table 2.21). Among prairie dog colony landscape variables, models incorporating ψ_{pdL3} ($\Sigma\, w_i = 0.36$) were always selected over similar models substituting ψ_{pdL2} or ψ_{pdL1} ($\Sigma\, w_i = 0.34$ and 0.27, respectively, Tables 2.12 and 2.21). Some top models also included an effect of the proportion of grassland in the surrounding landscapes (grsL1, grsL2, and grsL3) on ψ, although cumulative AIC_c weights were low ($\Sigma\, w_i = 0.09$, 0.11, and 0.18, respectively, Tables 2.12 and 2.21).

Based on minimum AIC_c, model $p_{.}\ \psi_{s+act+pdL3}$ ($w_i = 0.08$) was selected as the best approximating model of burrowing owl detection and occupancy probabilities (Table 2.12). The covariate point estimate ($\hat{\beta}$) from the top model suggested a positive relationship ($\hat{\beta}$ = 2.59, 95% CI = 1.07, 4.12) between burrowing owl occupancy and the activity status of the prairie dog colony (Table 2.22 and Figure 2.6). However, the amount of area covered by prairie dog colony in the surrounding landscape (pdL1, pdL2, and pdL3) had a negative effect (from highest-ranking model, $\hat{\beta}$ = -5.18, 95% CI = -9.37, -0.99) on burrowing owl occupancy, regardless of plot stratum (Table 2.22 and Figure 2.6).

Horned Lark

Throughout the survey season, horned larks were detected on a total of 281 plots – 90 prairie dogs colony plots, 99 grassland, and 92 dryland agriculture (Table 2.10). Based on raw detections alone, horned larks occurred virtually everywhere we surveyed, leaving no variance to be explained and, therefore, no need to run complex occupancy models. This conclusion is further supported by the highest-ranking model, $p_{.}\ \psi_{.}$, which had an AIC_c weight of 0.49 (Table 2.13).

Cassin's Sparrow

Throughout the survey season, Cassin's sparrows were detected on a total of 106 plots – 50 prairie dog colony plots, 47 grassland, and 9 dryland agriculture (Table 2.10). Models in which p was modeled as an additive combination of stratum (s) and several time-varying covariates (day + day^2 + eff + wind) consistently ranked higher than models

where p was constant (.) or varied by stratum or visit-specific covariates alone (Table 2.14).

Models incorporating a multiplicative effect of stratum (s) and the proportion of grassland in the surrounding landscapes (grsL1, grsL2, and grsL3) into occupancy estimates were always selected over models with a common effect of grassland (e.g., s + grsL3) and models lacking the effect all together (Table 2.14). In addition, models with ψ_{grsL3} ranked higher and had a much higher cumulative AIC_c weight ($\Sigma\, w_i = 0.61$) than models incorporating ψ_{grsL1} or ψ_{grsL2} ($\Sigma\, w_i = 0.06$ and 0.33, respectively, Table 2.23). Some top models also included an effect of the proportion of area covered by prairie dog colony in the plot (pdP, $\Sigma\, w_i = 0.23$) or in landscape 2 (pdL2, $\Sigma\, w_i = 0.17$) on occupancy estimation although cumulative AIC_c weights for these model parameters were relatively low (Tables 2.14 and 2.23).

Based on minimum AIC_c, model $p_{s+day+day^2+eff+wind}\, \psi_{s \times grsL3}$ ($w_i = 0.31$) was selected as the best approximating model of Cassin's sparrow detection and occupancy probabilities (Table 2.14). Covariate point estimates ($\hat{\beta}_i$'s) from the top model suggested a positive relationship between Cassin's sparrow occupancy and the variable 'grsL3', regardless of plot stratum, although two of three 95% CI's overlap zero (Table 2.24 and Figure 2.7). This effect was stronger on grassland and dryland agriculture plots, as represented by the steeper slopes (Figure 2.7).

Lark Sparrow

Throughout the survey season, lark sparrows were detected on a total of 65 plots – 26 prairie dog colony plots, 35 grassland, and 4 dryland agriculture (Table 2.10). Models

in which p was modeled as an additive combination of stratum (s) and time-varying covariates (day + temp + wind) consistently ranked higher than models where p was constant (.) or varied by stratum or visit-specific covariates alone (Table 2.15).

Models incorporating stratum (s) and the proportion of grassland in the surrounding landscapes (grsL1, grsL2, and grsL3) into occupancy estimates consistently ranked high among models with the same detection probability function (Table 2.15). In addition, models incorporating a multiplicative interaction between the grassland landscape variable and plot stratum were always selected over models with a common grassland effect. However, when modeling the interaction, the covariate could not be applied to dryland agriculture due to the low numbers of detections in that stratum (Table 2.10). Models with ψ_{grsL3} ranked higher and had a higher cumulative AIC_c weight ($\Sigma\, w_i$ = 0.41) than models incorporating ψ_{grsL1} or ψ_{grsL2} ($\Sigma\, w_i$ = 0.12 and 0.26, respectively, Table 2.25). Some top models also included a weak effect of the proportion of area covered by prairie dog colony in the plot (pdP, $\Sigma\, w_i$ = 0.24) and in the surrounding landscapes (pdL1 $\Sigma\, w_i$ = 0.14, pdL2 $\Sigma\, w_i$ = 0.02, pdL3 $\Sigma\, w_i$ = 0.02) on occupancy estimation (Tables 2.15 and 2.25).

Based on minimum AIC_c, model $p_{s+day+temp+wind}\, \psi_{s \times grsL3}$ (w_i = 0.11) was selected as the best approximating model of lark sparrow detection and occupancy probabilities (Table 2.15). Covariate point estimates ($\hat{\beta}_i$'s) from the top model suggested that the effect of the variable 'grsL3' on lark sparrow occupancy varied by stratum, showing some evidence for a positive effect for grassland plots ($\hat{\beta}$ = 2.56, 95% CI = -1.76, 6.88) and a negative effect for prairie dog colony plots ($\hat{\beta}$ = -2.64, 95% CI = -5.24, -0.03, Table 2.26 and Figure 2.8). This relationship was also revealed when substituting

‘grsL3’ with smaller-scale landscape variables (grsL1 and grsL2) and allowing a stratum-specific effect (Table 2.26).

Lark Bunting

Throughout the survey season, lark buntings were detected on a total of 217 plots – 65 prairie dog colony plots, 89 grassland, and 63 dryland agriculture (Table 2.10). Models in which *p* was modeled as an additive combination of stratum (s) and time-varying covariates (day + day^2 + effort + wind) consistently ranked higher than models where *p* was constant (.) or varied by stratum or visit-specific covariates alone (Table 2.16).

Models incorporating stratum (s) and the proportion of landscape 3 covered by prairie dog colony (pdL3) into occupancy estimates consistently ranked high (top 10 models, Table 2.16). These two covariates had the highest cumulative AIC$_c$ weights, totaling 1.00 and 0.96, respectively (Table 2.27). In addition, some top models also included an effect of the proportion of area covered by grassland in landscape 3 (grsL3) on occupancy probability, although the cumulative AIC$_c$ weight of this covariate was low ($\Sigma\, w_i = 0.26$, Tables 2.16 and 2.27).

Based on minimum AIC$_c$, model $p_{s+day+day^2+eff+wind}\, \psi_{s+pdL3}$ ($w_i = 0.20$) was selected as the best approximating model of lark bunting detection and occupancy probabilities (Table 2.16). The covariate point estimate ($\hat{\beta}$) from the top model suggested a strong negative relationship ($\hat{\beta}$ = -8.59, 95% CI = -13.21, -3.97) between lark bunting occupancy and the variable ‘pdL3’, regardless of plot stratum (Table 2.28 and Figure 2.9).

Grasshopper Sparrow

Throughout the survey season, grasshopper sparrows were detected on a total of 103 plots – 21 prairie dog colony plots, 30 grassland, and 52 dryland agriculture (Table 2.10). Models in which p was allowed to vary by an additive combination of time-varying covariates (day + day^2 + temp) were always selected for among models having the same occupancy probability function (Table 2.17).

Models incorporating stratum (s), the proportion of landscapes 2 and 3 covered by prairie dog colony (pdL2 and pdL3, respectively), and the proportion of landscape 3 covered by grassland (grsL3) into occupancy estimates consistently ranked high (top nine models, $\Delta AIC_c < 3.40$, Table 2.17). These four covariates also had the highest cumulative AIC_c weights, totaling 1.00, 0.33, 0.67, and 0.91, respectively (Table 2.29). In addition, modeling a stratum-specific effect of the variable 'grsL3' on ψ was always selected over models assuming a common grassland effect. Other top models substituted an effect of the proportion of landscape 2 covered by grassland (grsL2) on ψ, although the cumulative AIC_c weight for this model parameter was very low ($\Sigma\, w_i = 0.07$, Tables 2.17 and 2.29).

Based on minimum AIC_c, model $p_{day+day^2+temp}\, \psi_{s \times grsL3+pdL3}$ ($w_i = 0.21$) was selected as the best approximating model of grasshopper sparrow detection and occupancy probabilities (Table 2.17). The covariate point estimate ($\hat{\beta}$) from the top model suggested a strong negative relationship ($\hat{\beta}$ = -12.20, 95% CI = -18.62, -5.79) between grasshopper sparrow occupancy and the variable 'pdL3', regardless of plot stratum (Table 2.30 and Figure 2.10). However, the effect of the variable 'grsL3' on grasshopper

sparrow occupancy varied by stratum, showing a negative effect for prairie dog colony ($\hat{\beta}$ = -4.69, 95% CI = -7.85, -1.54) and dryland agriculture plots ($\hat{\beta}$ = -1.16, 95% CI = -3.69, 1.38) but virtually no effect for grassland plots ($\hat{\beta}$ = -0.06, 95% CI = -3.17, 3.04; Table 2.30 and Figure 2.11).

Western Meadowlark

Throughout the survey season, western meadowlarks were detected on a total of 271 plots – 85 prairie dog colony plots, 97 grassland, and 89 dryland agriculture (Table 2.10). Models in which *p* was allowed to vary by an additive combination of stratum (s) and time-varying covariates (eff + temp) consistently ranked higher than models in which *p* was constant (.) or varied by stratum (s) or visit-specific covariates alone or reduced additive models (Table 2.18).

Among models with the same detection probability function, models in which occupancy was constant were always selected over models incorporating stratum, habitat covariates, or an additive combination of these (Table 2.18). However, the cumulative AIC_c weight of the model parameter $\psi_.$ was only 0.28 (Table 2.31). Other top models allowed ψ to vary with the proportion of prairie dog colony and/or grassland in progressively larger landscapes (pdL1 Σw_i = 0.19 > pdL2 Σw_i = 0.09 > pdL3 Σw_i = 0.08, grsL1 Σw_i =0.21 > grsL2 Σw_i =0.09 > grsL3 Σw_i =0.08, Tables 2.18 and 2.31). The low cumulative AIC_c weights of model parameters likely indicate a high level of model uncertainty. Western meadowlark were quite common across all three strata (Table 2.10), and, therefore, meadowlark occupancy had little variance to be explained.

Based on minimum AIC_c, model $p_{s+eff+temp}\,\psi_{.}$ ($w_i = 0.22$) was selected as the best approximating model of western meadowlark detection and occupancy probabilities (Table 2.18). Covariate point estimates ($\hat{\beta}_i$'s) from other top models indicated that habitat covariates had only weak effects on western meadowlark occupancy, with 95% CI's always overlapping zero (Table 2.32).

DISCUSSION

My results suggest that occupancy methods are feasible for monitoring most grassland bird species over large areas. My study design resulted in sample sizes large enough for estimation for focal species and allows extrapolation of survey results to the larger area of interest (eastern Colorado). Using these methods, the effect of a number of time-varying and habitat variables on detection and occupancy probabilities was able to be estimated for most species. Field protocols were easy to teach and implement even for novice observers.

My results also suggest that probability-based sampling schemes can be used effectively in large-scale studies and demonstrate that statistical rigor need not be sacrificed to obtain large sample sizes. In addition, my study was the first avian-specific study to demonstrate the feasibility of a spatially balanced sampling design across such a large study area encompassing both public and private lands. I believe that this spatially balanced approach is useful for those instances when good coverage of the study area is desired, including studies investigating spatial variation of a response variable. The RRQRR algorithm allowed me to construct a survey order of plots that allowed substitution when I encountered conditions in the field that did not allow surveying to

occur. In my study, this proved especially useful when large numbers of selected prairie dog plots did not meet stratum criteria.

Effects on Detection Probabilities

For three species (mountain plover, burrowing owl, and horned lark), the results of my analyses indicated that detection could be modeled as being constant over time and space, in contrast to my predicted results (Tables 2.7). However, these results are time- and area-specific, and differ from my pilot study results. Contrary results may be due to improved training of observers, or differences in environmental conditions, spatial coverage, or avian behavior among study years and/or areas.

For the remaining five species (Cassin's sparrow, lark sparrow, lark bunting, grasshopper sparrow, and western meadowlark), my models suggest that detection probability was a function of plot stratum, day of visit, number of observers, and/or weather conditions during the survey. Model results generally support my *a priori* hypotheses, with a few exceptions. Plot stratum appeared to influence detection probability for three of the four species for which I had hypothesized the effect, and also influenced lark bunting detection probability. The effect of stratum generally coincided with my predicted results except for the western meadowlark for which detection probability on dryland agriculture plots was higher than on grassland plots. Although my hypotheses were primarily based on my pilot study results and species' vegetation preferences, these contrary results may be due to differences among study years, areas, and spatial extents.

A nonlinear effect of day (day + day^2) was in top models for Cassin's sparrow, lark bunting, and grasshopper sparrow, but not lark sparrow (contrary to my prediction) although there was evidence of a negative linear effect of day. Survey effort appeared to influence detection probability for Cassin's sparrow, lark bunting, and western meadowlark, consistently exhibiting a positive effect, as predicted. One or two weather covariates were included in top models for all species for which detection probability could not be considered constant. Across these species, the effect of temperature on detection was typically negative, as I hypothesized, with the exception of lark sparrow detection probability which increased with increasing temperature. The effect of wind speed on detection was consistently negative, supporting my *a priori* hypotheses.

Effects on Occupancy Probabilities

Plot-level effects

Plot-level habitat variables exhibited a strong effect on occupancy probability for a number of species. Plot stratum had the most important effect on ψ, as reflected in AIC_c weights equal to 1.00, for all but the most common species. Occupancy model results for three species (mountain plover, burrowing owl, and Cassin's sparrow) suggest a positive association with prairie dog colony at the plot level (Table 2.33). This association was strong for mountain plovers and burrowing owls, for which 95% CI's for ψ_{pd} did not overlap those of ψ_{grs} or ψ_{ag} (Table 2.33). These results correspond to those of Winter et al. (2003), whose study in shortgrass prairie in southeastern Colorado and southwestern Kansas found both species only on prairie dog colonies. Similar results have also been found for the burrowing owl in shortgrass and mixed-grass prairie in

South Dakota (Agnew et al. 1986) and the Oklahoma panhandle (Barko et al. 1999, Smith and Lomolino 2004). In contrast, Barko et al. (1999) only found mountain plover on uncolonized shortgrass, however their sample size was 10 sites.

Confidence intervals for estimated Cassin's sparrow occupancy probabilities on prairie dog colony and grassland plots slightly overlapped, although neither overlapped the 95% CI for ψ_{ag} (Table 2.33). This result differs somewhat from results of Smith and Lomolino (2004) which suggest that Cassin's sparrows were more highly associated with uncolonized sites. Lark sparrows and lark buntings were positively associated with grassland at the plot level (although 95% CI's overlapped with those of ψ_{pd} and/or ψ_{ag}), and grasshopper sparrows exhibited a strong positive association with dryland agriculture (Table 2.33). These results correspond to those of previous studies (Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004) which suggest a positive association with uncolonized sites for these species.

Although plot stratum did influence occupancy probability overall for most study species as I predicted, the direction of the effect was not always as I hypothesized. While pilot study results indicated that mountain plover occupancy was comparable on prairie dog colony and dryland agriculture plots, the results of my analyses suggest that occupancy was much higher on prairie dog colony plots than other strata (Table 2.33). Although estimated stratum-specific occupancy probabilities supported my *a priori* hypotheses for the burrowing owl and lark bunting, those for Cassin's sparrow, lark sparrow, and grasshopper sparrow differed somewhat from my predicted results and those for western meadowlark indicated no difference in occupancy among strata (Tables 2.8 and 2.33).

As previously mentioned, contrary results may be due to different habitat conditions resulting from differences in study year and/or area. In particular, yearly differences in the amount of seasonal precipitation and spring/summer temperatures typically result in significant differences in vegetation height and cover in eastern Colorado. In years with less precipitation and higher temperatures, vegetation height and cover will be less across all habitat types; in wetter, cooler years, the opposite is true. Prairie dog colony attributes considered favorable for some species (e.g., lower vegetation height, concentrated prey species, structural diversity in the landscape) result from differences in vegetation between colonized and uncolonized areas which may be most dramatic during summer (i.e., the breeding/growing season). In drought years, these effects would not be as great, while differences between colonized and uncolonized areas may be much more striking in wet years (Barko et al. 1999, Winter et al. 2003).

In general, both the winter and spring/summer of 2005 were wetter and cooler than that of 2004 (HCT pers. obs.), potentially resulting in increased vegetation height and cover in grassland and taller, more lush wheat in dryland agriculture fields. Thus, prairie dog colonies may have been more important to species preferring low grass height and bare ground, such as the mountain plover. In addition, divergent results may be caused by the effects of differences in the landscapes surrounding surveyed plots, including landscape composition and configuration, as well as patch shape and size as it extends outside plot boundaries (e.g., the size of the individual prairie dog colony or agricultural field).

In addition to a stratum effect, burrowing owl occupancy probability was also greatly influenced by the activity status of prairie dog colonies, showing a strong

association with active colonies (~82% of surveyed prairie dog colony plots) at the plot level (Table 2.33 and Figure 2.6). This result supports my hypothesis as well as previous research conducted in Colorado (Toombs 1997).

Landscape-level effects

Landscape variables, specifically the proportion of area covered by prairie dog colonies and/or grassland, also exhibited a strong effect on occupancy probabilities for six of my eight study species. Only horned lark and western meadowlark occupancy probabilities appeared independent of habitat (plot- and landscape-level) effects, although there was a fair amount of model uncertainty among meadowlark occupancy models.

With these exceptions, the highest-ranking model for all species included a combination of variables at plot- and landscape-scales, corresponding with results of previous grassland bird studies conducted in mixed-grass and tallgrass prairies (Cunningham and Johnson 2006, Winter et al. 2006). Results of my analyses also indicated that, among landscape variables, habitat characteristics at my largest spatial scale (landscape 3, a 2,500 ha area) had the greatest effect on occupancy probabilities, even for species with relatively small breeding home ranges (<6 ha) including Cassin's, lark, and grasshopper sparrows and lark bunting. Species' perceptual/functional ranges may be larger than typically considered and may be independent of body size (Cunningham and Johnson 2006), although caution should be used when interpreting these results due to the known correlation of nested habitat variables (Tables 2.4 and 2.5). A mechanistic explanation for the importance of landscape habitat variables would appear to support the hypothesis that species habitat selection is often constrained by

broad-scale (landscape-level) requirements which act as a filter for local (plot-level) habitat requirements (Poff 1997, Hamer et al. 2006).

The relationship between occupancy and large-scale habitat characteristics, as well as the magnitude of the effect, can typically be related to species breeding ecology and habitat preferences, including vegetation height, cover, and species composition (Chapter 1, Table 1.3). Mountain plover occupancy was closely tied to plot stratum as well as the amount of prairie dog colony in the immediate surrounding landscape (landscape 1, 225 ha), with preference for landscapes with more area covered by prairie dog colony (Figure 2.4). This area corresponds well with the average plover brood-rearing home range (56.6 ha ± 21.5 SE) as observed by Knopf and Rupert (1996) and Dreitz et al. (2005). Occupancy probability was also affected by the amount of grassland habitat in landscape 3, although the direction and magnitude of the effect varied based on the plot-level habitat type being used. This stratum-specific response (Figure 2.5) may be indicative of species that use one habitat type for nesting (e.g., open, bare ground found on prairie dog colonies and dryland agriculture fields) and another for brood-rearing (e.g., mixture of habitats, including taller vegetation found in grassland and fields of dryland wheat). While previous studies suggest such a relationship may exist for the mountain plover (Shackford and Leslie 1994, Knopf and Rupert 1996, Shackford 1996), no such movement patterns were observed for plovers in a more recent study (Dreitz et al. 2005).

In addition, while average minimum convex polygon home-range sizes were similar to those observed by Knopf and Rupert (1996), Dreitz et al. (2005) found that home-range size varied widely according to the size of the prairie dog colony (or complex) used for nesting and that plovers which nested on prairie dog colonies did not

move their broods to other habitat types. Although these results may be specific to habitat conditions during the study year (categorized as wet, Dreitz et al. 2005), they also suggest that additional landscape factors such as patch size and connectivity are important to plover breeding-site selection and should be considered in future analyses.

While burrowing owl occupancy probability was primarily affected by plot stratum and activity status of the prairie dog colony, owl occupancy was also negatively affected by the amount of prairie dog colony in the surrounding landscape – an effect which was most significant for larger landscapes (landscapes 2 and 3, Table 2.12 and Figure 2.6). This result did not support my *a priori* hypotheses. While this result may seem counterintuitive, the negative association, particularly at larger spatial scales, may indicate a need for habitat heterogeneity, reflecting greater prey availability (Orth and Kennedy 2001).

Results for lark bunting and grasshopper sparrow suggested a negative relationship between occupancy and the amount of prairie dog colony in the landscape (Figures 2.9 and 2.10). These results support my *a priori* hypotheses and are indicative of species' habitat preferences and the inverse relationship between habitat variables (i.e., as the proportion of prairie dog colony in an area increases, the amount of other habitat types such as grassland decreases). Larger-scale landscapes covered by large amounts of prairie dog colony could also translate to less varied landscapes, or landscapes with larger amounts of shorter vegetation and bare ground. A negative relationship between species occupancy probability and the amount of prairie dog colony in the landscape may reflect species requirements for less-heavily grazed prairie or for more-varied landscape structure. This may be especially true for those species for which a plot already

encompassed numerous breeding territories and may in itself reflect a landscape-level variable.

Cassin's sparrow, lark sparrow, and grasshopper sparrow exhibited preference for the amount (more or less) of grassland at my largest spatial scale (Figures 2.7, 2.8, and 2.11). The results of my analyses indicated a positive relationship between Cassin's sparrow occupancy and the amount of grassland in the landscape, reflecting a preference for native prairie. However, the magnitude of this effect varied with plot stratum, reflecting only a weak influence for Cassin's sparrows breeding on prairie dog colony plots (Figure 2.7). The effect of the amount of grassland in the landscape on lark sparrow occupancy also varied by stratum, exhibiting a positive effect for grassland plots but a negative effect for prairie dog plots (Figure 2.8). I did not expect this stratum-specific response. Because an increase in the amount of grassland reflects a decrease in other habitat types, this result may indicate a relationship between prairie dog colonies and other habitat types not investigated in my analyses.

In contrast, grasshopper sparrow occupancy decreased across all strata as the amount of grassland in the surrounding landscape increased (Figure 2.11). This result did not support my *a priori* hypotheses and suggests that, based on the sparrow's preference for taller, denser grass cover, more grassland does not necessarily translate to more-varied grassland (with regard to grass height) in Colorado. Specifically, the amount of grassland in the landscape is negatively correlated with the amount of other habitat types including CRP. This is also contrary to results of Fletcher and Koford (2002) which suggest a positive association with the amount of grassland in the landscape, although

differences in study area habitats (shortgrass versus tallgrass prairie) may prevent a valid comparison.

For most species, both plot- and landscape-level features are important in determining patterns of grassland bird occupancy. If landscape factors are not considered, apparent avian-habitat relationships may be confounded by potential effects of differences in the landscapes surrounding plots, making comparisons with future study results less useful (Rotenberry and Knick 1999). Little information exists on the effects of landscape factors on Colorado's grassland birds, as the majority of studies examining avian-landscape associations have been conducted in mixed-grass and tallgrass prairies in the Midwest. Future studies are needed in Colorado's shortgrass prairie to corroborate (or contradict) my results. Although my analyses focused on the effect of landscape composition on avian occupancy, future studies should also investigate the potential effects of landscape configuration including patch size and shape and habitat arrangement within the landscape.

Limitations on Inference

Caution should be used when interpreting model results with respect to landscape habitat variables due to correlations of nested variables. Inference is also limited by the short time span of my study. A single-year study cannot consider the changing habitat conditions in eastern Colorado which result from fluctuations in precipitation and temperature. Replication and longer-term studies are desirable to obtain additional information on species-habitat associations.

In addition, extrapolation of my study results to all of eastern Colorado is limited by the proportion of plots that I could not include in my sampling frame. For example, I was not able to survey 188 prairie dog colony plots due to either my inability to contact plot landowners or lessees (i.e., no contact) or because access was denied (Table 2.8). In addition, I did not survey 106 prairie dog plots because stratum criteria were not met (i.e., the plot had <25% coverage by prairie dog colony). Thus, extrapolation of my study results is limited to only ~50% of prairie dog colony habitat in eastern Colorado. This problem of limited inference could be lessened in future studies by decreasing the number of plots not surveyed. This could be achieved by allowing for additional time to contact landowners and lessees, and, in the case of prairie dog habitat specifically, improving prairie dog location data or limiting data used to only the most recent (e.g., collected within the previous 2-3 years).

Results from my study will be useful in the planning of future studies (Chapter 4). Estimated stratum-specific detection and occupancy probabilities (Table 2.34) can be used as a starting point for biologists when optimizing occupancy study design (MacKenzie and Royle 2005). Sample size calculations based on my pilot study data using these optimization methods allowed me to obtain a sufficient number of detections for my focal species (mountain plover and burrowing owl) as well as for a number of other grassland birds. These same methods can be applied to different focal species by adjusting the sampling frame to include additional habitats (strata) or landscape features based on individual species ecology.

LITERATURE CITED

Agnew, W., D. W. Uresk, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. Journal of Range Management 39:135-139.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Barko, V. A., J. H. Shaw, and D. M. Leslie. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwestern Naturalist 44:484-489.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies - mammals. Pages 149-166 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C, USA.

Borchers, D. L., S. T. Buckland, and W. Zucchini. 2002. Estimating Animal Abundance – Closed Populations. Springer, New York, New York, USA.

Brennan, L. A., and W. P. Kuvlesky. 2005. North American grassland birds: An unfolding conservation crisis? Journal of Wildlife Management 69:1-13.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: Initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference - A Practical Information-Theoretic Approach. Springer, New York, New York, USA.

Colorado Division of Wildlife. 2003a. Colorado Vegetation Classification Project. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Colorado Division of Wildlife. 2003b. Conservation Plan for Grassland Species in Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Conway, C. J., and J. C. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501-511.

Cunningham, M. A., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Applications 16:1062-1075.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, P. A. Rabie, and B. R. Euliss. 2003. Effects of management practices on grassland birds: Burrowing Owl. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: A 7 year analysis. Journal of Wildlife Management 64:1067-1075.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2003. Annual survival and population estimates of mountain plovers in southern Phillips County, Montana. Ecological Applications 13:1013-1026.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2005. Mountain plover population responses to black-tailed prairie dogs in Montana. Journal of Wildlife Management 69:1546-1553.

Dreitz, V. J. 2005. Resolving conflicts of Mountain Plovers (*Charadrius montanus*) breeding on agricultural lands in Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado, USA.

Dreitz, V. J., P. M. Lukacs, and F. L. Knopf. 2006. Monitoring low density avian populations: an example using Mountain Plover. Condor 108:700-706.

Dreitz, V. J., M. B. Wunder, and F. L. Knopf. 2005. Movements and home ranges of Mountain Plovers raising broods in three Colorado landscapes. Wilson Bulletin 117:128-132.

Fletcher, R. J., and R. R. Koford. 2002. Habitat and landscape associations of breeding birds in native and restored grasslands. Journal of Wildlife Management 66:1011-1022.

Hamer, T. L., C. H. Flather, and B. R. Noon. 2006. Factors associated with grassland bird species richness: the relative roles of grassland area, landscape structure, and prey. Landscape Ecology 21:569-583.

Hanni, D. 2002. A comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Hanni, D. 2003. Section-based monitoring of breeding birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington, D.C, USA.

Hutto, R. L., and J. S. Young. 2002. Regional landbird monitoring: Perspectives from the northern Rocky Mountains. Wildlife Society Bulletin 30:738-750.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

Knopf, F. L. 1996a. Mountain Plover (*Charadrius montanus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 211. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C, USA.

Knopf, F. L. 1996b. Prairie legacies - birds. Pages 135-148 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C, USA.

Knopf, F. L., and B. J. Miller. 1994. *Charadrius montanus* - montane, grassland, or bare-ground plover? Auk 111:504-506.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

Knopf, F. L., and J. R. Rupert. 1999. The use of crop fields by breeding Mountain Plovers. Studies in Avian Biology 19:81-86.

Knowles, C. J., C. J. Stoner, and S. P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland, USA.

Lomolino, M. V., R. Channell, D. R. Perault, and G. A. Smith. 2001. Downsizing nature: Anthropogenic dwarfing of species and ecosystems. Pages 223-243 *in* J. L. Lockwood and M. L. McKinney, editors. Biotic Homogenization. Kluwer, New York, New York, USA.

Lueders, A. S. 2002. Influences of vegetative structure on avian populations under grazing regimes in North Dakota mixed-grass prairie. Thesis, Colorado State University, Fort Collins, Colorado, USA.

MacKenzie, D. I. 2006. Modeling the probability of resource use: The effect of, and dealing with, detecting a species imperfectly. Journal of Wildlife Management 70:367-374.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier Inc., San Diego, California, USA.

MacKenzie, D. I., J. D. Nichols, N. Sutton, K. Kawanishi, and L. L. Bailey. 2005. Improving inferences in population studies of rare species that are detected imperfectly. Ecology 86:1101-1113.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42:1105–1114.

Miller, S. D., and J. F. Cully. 2001. Conservation of black-tailed prairie dogs (*Cynomys ludovicianus*). Journal of Mammalogy 82:889-893.

National Drought Mitigation Center. 2004. The Drought Monitor. University of Nebraska-Lincoln, Lincoln, Nebraska, USA. Online at <http://drought.unl.edu>.

Nichols, J. D. 1999. Monitoring is not enough: On the need for a model-based approach to migratory bird management. *In* R. Bonney, D. N. Pashley, R. J. Cooper, and L. Niles, editors. Strategies for Bird Conservation: The Partners in Flight Planning Process. Cornell Lab of Ornithology, Cape May, New Jersey, USA. Online at <http://birds.cornell.edu/pifcapemay>.

Olson, S. L., and D. Edge. 1985. Nest site selection by mountain plovers in northcentral Montana. Journal of Range Management 38:280-282.

Orth, P. B., and P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by burrowing owls (*Athene cunicularia hypugaea*) in northeastern Colorado? Canadian Journal of Zoology-Revue Canadienne de Zoologie 79:1038-1045.

Poff, N. L. 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. Journal of the North American Benthological Society 16:391-409.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105-119.

Rotenberry, J. T., and S. T. Knick. 1999. Multiscale habitat associations of the Sage Sparrow: Implications for conservation biology. Studies in Avian Biology 19:95-103.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin 32:6-15.

Sauer, J. R., J. E. Fallon, and R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for bird conservation regions. Journal of Wildlife Management 67:372-389.

Shackford, J. S. 1996. Studies and observations of Mountain Plover in the Great Plains. Page 27 *in* D. P. Coffin, editor. Summary report - shortgrass prairie/Mountain Plover workshop. Denver Audubon Society, Aurora, Colorado, USA.

Shackford, J. S., and D. M. Leslie. 1994. Mountain Plover breeding activity on cultivated fields. Federal aid project E-26-1. Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma, USA.

Shackford, J. S., D. M. Leslie, and W. D. Harden. 1999. Range-wide use of cultivated fields by Mountain Plovers during the breeding season. Journal of Field Ornithology 70:114-120.

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, D. N. Svingen. 2001a. Occurrence of Burrowing Owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research. 35:316-321.

Sidle, J. G., D. H. Johnson, and B. R. Euliss. 2001b. Estimated areal extent of colonies of black-tailed prairie dogs in the northern Great Plains. Journal of Mammalogy 82:928-936.

Smith, G. A., and M. V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138:592-602.

Stapp, P. 1998. A reevaluation of the role of prairie dogs in Great Plains grasslands. Conservation Biology 12:1253-1259.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Theobald, D. T. 2004. GIS - GRTS: Spatially balanced sampling tool. ArcGIS v.9.0 extension. Language: Python. Operating System: Windows XP. Software Application ESRI ArcGIS v.9.0. Colorado State University, Fort Collins, Colorado, USA.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

Thompson, W. L. 2002. Towards reliable bird surveys: Accounting for individuals present but not detected. Auk 119:18-25.

Toombs, T. P. 1997. Burrowing owl nest-site selection in relation to soil texture and prairie dog colony attributes. Thesis, Colorado State University, Fort Collins, Colorado, USA.

U.S. Fish and Wildlife Service. 1999. Proposed threatened status for the Mountain Plover. Pages 7587-7601 *in* Federal Register Volume 64, Number 30. Washington D.C., USA.

Valiulis, J. 2003. The use of continuous and categorical measures of landscape structure in predicting biotic response: An example using grassland birds. Thesis, Colorado State University, Fort Collins, Colorado, USA.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46, Supplement, 120-138.

White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265-272.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Vertebrate Populations. Academic Press, San Diego, California, USA.

Winter, M., D. H. Johnson, J. A. Shaffer, T. M. Donovan, and W. D. Svedarsky. 2006. Patch size and landscape effects on density and nesting success of grassland birds. Journal of Wildlife Management 70:158-172.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2002. Vegetation of prairie dog colonies and non-colonized shortgrass prairie. Journal of Range Management 55:502-508.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2003. Breeding season avifauna of prairie dog colonies and non-colonized areas in shortgrass prairie. Transactions of the Kansas Academy of Science 106:129-138.

Table 2.1. Correlation matrix for 10 visit-specific variables recorded during 1074 occupancy surveys of 282 plots in eastern Colorado in 2005. 'SurvPer' is the survey period (1-4) in which the visit occurred. 'Day' is an assigned value (1-59) representing date of visit within the survey season (2 May – 29 Jun), where 'Day' = 1 indicates 2 May 2005. 'StartTime' is the time of day at which the survey began. 'SurvDur' is the survey duration in minutes. 'AvgTemp' is the mean of recorded start and end temperatures, measured in °C. 'MaxTemp' is the higher of the recorded start or end temperatures. 'AvgWind' is the mean of recorded start and end wind speeds, measured in meters per second. 'MaxWind' is the greater of the recorded start or end wind speeds. 'AvgCloud' is the mean of recorded start and end cloud cover, estimated visually and coded as 1-4 representing 0-25%, 26-50%, 51-75% and >75% cover, respectively. 'MaxCloud' is the greater of the recorded start or end cloud cover.

	Surv Per	Day	Start Time	Surv Dur	Avg Temp	Max Temp	Avg Wind	Max Wind	Avg Cloud	Max Cloud
SurvPer	1.00									
Day	0.97	1.00								
StartTime	0.06	0.05	1.00							
SurvDur	-0.27	-0.28	0.00	1.00						
AvgTemp	0.43	0.40	0.41	-0.08	1.00					
MaxTemp	0.42	0.39	0.41	-0.05	0.99	1.00				
AvgWind	-0.08	-0.07	0.25	-0.01	0.17	0.16	1.00			
MaxWind	-0.08	-0.07	0.27	0.01	0.17	0.16	0.97	1.00		
AvgCloud	-0.13	-0.12	0.17	0.03	-0.15	-0.15	0.15	0.15	1.00	
MaxCloud	-0.13	-0.12	0.19	0.03	-0.14	-0.14	0.16	0.16	0.98	1.00

Table 2.2. Correlation matrix for 9 plot-level variables representing habitat characteristics of 282 occupancy plots in eastern Colorado in 2005. 'North' is the latitude of the plot center as represented by North American Datum 1927, Universal Transverse Mercator Zone 13 North. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony. 'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland.

	north	actPlot	pdP	pdL1	pdL2	pdL3	grsL1	grsL2	grsL3
north	1.00								
actPlot	-0.22	1.00							
pdP	-0.26	0.81	1.00						
pdL1	-0.26	0.72	0.93	1.00					
pdL2	-0.25	0.57	0.80	0.92	1.00				
pdL3	-0.26	0.52	0.73	0.86	0.97	1.00			
grsL1	-0.01	-0.24	-0.31	-0.35	-0.32	-0.28	1.00		
grsL2	-0.07	-0.08	-0.10	-0.13	-0.16	-0.14	0.92	1.00	
grsL3	-0.09	-0.04	-0.04	-0.06	-0.08	-0.08	0.87	0.98	1.00

Table 2.3. Correlation matrices for nine plot-level variables representing habitat characteristics of occupancy plots in three strata – (a) prairie dog colony, (b) grassland, and (c) dryland agriculture – in eastern Colorado in 2005. 'North' is the latitude of the plot center as represented by North American Datum 1927, Universal Transverse Mercator Zone 13 North. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS; 'pdP' equals zero for all grassland and dryland agriculture plots. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony. 'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland.

(a) prairie dog colony

	north	actPlot	pdP	pdL1	pdL2	pdL3	grsL1	grsL2	grsL3
north	1.00								
actPlot	-0.06	1.00							
pdP	-0.19	-0.07	1.00						
pdL1	-0.20	-0.14	0.68	1.00					
pdL2	-0.12	-0.23	0.40	0.84	1.00				
pdL3	-0.12	-0.23	0.33	0.75	0.96	1.00			
grsL1	0.31	-0.03	-0.53	-0.77	-0.66	-0.59	1.00		
grsL2	0.35	-0.04	-0.25	-0.40	-0.48	-0.47	0.80	1.00	
grsL3	0.35	-0.07	-0.17	-0.24	-0.32	-0.35	0.67	0.96	1.00

…table continued

…table continued

(b) grassland

	north	actPlot	pdP	pdL1	pdL2	pdL3	grsL1	grsL2	grsL3
north	1.00								
actPlot	-0.10	1.00							
pdP	N/A	N/A	1.00						
pdL1	0.13	0.25	N/A	1.00					
pdL2	-0.13	0.05	N/A	0.49	1.00				
pdL3	-0.18	-0.01	N/A	0.31	0.86	1.00			
grsL1	-0.34	-0.03	N/A	-0.43	-0.22	-0.12	1.00		
grsL2	-0.29	0.04	N/A	-0.27	-0.28	-0.18	0.83	1.00	
grsL3	-0.28	0.04	N/A	-0.24	-0.23	-0.21	0.76	0.96	1.00

(c) dryland agriculture

	north	actPlot	pdP	pdL1	pdL2	pdL3	grsL1	grsL2	grsL3
north	1.00								
actPlot	0.09	1.00							
pdP	N/A	N/A	1.00						
pdL1	-0.09	-0.02	N/A	1.00					
pdL2	-0.29	-0.04	N/A	0.57	1.00				
pdL3	-0.32	-0.04	N/A	0.64	0.94	1.00			
grsL1	-0.04	-0.08	N/A	0.43	0.32	0.32	1.00		
grsL2	-0.12	-0.13	N/A	0.40	0.30	0.31	0.83	1.00	
grsL3	-0.17	-0.12	N/A	0.40	0.35	0.35	0.75	0.96	1.00

Table 2.4. Variables used as covariates in models estimating detection (*p)* and occupancy (ψ) probabilities of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown. Values of habitat variables are presented for all plots combined as well as for prairie dog colony (PD), grassland (Grass), and dryland agriculture (Ag) plots separately. In variable definitions, "landscape 1" refers to a plot plus its 500-m buffer, "landscape 2" refers to a plot plus its 1500-m buffer, and "landscape 3" refers to a plot plus its 2250-m buffer.

P	ψ	Visit-specific variable	Definition	Value range	Mean ± SD
x		day[a]	Assigned value representing date of visit within the survey season (2 May – 29 Jun), where 'day' = 1 indicates 2 May 2005	1 – 59[a]	34 ± 17.5
x		eff	Indicator variable representing survey effort. Visits 1, 3, and 4 had a single observer and visit 2 had 2 observers	N/A	N/A
x		temp	Average temperature during each plot visit, calculated as the mean of recorded start and end temperatures measured in degrees Celsius	0.65 – 30.70	18.04 ± 5.97
x		wind	Average wind speed during each plot visit, calculated as the mean of recorded start and end wind speeds measured in meters per second	0.00 – 7.20	2.01 ± 1.55

…table continued

…table continued

p	ψ	Plot-level variable	Definition	Value range	Mean ± SD
x	x	s	Categorical designation of plot stratum – prairie dog colony, grassland, or dryland agriculture	N/A	N/A
x	x	north	Latitude of plot center as represented by North American Datum 1927, Universal Transverse Mercator Zone 13 North	4113849 - 4539969	4284713 ± 114641.7
	x	act	Indicator variable representing prairie dog activity within a plot, assessed throughout the survey season	N/A	N/A
	x	pdP	Proportion of plot occupied by prairie dog colony for all plots and for prairie dog colony plots alone	All plots = 0.00 – 1.00 PD plots = 0.30 – 1.00	All plots = 0.26 ± 0.39 PD plots = 0.81 ± 0.20
		Landscape-level variable			
	x	pdL1	Proportion of landscape 1 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.07 – 1.00 Grass plots = 0.00 – 0.15 Ag plots = 0.00 – 0.15	All plots = 0.17 ± 0.28 PD plots = 0.53 ± 0.24 Grass plots = 0.01 ± 0.03 Ag plots = 0.00 ± 0.02

…table continued

…table continued

p	*ψ*	Landscape-level variable	Definition	Value range	Mean ± SD
	x	pdL2	Proportion of landscape 2 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 0.67 PD plots = 0.02 – 0.67 Grass plots = 0.00 – 0.16 Ag plots = 0.00 – 0.19	All plots = 0.09 ± 0.15 PD plots = 0.26 ± 0.17 Grass plots = 0.02 ± 0.03 Ag plots = 0.01 ± 0.03
	x	pdL3	Proportion of landscape 3 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 0.57 PD plots = 0.01 – 0.57 Grass plots = 0.00 – 0.19 Ag plots = 0.00 – 0.22	All plots = 0.07 ± 0.12 PD plots = 0.19 ± 0.14 Grass plots = 0.02 ± 0.03 Ag plots = 0.01 ± 0.03
	x	grsL1	Proportion of landscape 1 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.00 – 0.92 Grass plots = 0.67 – 1.00 Ag plots = 0.00 – 0.77	All plots = 0.49 ± 0.38 PD plots = 0.34 ± 0.22 Grass plots = 0.94 ± 0.08 Ag plots = 0.14 ± 0.17
	x	grsL2	Proportion of landscape 2 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.14 – 0.97 Grass plots = 0.47 – 1.00 Ag plots = 0.00 – 0.94	All plots = 0.57 ± 0.31 PD plots = 0.53 ± 0.21 Grass plots = 0.88 ± 0.13 Ag plots = 0.26 ± 0.19

…table continued

…table continued

p	*ψ*	Landscape-level variable	Definition	Value range	Mean ± SD
	x	grsL3	Proportion of landscape 3 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.16 – 0.96 Grass plots = 0.40 – 1.00 Ag plots = 0.00 – 0.91	All plots = 0.58 ± 0.29 PD plots = 0.57 ± 0.21 Grass plots = 0.85 ± 0.14 Ag plots = 0.29 ± 0.18

[a] The variable 'day^2' was also calculated as the square of its respective 'day' value (resulting value range = 1-3481, mean ± SD = 1469 ± 1107) and included in some species models to test for a nonlinear effect of day in season on species detection probability.

Table 2.5. Predicted results of covariate-modeled detection probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific detection probabilities. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species detection probability. Explanation and coding of model parameters are provided in Table 2.4.

	Species							
Visit-specific covariate	Mountain plover	Burrowing owl	Horned lark	Cassin's sparrow	Lark sparrow	Lark bunting	Grasshopper sparrow	Western meadowlark
day	+	+	NE	+	+	+	+	NE
day^{2}[a]	NE	NE	NE	−	−	−	−	NE
eff	+	+	+	+	+	+	+	+
temp	−	−	−	−	−	−	−	−
wind	−	−	−	−	−	−	−	−
Plot-level covariate								
s	pd = ag > grass	pd > grass = ag	NE	pd = grass > ag	pd = grass > ag	NE	NE	pd > grass > ag
north[b]	+	NE	NE	NE	NE	NE	NE	NE

[a] The variable 'day^{2}' was always modeled in an additive combination with day (i.e., day + day^{2}) to test for a nonlinear effect of day in season on species detection probability.
[b] The variable 'north' was always modeled as a multiplicative interaction with day (i.e., day × north) to test for an effect of differences in the timing of breeding activities across the study area on mountain plover occupancy probability.

Table 2.6. Predicted results of covariate-modeled occupancy probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific occupancy probabilities. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species occupancy probability. Explanation and coding of model parameters are provided in Table 2.4.

	Species							
Plot-level variable	Mountain plover	Burrowing owl	Horned lark[a]	Cassin's sparrow	Lark sparrow	Lark bunting	Grasshopper sparrow	Western meadowlark
s	pd = ag >> grass	pd >> grass = ag	NE	pd = grass > ag	pd = grass > ag	grass > pd > ag	grass > ag > pd	grass > pd > ag
north[b]	−	NE	NE	NE	NE	NE	+	NE
act	NE	+	NE	NE	NE	NE	NE	NE
pdP	+	+	NE	−	−	−	−	NE
Landscape-level variable								
pdL1	+	+	NE	−	−	−	−	NE
pdL2	+	+	NE	−	−	−	−	NE
pdL3	+	+	NE	−	−	−	−	NE
grsL1	+	+	NE	+	+	+	+	+
grsL2	+	+	NE	+	+	+	+	+
grsL3	+	+	NE	+	+	+	+	+

[a] Because horned larks were detected on virtually all plots surveyed, occupancy probability was not expected to vary with any plot- or landscape-level variables.
[b] The variable 'north' was always modeled as a multiplicative interaction with stratum (i.e., s × north) to test for an effect of differences in vegetative structure (e.g., grass height) resulting from climatic differences across the study area on species occupancy probabilities.

Table 2.7. Number of plots surveyed for grassland avifauna in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado during four survey periods in 2005. Survey periods were 1 May – 16 May (period 1), 17 May – 6 June (period 2), 7 June – 16 June (period 3), and 17 June – 30 June (period 4).

	Stratum			
Survey period	Prairie dog	Grassland	Dryland ag	Total
1	51	96	85	232
2	87	100	91	278
3	90	100	92	282
4	90	100	92	282

Table 2.8. Reasons and respective numbers of plots which I did not survey in 2005. Numbers are shown for three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado. "No contact" indicates plots for which I was unable to contact landowners or lessees.

	Stratum			
Reason not surveyed	Prairie dog	Grassland	Dryland ag	Total
No contact	140	113	120	373
Access denied	48	34	30	112
Strata criteria not met	106	18	17	141

Table 2.9. Results of goodness-of-fit tests using the parametric bootstrap procedure in program MARK for eight grassland bird species in eastern Colorado in 2005. Data were simulated under the most general (global) model, without individual covariates, for each species. Due to the low numbers of detections on grassland and dryland agriculture plots, the global model for burrowing owl was $p_t \psi_s$. For the remaining seven species, this was model $p_{s \times t} \psi_s$. The probability of observing a deviance larger than the observed value (p [deviance]) and estimates of the overdispersion parameter ($\hat{c}$) are shown. Values of $\hat{c}$ were calculated using both deviance (observed deviance ÷ mean of simulated deviances) and $\hat{c}$ (observed $\hat{c}$ ÷ mean of simulated $\hat{c}$) methods.

Species	p (deviance)	$\hat{c}$ (deviance method)	$\hat{c}$ ($\hat{c}$ method)
Mountain plover	0.67	< 1	< 1
Burrowing owl	0.95	< 1	< 1
Horned lark	0.54	< 1	< 1
Cassin's sparrow	0.59	< 1	< 1
Lark sparrow	0.64	< 1	< 1
Lark bunting	0.91	< 1	< 1
Grasshopper sparrow	0.48	1.00	< 1
Western meadowlark	0.89	< 1	< 1

Table 2.10. Number (and %) of plots on which eight grassland bird species were detected in eastern Colorado in 2005. Raw detections are shown for three strata – prairie dog colony (90 plots surveyed), grassland (100 plots), and dryland agriculture (92 plots).

	Stratum			
Species	Prairie dog colony	Grassland	Dryland ag	Total
Mountain plover	40 (44.4)	7 (7.0)	12 (13.0)	59 (20.9)
Burrowing owl	58 (64.4)	1 (1.0)	0 (0.0)	59 (20.9)
Horned lark	90 (100.0)	99 (99.0)	92 (100.0)	281 (99.6)
Cassin's sparrow	50 (55.6)	47 (47.0)	9 (9.8)	106 (37.6)
Lark sparrow	26 (28.9)	35 (35.0)	4 (4.3)	65 (23.0)
Lark bunting	65 (72.2)	89 (89.0)	63 (68.5)	217 (77.0)
Grasshopper sparrow	21 (23.3)	30 (30.0)	52 (56.5)	103 (36.5)
Western meadowlark	85 (94.4)	97 (97.0)	89 (96.7)	271 (96.1)

Table 2.11. Model selection results for 70 models of detection probability and occupancy for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{.}\ \psi_{s\times grsL3+pdL1}$	534.09	0.00	0.11	1.00	8	517.56
$p_{.}\ \psi_{s+pdL1+grsL3}$	534.55	0.46	0.09	0.80	6	522.24
$p_{s}\ \psi_{s\times grsL3+pdL1}$	534.62	0.53	0.09	0.77	10	513.80
$p_{s}\ \psi_{s+pdL1+grsL3}$	534.91	0.82	0.07	0.66	8	518.39
$p_{eff}\ \psi_{s\times grsL3+pdL1}$	535.39	1.30	0.06	0.52	9	516.73
$p_{.}\ \psi_{s\times grsL3+pdL2}$	535.62	1.53	0.05	0.46	8	519.10
$p_{eff}\ \psi_{s+pdL1+grsL3}$	535.82	1.73	0.05	0.42	7	521.41
$p_{s+eff}\ \psi_{s\times grsL3+pdL1}$	536.00	1.91	0.04	0.38	11	513.02
$p_{.}\ \psi_{s+pdL2+grsL3}$	536.04	1.95	0.04	0.38	6	523.73
$p_{temp}\ \psi_{s\times grsL3+pdL1}$	536.11	2.02	0.04	0.36	9	517.45
$p_{day}\ \psi_{s\times grsL3+pdL1}$	536.15	2.06	0.04	0.36	9	517.49
$p_{s}\ \psi_{s\times grsL3+pdL2}$	536.16	2.07	0.04	0.36	10	515.35
$p_{s+eff}\ \psi_{s+pdL1+grsL3}$	536.27	2.18	0.04	0.34	9	517.60
$p_{s}\ \psi_{s+pdL2+grsL3}$	536.48	2.39	0.03	0.30	8	519.96
$p_{temp}\ \psi_{s+pdL1+grsL3}$	536.56	2.47	0.03	0.29	7	522.15
$p_{day}\ \psi_{s+pdL1+grsL3}$	536.57	2.47	0.03	0.29	7	522.16
$p_{.}\ \psi_{s+pdL1+grsL2}$	536.80	2.71	0.03	0.26	6	524.50
$p_{s}\ \psi_{s+pdL1+grsL2}$	537.33	3.24	0.02	0.20	8	520.81
$p_{.}\ \psi_{s\times grsL2+pdL1}$	537.53	3.44	0.02	0.18	8	521.00
$p_{s}\ \psi_{s\times grsL2+pdL1}$	538.17	4.08	0.01	0.13	10	517.35
$p_{.}\ \psi_{s+pdL2+grsL2}$	538.28	4.19	0.01	0.12	6	525.98
$p_{.}\ \psi_{s+pdL1}$	540.31	6.22	0.00	0.04	5	530.10
$p_{day\times north}\ \psi_{s\times grsL3+pdL1}$	540.42	6.33	0.00	0.04	11	517.44
$p_{s}\ \psi_{s+pdL1}$	541.11	7.02	0.00	0.03	7	526.70

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{.}\ \psi_{s+pdL1+grsL1}$	541.50	7.41	0.00	0.02	6	529.19
$p_{eff}\ \psi_{s+pdL1}$	541.57	7.48	0.00	0.02	6	529.27
$p_{.}\ \psi_{s+pdL2}$	541.86	7.77	0.00	0.02	5	531.64
$p_{.}\ \psi_{s+grsL3}$	542.01	7.92	0.00	0.02	5	531.79
$p_{s}\ \psi_{s+pdL1+grsL1}$	542.28	8.19	0.00	0.02	8	525.75
$p_{s+eff}\ \psi_{s+pdL1}$	542.44	8.35	0.00	0.02	8	525.91
$p_{.}\ \psi_{s\times grsL3}$	542.44	8.35	0.00	0.02	7	528.03
$p_{.}\ \psi_{s+pdP}$	542.77	8.68	0.00	0.01	5	532.55
$p_{s}\ \psi_{s+grsL3}$	542.77	8.68	0.00	0.01	7	528.37
$p_{s}\ \psi_{s+pdL2}$	542.81	8.72	0.00	0.01	7	528.40
$p_{.}\ \psi_{s+pdL3}$	543.03	8.94	0.00	0.01	5	532.81
$p_{eff}\ \psi_{s+pdL2}$	543.13	9.04	0.00	0.01	6	530.82
$p_{s}\ \psi_{s+pdP}$	543.54	9.45	0.00	0.01	7	529.13
$p_{.}\ \psi_{s\times pdL1}$	543.72	9.63	0.00	0.01	7	529.31
$p_{s}\ \psi_{s+pdL3}$	544.08	9.99	0.00	0.01	7	529.67
$p_{eff}\ \psi_{s+pdP}$	544.08	9.99	0.00	0.01	6	531.78
$p_{eff}\ \psi_{s+pdL3}$	544.31	10.21	0.00	0.01	6	532.00
$p_{s}\ \psi_{s\times pdL1}$	544.55	10.46	0.00	0.01	9	525.89
$p_{.}\ \psi_{s+grsL2}$	545.27	11.18	0.00	0.00	5	535.05
$p_{.}\ \psi_{s}$	545.37	11.28	0.00	0.00	4	537.23
$p_{s}\ \psi_{s+grsL2}$	546.14	12.04	0.00	0.00	7	531.73
$p_{s}\ \psi_{s}$	546.20	12.11	0.00	0.00	6	533.90
$p_{day\times north}\ \psi_{s+pdL1}$	546.30	12.21	0.00	0.00	8	529.77
$p_{.}\ \psi_{s+grsL1}$	546.43	12.34	0.00	0.00	5	536.22
$p_{eff}\ \psi_{s}$	546.63	12.53	0.00	0.00	5	536.41
$p_{s}\ \psi_{s+grsL1}$	547.27	13.17	0.00	0.00	7	532.86
$p_{.}\ \psi_{s+north}$	547.31	13.21	0.00	0.00	5	537.09
$p_{temp}\ \psi_{s}$	547.31	13.22	0.00	0.00	5	537.10
$p_{day}\ \psi_{s}$	547.40	13.31	0.00	0.00	5	537.18

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+eff}\ \psi_s$	547.52	13.43	0.00	0.00	7	533.11
$p_{s+day}\ \psi_s$	548.26	14.17	0.00	0.00	7	533.85
$p_{day+eff}\ \psi_s$	548.46	14.37	0.00	0.00	6	536.15
$p_{eff+temp}\ \psi_s$	548.51	14.42	0.00	0.00	6	536.20
$p_{s+eff+temp}\ \psi_s$	549.27	15.18	0.00	0.00	8	532.75
$p_{s+day+eff}\ \psi_s$	549.38	15.29	0.00	0.00	8	532.86
$p_t\ \psi_s$	549.96	15.87	0.00	0.00	7	535.55
$p_{s+day+day^2}\ \psi_s$	550.37	16.28	0.00	0.00	8	533.84
$p_{s+t}\ \psi_s$	550.95	16.86	0.00	0.00	9	532.29
$p_{day\times north}\ \psi_s$	551.47	17.38	0.00	0.00	7	537.06
$p_{s+day\times north}\ \psi_s$	552.01	17.92	0.00	0.00	9	533.35
$p_{s\times t}\ \psi_s$	556.68	22.59	0.00	0.00	15	524.88
$p_s\ \psi_.$	562.67	28.58	0.00	0.00	4	554.52
$p_{s+t}\ \psi_.$	567.40	33.31	0.00	0.00	7	552.99
$p_{s\times t}\ \psi_.$	574.33	40.24	0.00	0.00	13	546.97
$p_.\ \psi_.$	587.54	53.45	0.00	0.00	2	583.49
$p_t\ \psi_.$	591.74	57.65	0.00	0.00	5	581.52

Table 2.12. Model selection results for 54 models of detection probability and occupancy for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p.\ \psi_{s+act+pdL3}$	394.19	0.00	0.08	1.00	6	381.89
$p.\ \psi_{s+act+pdL2}$	394.61	0.42	0.07	0.81	6	382.31
$p_{eff}\ \psi_{s+act+pdL3}$	394.77	0.58	0.06	0.75	7	380.36
$p.\ \psi_{s+act+pdL1}$	395.01	0.82	0.05	0.66	6	382.71
$p.\ \psi_{s+act+pdL3+grsL3}$	395.06	0.87	0.05	0.65	7	380.65
$p_{eff}\ \psi_{s+act+pdL2}$	395.19	1.00	0.05	0.61	7	380.78
$p.\ \psi_{s+act+pdL1+grsL1}$	395.23	1.04	0.05	0.59	7	380.83
$p.\ \psi_{s+act+pdL2+grsL2}$	395.38	1.18	0.05	0.55	7	380.97
$p_{eff}\ \psi_{s+act+pdL1}$	395.59	1.39	0.04	0.50	7	381.18
$p_{eff}\ \psi_{s+act+pdL3+grsL3}$	395.64	1.45	0.04	0.48	8	379.12
$p.\ \psi_{s+act+pdL2+grsL3}$	395.76	1.57	0.04	0.46	7	381.35
$p_{eff}\ \psi_{s+act+pdL1+grsL1}$	395.84	1.64	0.04	0.44	8	379.31
$p_{day+eff}\ \psi_{s+act+pdL3}$	395.92	1.72	0.03	0.42	8	379.39
$p_{eff}\ \psi_{s+act+pdL2+grsL2}$	395.97	1.78	0.03	0.41	8	379.44
$p_{day}\ \psi_{s+act+pdL3}$	396.06	1.87	0.03	0.39	7	381.65
$p_{temp}\ \psi_{s+act+pdL3}$	396.13	1.94	0.03	0.38	7	381.72
$p_{day+eff}\ \psi_{s+act+pdL2}$	396.34	2.14	0.03	0.34	8	379.81
$p_{eff}\ \psi_{s+act+pdL2+grsL3}$	396.35	2.16	0.03	0.34	8	379.82
$p_{day}\ \psi_{s+act+pdL2}$	396.48	2.29	0.03	0.32	7	382.07
$p.\ \psi_{s+act+pdL1+grsL2}$	396.53	2.34	0.03	0.31	7	382.13
$p_{temp}\ \psi_{s+act+pdL2}$	396.56	2.37	0.03	0.31	7	382.15
$p.\ \psi_{s+act+pdL1+grsL3}$	396.70	2.51	0.02	0.29	7	382.29
$p_{day}\ \psi_{s+act+pdL1}$	396.88	2.68	0.02	0.26	7	382.47

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{temp}\ \psi_{s+act+pdL1}$	396.97	2.78	0.02	0.25	7	382.56
$p_{day+\ day^2}\ \psi_{s+act+pdL3}$	397.20	3.00	0.02	0.22	8	380.67
$p_{.}\ \psi_{s+act}$	398.37	4.17	0.01	0.12	5	388.15
$p_{eff}\ \psi_{s+act}$	398.97	4.77	0.01	0.09	6	386.66
$p_{day+eff}\ \psi_{s+act}$	399.99	5.79	0.00	0.06	7	385.58
$p_{day}\ \psi_{s+act}$	400.16	5.97	0.00	0.05	6	387.86
$p_{.}\ \psi_{s+pdL3}$	405.28	11.08	0.00	0.00	5	395.06
$p_{.}\ \psi_{s+pdL2}$	405.66	11.47	0.00	0.00	5	395.45
$p_{eff}\ \psi_{s+pdL3}$	405.88	11.69	0.00	0.00	6	393.57
$p_{eff}\ \psi_{s+pdL2}$	406.27	12.08	0.00	0.00	6	393.97
$p_{day+eff}\ \psi_{s+pdL3}$	407.05	12.85	0.00	0.00	7	392.64
$p_{day}\ \psi_{s+pdL3}$	407.14	12.95	0.00	0.00	6	394.84
$p_{day+eff}\ \psi_{s+pdL2}$	407.45	13.26	0.00	0.00	7	393.04
$p_{day}\ \psi_{s+pdL2}$	407.53	13.34	0.00	0.00	6	395.23
$p_{.}\ \psi_{s+pdL1}$	407.96	13.77	0.00	0.00	5	397.75
$p_{eff}\ \psi_{s+pdL1}$	408.58	14.38	0.00	0.00	6	396.27
$p_{day+eff}\ \psi_{s+pdL1}$	409.74	15.54	0.00	0.00	7	395.33
$p_{day}\ \psi_{s+pdL1}$	409.83	15.63	0.00	0.00	6	397.52
$p_{.}\ \psi_{s+pdP}$	413.43	19.24	0.00	0.00	5	403.22
$p_{.}\ \psi_{s}$	413.74	19.54	0.00	0.00	4	405.59
$p_{eff}\ \psi_{s+pdP}$	414.03	19.83	0.00	0.00	6	401.72
$p_{eff}\ \psi_{s}$	414.38	20.18	0.00	0.00	5	404.16
$p_{day+eff}\ \psi_{s+pdP}$	415.15	20.95	0.00	0.00	7	400.74
$p_{day}\ \psi_{s+pdP}$	415.28	21.09	0.00	0.00	6	402.97
$p_{day+eff}\ \psi_{s}$	415.41	21.22	0.00	0.00	6	403.11
$p_{day}\ \psi_{s}$	415.53	21.34	0.00	0.00	5	405.31
$p_{temp}\ \psi_{s}$	415.67	21.47	0.00	0.00	5	405.45
$p_{day+\ day^2}\ \psi_{s}$	416.81	22.62	0.00	0.00	6	404.51
$p_{t}\ \psi_{s}$	417.66	23.47	0.00	0.00	7	403.25
$p_{.}\ \psi_{.}$	572.79	178.60	0.00	0.00	2	568.75
$p_{t}\ \psi_{.}$	576.08	181.89	0.00	0.00	5	565.86

Table 2.13. Model selection results for 10 models of detection probability and occupancy for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{.}\ \psi_{.}$	325.62	0.00	0.49	1.00	2	321.57
$p_s\ \psi_{.}$	327.52	1.90	0.19	0.39	4	319.38
$p_{.}\ \psi_s$	327.65	2.03	0.18	0.36	4	319.51
$p_s\ \psi_s$	329.63	4.02	0.07	0.13	6	317.33
$p_t\ \psi_{.}$	330.31	4.69	0.05	0.10	5	320.09
$p_t\ \psi_s$	332.43	6.82	0.02	0.03	7	318.02
$p_{s+t}\ \psi_{.}$	332.47	6.85	0.02	0.03	7	318.06
$p_{s+t}\ \psi_s$	334.66	9.05	0.01	0.01	9	316.00
$p_{s\times t}\ \psi_{.}$	341.73	16.12	0.00	0.00	13	314.38
$p_{s\times t}\ \psi_s$	344.13	18.51	0.00	0.00	15	312.32

Table 2.14. Model selection results for 50 models of detection probability and occupancy for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3}$	797.40	0.00	0.31	1.00	13	770.04
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL2}$	798.63	1.23	0.17	0.54	13	771.27
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3+pdP}$	798.96	1.56	0.14	0.46	14	769.38
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3+pdL2}$	799.47	2.07	0.11	0.36	14	769.90
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL2+pdP}$	800.20	2.81	0.08	0.25	14	770.63
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL2+pdL2}$	800.61	3.21	0.06	0.20	14	771.04
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1}$	801.58	4.18	0.04	0.12	13	774.22
$p_{s+day+eff+wind}\ \psi_{s\times grsL3}$	802.49	5.10	0.02	0.08	12	777.33
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1+pdP}$	803.22	5.82	0.02	0.05	14	773.64
$p_{s+day+eff+wind}\ \psi_{s\times grsL2}$	803.73	6.33	0.01	0.04	12	778.57
$p_{s+t}\ \psi_{s\times grsL3}$	803.73	6.34	0.01	0.04	12	778.57
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL3}$	803.89	6.50	0.01	0.04	11	780.92
$p_{s+t}\ \psi_{s\times grsL2}$	804.86	7.46	0.01	0.02	12	779.70
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL2}$	805.78	8.38	0.00	0.02	11	782.80
$p_{s+day+eff+wind}\ \psi_{s\times grsL1}$	806.67	9.27	0.00	0.01	12	781.51
$p_{s+t}\ \psi_{s+grsL3}$	809.98	12.59	0.00	0.00	10	789.17
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL1}$	811.34	13.94	0.00	0.00	11	788.36
$p_{s+t}\ \psi_{s+grsL2}$	811.96	14.56	0.00	0.00	10	791.15
$p_{s+day+day^2+eff+wind}\ \psi_{s}$	814.37	16.97	0.00	0.00	10	793.55
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdP}$	816.01	18.61	0.00	0.00	11	793.03
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL2}$	816.49	19.09	0.00	0.00	11	793.51
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL3}$	816.50	19.10	0.00	0.00	11	793.52
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL1}$	816.50	19.10	0.00	0.00	11	793.52
$p_{s+day+eff+wind}\ \psi_{s}$	819.52	22.12	0.00	0.00	9	800.86

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+eff+temp+wind}\ \psi_s$	820.60	23.21	0.00	0.00	10	799.79
$p_{s+t}\ \psi_s$	820.88	23.48	0.00	0.00	9	802.21
$p_{s+t}\ \psi_{s+pdP}$	822.63	25.23	0.00	0.00	10	801.82
$p_{s+t}\ \psi_{s+pdL2}$	822.97	25.57	0.00	0.00	10	802.16
$p_{s+t}\ \psi_{s+pdL3}$	822.99	25.59	0.00	0.00	10	802.17
$p_{s+t}\ \psi_{s+pdL1}$	823.01	25.62	0.00	0.00	10	802.20
$p_{s+day+\ day^2}\ \psi_s$	824.80	27.40	0.00	0.00	8	808.27
$p_t\ \psi_s$	826.77	29.37	0.00	0.00	7	812.36
$p_{s+day+eff}\ \psi_s$	829.60	32.20	0.00	0.00	8	813.07
$p_{s+t}\ \psi_.$	829.73	32.34	0.00	0.00	7	815.32
$p_{s+day+eff+temp}\ \psi_s$	831.69	34.29	0.00	0.00	9	813.02
$p_{s+day+wind}\ \psi_s$	835.08	37.68	0.00	0.00	8	818.55
$p_{s+day}\ \psi_s$	842.37	44.98	0.00	0.00	7	827.97
$p_{s+day+temp}\ \psi_s$	842.73	45.33	0.00	0.00	8	826.20
$p_{day}\ \psi_s$	845.74	48.34	0.00	0.00	5	835.52
$p_{s+wind}\ \psi_s$	856.69	59.29	0.00	0.00	7	842.28
$p_{s+temp}\ \psi_s$	857.31	59.91	0.00	0.00	7	842.90
$p_{temp}\ \psi_s$	858.04	60.65	0.00	0.00	5	847.83
$p_{wind}\ \psi_s$	858.67	61.27	0.00	0.00	5	848.45
$p_{s+eff}\ \psi_s$	861.30	63.90	0.00	0.00	7	846.89
$p_s\ \psi_s$	863.72	66.32	0.00	0.00	6	851.41
$p_{eff}\ \psi_s$	864.17	66.77	0.00	0.00	5	853.95
$p_.\ \psi_s$	866.37	68.97	0.00	0.00	4	858.23
$p_s\ \psi_.$	872.95	75.55	0.00	0.00	4	864.80
$p_t\ \psi_.$	875.64	78.24	0.00	0.00	5	865.42
$p_.\ \psi_.$	916.43	119.03	0.00	0.00	2	912.39

Table 2.15. Model selection results for 47 models of detection probability and occupancy for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+temp+wind}\ \psi_{s\times grsL3}$	573.58	0.00	0.11	1.00	11	550.60
$p_{s+day+temp+wind}\ \psi_{s\times grsL3+pdP}$	573.96	0.38	0.09	0.83	12	548.80
$p_{s+day+temp+wind}\ \psi_{s+grsL3}$	574.08	0.50	0.08	0.78	10	553.27
$p_{s+day+temp+wind}\ \psi_{s+grsL2}$	574.20	0.62	0.08	0.73	10	553.39
$p_{s+day+temp+wind}\ \psi_{s\times grsL3+pdL1}$	574.56	0.98	0.06	0.61	12	549.40
$p_{s+day+temp+wind}\ \psi_{s\times grsL2}$	574.71	1.14	0.06	0.57	11	551.74
$p_{s+day+temp+wind}\ \psi_{s\times grsL2+pdP}$	574.75	1.18	0.06	0.56	12	549.59
$p_{s+day+temp+wind}\ \psi_{s\times grsL2+pdL1}$	574.90	1.32	0.05	0.52	12	549.74
$p_{s+day+temp+wind}\ \psi_{s}$	574.94	1.36	0.05	0.51	9	556.28
$p_{s+day+eff+temp+wind}\ \psi_{s\times grsL3}$	575.74	2.16	0.04	0.34	12	550.58
$p_{s+day+temp+wind}\ \psi_{s+pdP+grsL1}$	575.88	2.30	0.03	0.32	11	552.90
$p_{s+day+temp+wind}\ \psi_{.}$	576.08	2.50	0.03	0.29	7	561.67
$p_{s+day+eff+temp+wind}\ \psi_{s\times grsL3+pdP}$	576.13	2.55	0.03	0.28	13	548.77
$p_{s+day+temp+wind}\ \psi_{s+pdP}$	576.20	2.62	0.03	0.27	10	555.39
$p_{s+day+temp+wind}\ \psi_{s+grsL1}$	576.23	2.65	0.03	0.27	10	555.42
$p_{s+day+temp+wind}\ \psi_{s\times grsL1}$	576.25	2.67	0.03	0.26	11	553.27
$p_{s+day+temp+wind}\ \psi_{grsL1}$	576.33	2.75	0.03	0.25	8	559.80
$p_{s+day+temp+wind}\ \psi_{s+pdL1}$	576.69	3.11	0.02	0.21	10	555.88
$p_{s+day+temp+wind}\ \psi_{s+pdL2}$	577.06	3.48	0.02	0.18	10	556.25
$p_{s+day+eff+temp+wind}\ \psi_{s}$	577.08	3.50	0.02	0.17	10	556.27
$p_{s+day+temp+wind}\ \psi_{s+pdL3}$	577.09	3.51	0.02	0.17	10	556.28
$p_{s+day+temp+wind}\ \psi_{grsL2}$	578.01	4.43	0.01	0.11	8	561.48
$p_{s+day+temp+wind}\ \psi_{grsL3}$	578.17	4.59	0.01	0.10	8	561.64
$p_{day+temp+wind}\ \psi_{s}$	578.19	4.61	0.01	0.10	7	563.78

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+eff+temp+wind}\ \psi_{.}$	578.20	4.62	0.01	0.10	8	561.67
$p_{s+day+temp}\ \psi_{s\times grsL3}$	585.72	12.14	0.00	0.00	10	564.91
$p_{s+day+temp}\ \psi_{.}$	585.99	12.41	0.00	0.00	6	573.68
$p_{s+day+temp}\ \psi_{s}$	587.08	13.50	0.00	0.00	8	570.55
$p_{s+day+wind}\ \psi_{.}$	588.63	15.05	0.00	0.00	6	576.32
$p_{s+day+wind}\ \psi_{s}$	588.97	15.39	0.00	0.00	8	572.44
$p_{s+day}\ \psi_{s}$	594.25	20.67	0.00	0.00	7	579.84
$p_{day}\ \psi_{s}$	594.34	20.76	0.00	0.00	5	584.12
$p_{s+day+\ day^2}\ \psi_{s}$	596.31	22.73	0.00	0.00	8	579.79
$p_{s+t}\ \psi_{.}$	599.42	25.85	0.00	0.00	7	585.02
$p_{s+t}\ \psi_{s}$	600.99	27.42	0.00	0.00	9	582.33
$p_{t}\ \psi_{s}$	601.17	27.59	0.00	0.00	7	586.76
$p_{s}\ \psi_{.}$	602.98	29.40	0.00	0.00	4	594.83
$p_{temp}\ \psi_{s}$	603.05	29.47	0.00	0.00	5	592.83
$p_{s+temp}\ \psi_{s}$	603.31	29.73	0.00	0.00	7	588.90
$p_{eff}\ \psi_{s}$	603.95	30.37	0.00	0.00	5	593.73
$p_{.}\ \psi_{s}$	604.13	30.56	0.00	0.00	4	595.99
$p_{s+eff}\ \psi_{s}$	604.32	30.75	0.00	0.00	7	589.92
$p_{s}\ \psi_{s}$	604.40	30.82	0.00	0.00	6	592.09
$p_{s\times t}\ \psi_{.}$	606.46	32.88	0.00	0.00	13	579.10
$p_{s\times t}\ \psi_{s}$	607.29	33.72	0.00	0.00	15	575.49
$p_{t}\ \psi_{.}$	631.66	58.08	0.00	0.00	5	621.44
$p_{.}\ \psi_{.}$	634.47	60.89	0.00	0.00	2	630.42

Table 2.16. Model selection results for 43 models of detection probability and occupancy for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL3}$	1286.63	0.00	0.20	1.00	11	1263.66
$p_{s+day+day^2+eff}\ \psi_{s+pdL3}$	1287.02	0.38	0.16	0.83	10	1266.20
$p_{s+day+day^2+wind}\ \psi_{s+pdL3}$	1287.14	0.51	0.15	0.78	10	1266.33
$p_{s+day+day^2}\ \psi_{s+pdL3}$	1287.49	0.85	0.13	0.65	9	1268.82
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL3+grsL3}$	1287.88	1.25	0.11	0.54	12	1262.72
$p_{s+day+day^2+eff}\ \psi_{s+pdL3+grsL3}$	1288.18	1.55	0.09	0.46	11	1265.20
$p_{s+t}\ \psi_{s+pdL3}$	1289.64	3.01	0.04	0.22	10	1268.83
$p_{s+day+day^2+eff+wind}\ \psi_{s\times pdL3}$	1290.60	3.97	0.03	0.14	13	1263.25
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3+pdL3}$	1290.81	4.18	0.02	0.12	14	1261.24
$p_{s+day+day^2+eff}\ \psi_{s\times grsL3+pdL3}$	1291.05	4.42	0.02	0.11	13	1263.70
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL2}$	1291.20	4.57	0.02	0.10	11	1268.22
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL2+grsL3}$	1291.96	5.32	0.01	0.07	12	1266.80
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL1}$	1295.42	8.79	0.00	0.01	11	1272.44
$p_{s+day+day^2+eff+wind}\ \psi_{s\times pdL2}$	1295.46	8.83	0.00	0.01	13	1268.10
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1}$	1299.68	13.05	0.00	0.00	13	1272.33
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1+pdL1}$	1299.81	13.17	0.00	0.00	14	1270.24
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdP}$	1301.92	15.28	0.00	0.00	11	1278.94
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL2}$	1302.46	15.82	0.00	0.00	13	1275.10
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL3}$	1302.88	16.25	0.00	0.00	11	1279.90
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3}$	1302.95	16.32	0.00	0.00	13	1275.59
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL2}$	1303.51	16.88	0.00	0.00	11	1280.54
$p_{s+day+day^2+eff+wind}\ \psi_{s+grsL1}$	1304.06	17.42	0.00	0.00	11	1281.08
$p_{s+day+day^2+eff+wind}\ \psi_{s}$	1304.31	17.68	0.00	0.00	10	1283.50
$p_{s+day+day^2+eff}\ \psi_{s}$	1304.52	17.88	0.00	0.00	9	1285.86

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day+\ day^2+wind}\ \psi_s$	1304.89	18.26	0.00	0.00	9	1286.23
$p_{s+day+\ day^2}\ \psi_s$	1305.05	18.42	0.00	0.00	8	1288.53
$p_{s+day+\ day^2+temp}\ \psi_s$	1306.08	19.44	0.00	0.00	9	1287.42
$p_{s+t}\ \psi_s$	1307.09	20.45	0.00	0.00	9	1288.42
$p_{s\times t}\ \psi_s$	1310.97	24.34	0.00	0.00	15	1279.17
$p_{s+t}\ \psi_.$	1313.23	26.59	0.00	0.00	7	1298.82
$p_{s+eff}\ \psi_s$	1313.84	27.21	0.00	0.00	7	1299.43
$p_{s\times t}\ \psi_.$	1316.94	30.30	0.00	0.00	13	1289.58
$p_t\ \psi_s$	1322.36	35.73	0.00	0.00	7	1307.95
$p_{eff}\ \psi_s$	1329.33	42.70	0.00	0.00	5	1319.12
$p_{s+day}\ \psi_s$	1330.92	44.28	0.00	0.00	7	1316.51
$p_t\ \psi_.$	1331.61	44.98	0.00	0.00	5	1321.39
$p_s\ \psi_s$	1338.43	51.79	0.00	0.00	6	1326.12
$p_s\ \psi_.$	1344.34	57.71	0.00	0.00	4	1336.20
$p_{day}\ \psi_s$	1344.92	58.28	0.00	0.00	5	1334.70
$p_.\ \psi_s$	1353.30	66.67	0.00	0.00	4	1345.16
$p_{wind}\ \psi_s$	1355.23	68.59	0.00	0.00	5	1345.01
$p_{temp}\ \psi_s$	1355.37	68.73	0.00	0.00	5	1345.15
$p_.\ \psi_.$	1362.79	76.16	0.00	0.00	2	1358.75

Table 2.17. Model selection results for 44 models of detection probability and occupancy for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL3}$	828.10	0.00	0.21	1.00	11	805.13
$p_{day+\ day^2}\ \psi_{s\times grsL3+pdL3}$	828.97	0.87	0.14	0.65	10	808.16
$p_{day+\ day^2+temp}\ \psi_{s+pdL3+grsL3}$	829.12	1.01	0.13	0.60	9	810.45
$p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL2}$	829.45	1.34	0.11	0.51	11	806.47
$p_{day+\ day^2+temp+wind}\ \psi_{s\times grsL3+pdL3}$	830.23	2.12	0.07	0.35	12	805.07
$p_{day+\ day^2}\ \psi_{s\times grsL3+pdL2}$	830.28	2.18	0.07	0.34	10	809.47
$p_{day+\ day^2+temp}\ \psi_{s+pdL2+grsL3}$	830.39	2.29	0.07	0.32	9	811.73
$p_{day+temp}\ \psi_{s\times grsL3+pdL3}$	830.58	2.48	0.06	0.29	10	809.77
$p_{day}\ \psi_{s\times grsL3+pdL3}$	831.50	3.39	0.04	0.18	9	812.84
$p_{day+\ day^2+temp}\ \psi_{s+pdL2+grsL2}$	831.56	3.45	0.04	0.18	9	812.90
$p_{day+\ day^2+temp}\ \psi_{s\times grsL2+pdL2}$	831.91	3.81	0.03	0.15	11	808.93
$p_{day+\ day^2+temp}\ \psi_{s+pdL3}$	833.73	5.62	0.01	0.06	8	817.20
$p_{day+\ day^2+temp}\ \psi_{s+pdL2}$	835.26	7.16	0.01	0.03	8	818.73
$p_{day+\ day^2+temp}\ \psi_{s+north+pdL3}$	835.72	7.61	0.00	0.02	9	817.05
$p_t\ \psi_{s+pdL3}$	839.78	11.68	0.00	0.00	8	823.25
$p_t\ \psi_{s+pdL2}$	841.34	13.24	0.00	0.00	8	824.81
$p_{day+\ day^2+temp}\ \psi_{s+pdL1}$	844.01	15.91	0.00	0.00	8	827.48
$p_{day+\ day^2+temp}\ \psi_{s+grsL3}$	848.01	19.91	0.00	0.00	8	831.48
$p_{day+\ day^2+temp}\ \psi_{s\times grsL3}$	849.95	21.85	0.00	0.00	10	829.14
$p_{day+\ day^2+temp}\ \psi_{s}$	849.96	21.86	0.00	0.00	7	835.55
$p_{day+\ day^2+temp}\ \psi_{s+pdP+grsL3}$	850.04	21.93	0.00	0.00	9	831.37
$p_{day+\ day^2+temp}\ \psi_{s+grsL2}$	850.22	22.12	0.00	0.00	8	833.69
$p_t\ \psi_{s+pdL1}$	850.23	22.12	0.00	0.00	8	833.70

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{day+\ day^2}\ \psi_s$	850.85	22.74	0.00	0.00	6	838.54
$p_{day+\ day^2+temp}\ \psi_{s+north}$	851.01	22.91	0.00	0.00	8	834.48
$p_{day+\ day^2+temp}\ \psi_{s+pdP}$	852.06	23.96	0.00	0.00	8	835.53
$p_{day+\ day^2+temp}\ \psi_{s+grsL1}$	852.08	23.98	0.00	0.00	8	835.55
$p_{day+\ day^2+wind}\ \psi_s$	852.54	24.44	0.00	0.00	7	838.14
$p_{day}\ \psi_s$	853.43	25.33	0.00	0.00	5	843.21
$p_{day+\ day^2+temp}\ \psi_{s\times grsL2}$	853.95	25.84	0.00	0.00	10	833.14
$p_t\ \psi_s$	856.22	28.11	0.00	0.00	7	841.81
$p_{s\times t}\ \psi_s$	857.02	28.91	0.00	0.00	15	825.21
$p_{s+t}\ \psi_s$	858.28	30.17	0.00	0.00	9	839.62
$p_t\ \psi_{s+pdP}$	858.32	30.21	0.00	0.00	8	841.79
$p_t\ \psi_.$	876.18	48.07	0.00	0.00	5	865.96
$p_{s+t}\ \psi_.$	876.29	48.18	0.00	0.00	7	861.88
$p_{s\times t}\ \psi_.$	876.33	48.22	0.00	0.00	13	848.97
$p_.\ \psi_s$	890.73	62.63	0.00	0.00	4	882.59
$p_{wind}\ \psi_s$	891.54	63.44	0.00	0.00	5	881.32
$p_{temp}\ \psi_s$	891.78	63.67	0.00	0.00	5	881.56
$p_{eff}\ \psi_s$	892.54	64.44	0.00	0.00	5	882.33
$p_s\ \psi_s$	892.92	64.81	0.00	0.00	6	880.61
$p_.\ \psi_.$	910.42	82.32	0.00	0.00	2	906.38
$p_s\ \psi_.$	910.73	82.63	0.00	0.00	4	902.59

Table 2.18. Model selection results for 37 models of detection probability and occupancy for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+eff+temp}\ \psi_{.}$	1153.46	0.00	0.22	1.00	6	1141.15
$p_{s+eff+temp}\ \psi_{pdL1}$	1154.83	1.37	0.11	0.51	7	1140.42
$p_{s+eff+temp}\ \psi_{grsL1}$	1155.22	1.76	0.09	0.41	7	1140.81
$p_{s+eff+temp}\ \psi_{pdL2}$	1155.32	1.86	0.09	0.40	7	1140.91
$p_{s+eff+temp}\ \psi_{grsL2}$	1155.36	1.90	0.09	0.39	7	1140.95
$p_{s+eff+temp}\ \psi_{pdL3}$	1155.42	1.95	0.08	0.38	7	1141.01
$p_{s+eff+temp}\ \psi_{grsL3}$	1155.52	2.06	0.08	0.36	7	1141.11
$p_{s+eff+temp}\ \psi_{pdL1+grsL1}$	1156.85	3.39	0.04	0.18	8	1140.33
$p_{s+eff+temp}\ \psi_{pdP+grsL1}$	1156.98	3.52	0.04	0.17	8	1140.46
$p_{s+temp}\ \psi_{.}$	1157.09	3.63	0.04	0.16	5	1146.87
$p_{temp}\ \psi_{.}$	1158.12	4.66	0.02	0.10	3	1152.03
$p_{s+temp}\ \psi_{pdL1}$	1158.42	4.96	0.02	0.08	6	1146.11
$p_{s+temp}\ \psi_{grsL1}$	1158.83	5.37	0.01	0.07	6	1146.53
$p_{s+eff+temp}\ \psi_{s+pdL1}$	1159.02	5.56	0.01	0.06	9	1140.36
$p_{s+eff+temp}\ \psi_{s+grsL1}$	1159.03	5.57	0.01	0.06	9	1140.37
$p_{s+eff+temp}\ \psi_{s+pdP}$	1159.21	5.75	0.01	0.06	9	1140.55
$p_{temp}\ \psi_{pdL1}$	1159.60	6.14	0.01	0.05	4	1151.45
$p_{temp}\ \psi_{grsL1}$	1159.87	6.41	0.01	0.04	4	1151.73
$p_{s+temp}\ \psi_{s}$	1160.71	7.25	0.01	0.03	7	1146.30
$p_{s+eff}\ \psi_{.}$	1161.87	8.41	0.00	0.01	5	1151.65
$p_{temp}\ \psi_{s}$	1161.95	8.49	0.00	0.01	5	1151.73
$p_{eff}\ \psi_{.}$	1163.02	9.56	0.00	0.01	3	1156.94
$p_{s}\ \psi_{.}$	1165.21	11.74	0.00	0.00	4	1157.06
$p_{wind}\ \psi_{.}$	1165.70	12.23	0.00	0.00	3	1159.61

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{s+day}\ \psi_{.}$	1165.85	12.39	0.00	0.00	5	1155.64
$p_{s+t}\ \psi_{.}$	1166.02	12.56	0.00	0.00	7	1151.61
$p_{.}\ \psi_{.}$	1166.56	13.09	0.00	0.00	2	1162.51
$p_{t}\ \psi_{.}$	1167.14	13.68	0.00	0.00	5	1156.92
$p_{day}\ \psi_{.}$	1167.32	13.86	0.00	0.00	3	1161.24
$p_{s}\ \psi_{s}$	1168.69	15.23	0.00	0.00	6	1156.39
$p_{s+day}\ \psi_{s}$	1169.41	15.95	0.00	0.00	7	1155.00
$p_{s+t}\ \psi_{s}$	1169.62	16.16	0.00	0.00	9	1150.96
$p_{.}\ \psi_{s}$	1170.26	16.80	0.00	0.00	4	1162.12
$p_{t}\ \psi_{s}$	1170.94	17.48	0.00	0.00	7	1156.53
$p_{s\times t}\ \psi_{.}$	1170.95	17.49	0.00	0.00	13	1143.59
$p_{day}\ \psi_{s}$	1171.09	17.63	0.00	0.00	5	1160.87
$p_{s\times t}\ \psi_{s}$	1174.67	21.21	0.00	0.00	15	1142.86

Table 2.19. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
ψ_s	1.00
ψ_{pdL1}	0.80
ψ_{pdL2}	0.19
ψ_{grsL2}	0.10
ψ_{grsL3}	0.87

Table 2.20. Covariate estimates ($\hat{\beta}_i$) under the top 21 occupancy models (AIC_c weight [w_i] ≥ 0.01) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p.\ \psi_{s\times grsL3+pdL1}$	534.09	0.00	0.11	8	p_{int}	=	-0.28	0.16	-0.60	0.03
					ψ_{int}	=	-4.47	1.37	-7.15	-1.79
					ψ_{grs}	=	3.91	2.40	-0.79	8.61
					ψ_{ag}	=	1.82	1.54	-1.21	4.85
					ψ_{pdL1}	=	3.89	1.31	1.32	6.46
					$\psi_{grsL3*grs}$	=	-2.35	2.44	-7.13	2.42
					$\psi_{grsL3*ag}$	=	2.73	1.80	-0.81	6.26
					$\psi_{grsL3*pd}$	=	4.25	1.56	1.20	7.30
$p.\ \psi_{s+pdL1+grsL3}$	534.55	0.46	0.09	6	p_{int}	=	-0.28	0.16	-0.59	0.03
					ψ_{int}	=	-3.44	1.01	-5.42	-1.45
					ψ_{grs}	=	-1.52	0.79	-3.07	0.02
					ψ_{ag}	=	0.75	0.84	-0.89	2.40
					ψ_{pdL1}	=	3.49	1.21	1.12	5.86
					ψ_{grsL3}	=	2.83	1.05	0.76	4.89
$p_s\ \psi_{s\times grsL3+pdL1}$	534.62	0.53	0.09	10	p_{int}	=	-0.12	0.19	-0.49	0.26
					p_{grs}	=	-1.09	0.64	-2.34	0.17
					p_{ag}	=	-0.29	0.41	-1.09	0.52
					ψ_{int}	=	-4.47	1.33	-7.09	-1.86
					ψ_{grs}	=	4.47	2.61	-0.64	9.58
					ψ_{ag}	=	1.84	1.52	-1.14	4.81
					ψ_{pdL1}	=	3.83	1.26	1.36	6.31
					$\psi_{grsL3*grs}$	=	-2.59	2.67	-7.82	2.65

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					$\psi_{grsL3*ag}$	=	2.80	1.86	-0.84	6.44
					$\psi_{grsL3*pd}$	=	4.17	1.50	1.23	7.11
$p_s\ \psi_{s+pdL1+grsL3}$	534.91	0.82	0.07	8	p_{int}	=	-0.11	0.19	-0.48	0.26
					p_{grs}	=	-1.11	0.65	-2.40	0.17
					p_{ag}	=	-0.29	0.41	-1.10	0.51
					ψ_{int}	=	-3.53	1.01	-5.51	-1.54
					ψ_{grs}	=	-1.10	0.86	-2.78	0.58
					ψ_{ag}	=	0.86	0.85	-0.80	2.52
					ψ_{pdL1}	=	3.45	1.17	1.17	5.74
					ψ_{grsL3}	=	2.88	1.05	0.82	4.94
$p_{eff}\ \psi_{s\times grsL3+pdL1}$	535.39	1.30	0.06	9	p_{int}	=	-0.35	0.18	-0.70	0.00
					p_{eff}	=	0.26	0.29	-0.30	0.83
					ψ_{int}	=	-4.47	1.37	-7.15	-1.80
					ψ_{grs}	=	3.91	2.40	-0.79	8.61
					ψ_{ag}	=	1.83	1.54	-1.20	4.85
					ψ_{pdL1}	=	3.89	1.31	1.32	6.46
					$\psi_{grsL3*grs}$	=	-2.35	2.44	-7.13	2.43
					$\psi_{grsL3*ag}$	=	2.71	1.80	-0.81	6.23
					$\psi_{grsL3*pd}$	=	4.25	1.55	1.20	7.29
$p_{.}\ \psi_{s\times grsL3+pdL2}$	535.62	1.53	0.05	8	p_{int}	=	-0.29	0.16	-0.60	0.03
					ψ_{int}	=	-3.69	1.18	-5.99	-1.38
					ψ_{grs}	=	3.03	2.30	-1.49	7.54
					ψ_{ag}	=	1.03	1.37	-1.66	3.71
					ψ_{pdL2}	=	4.84	1.76	1.39	8.29
					$\psi_{grsL3*grs}$	=	-2.29	2.46	-7.11	2.53
					$\psi_{grsL3*ag}$	=	2.62	1.79	-0.88	6.13
					$\psi_{grsL3*pd}$	=	4.28	1.53	1.27	7.29

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{eff}\ \psi_{s+pdL1+grsL3}$	535.82	1.73	0.05	7	p_{int}	=	-0.35	0.18	-0.69	0.00
					p_{eff}	=	0.26	0.29	-0.30	0.83
					ψ_{int}	=	-3.43	1.01	-5.42	-1.45
					ψ_{grs}	=	-1.52	0.79	-3.06	0.02
					ψ_{ag}	=	0.75	0.84	-0.89	2.39
					ψ_{pdL1}	=	3.49	1.21	1.12	5.85
					ψ_{grsL3}	=	2.82	1.05	0.76	4.88
$p_{s+eff}\ \psi_{s\times grsL3+pdL1}$	536.00	1.91	0.04	11	p_{int}	=	-0.18	0.21	-0.59	0.22
					p_{grs}	=	-1.08	0.64	-2.33	0.17
					p_{ag}	=	-0.28	0.41	-1.09	0.52
					p_{eff}	=	0.26	0.29	-0.31	0.82
					ψ_{int}	=	-4.48	1.33	-7.09	-1.86
					ψ_{grs}	=	4.46	2.60	-0.64	9.56
					ψ_{ag}	=	1.84	1.52	-1.13	4.82
					ψ_{pdL1}	=	3.83	1.26	1.36	6.30
					$\psi_{grsL3*grs}$	=	-2.58	2.67	-7.80	2.65
					$\psi_{grsL3*ag}$	=	2.78	1.85	-0.84	6.40
					$\psi_{grsL3*pd}$	=	4.17	1.50	1.23	7.11
$p_{.}\ \psi_{s+pdL2+grsL3}$	536.04	1.95	0.04	6	p_{int}	=	-0.29	0.16	-0.60	0.03
					ψ_{int}	=	-2.73	0.86	-4.41	-1.04
					ψ_{grs}	=	-2.28	0.65	-3.56	-1.01
					ψ_{ag}	=	0.00	0.66	-1.30	1.29
					ψ_{pdL2}	=	4.40	1.69	1.08	7.72
					ψ_{grsL3}	=	2.84	1.05	0.79	4.90
$p_{temp}\ \psi_{s\times grsL3+pdL1}$	536.11	2.02	0.04	9	p_{int}	=	-0.15	0.42	-0.97	0.67
					p_{temp}	=	-0.01	0.02	-0.05	0.04
					ψ_{int}	=	-4.48	1.37	-7.17	-1.79

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{grs}	=	3.92	2.40	-0.78	8.63
					ψ_{ag}	=	1.82	1.55	-1.21	4.86
					ψ_{pdL1}	=	3.89	1.32	1.31	6.48
					$\psi_{grsL3*grs}$	=	-2.36	2.44	-7.14	2.42
					$\psi_{grsL3*ag}$	=	2.74	1.81	-0.81	6.28
					$\psi_{grsL3*pd}$	=	4.27	1.57	1.20	7.35
$p_{day}\ \psi_{s\times grsL3+pdL1}$	536.15	2.06	0.04	9	p_{int}	=	-0.35	0.29	-0.92	0.22
					p_{day}	=	0.00	0.01	-0.01	0.02
					ψ_{int}	=	-4.47	1.37	-7.15	-1.80
					ψ_{grs}	=	3.91	2.40	-0.79	8.61
					ψ_{ag}	=	1.83	1.54	-1.20	4.85
					ψ_{pdL1}	=	3.90	1.31	1.33	6.47
					$\psi_{grsL3*grs}$	=	-2.35	2.44	-7.12	2.43
					$\psi_{grsL3*ag}$	=	2.72	1.80	-0.81	6.24
					$\psi_{grsL3*pd}$	=	4.24	1.55	1.20	7.29
$p_{s}\ \psi_{s\times grsL3+pdL2}$	536.16	2.07	0.04	10	p_{int}	=	-0.12	0.19	-0.50	0.25
					p_{grs}	=	-1.10	0.65	-2.37	0.17
					p_{ag}	=	-0.28	0.41	-1.08	0.53
					ψ_{int}	=	-3.73	1.16	-6.01	-1.45
					ψ_{grs}	=	3.68	2.56	-1.34	8.70
					ψ_{ag}	=	1.09	1.37	-1.59	3.76
					ψ_{pdL2}	=	4.80	1.69	1.48	8.12
					$\psi_{grsL3*grs}$	=	-2.57	2.71	-7.87	2.74
					$\psi_{grsL3*ag}$	=	2.69	1.83	-0.90	6.27
					$\psi_{grsL3*pd}$	=	4.24	1.49	1.32	7.16
$p_{s+eff}\ \psi_{s+pdL1+grsL3}$	536.27	2.18	0.04	9	p_{int}	=	-0.18	0.21	-0.58	0.22
					p_{grs}	=	-1.11	0.65	-2.39	0.17

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					p_{ag}	=	-0.29	0.41	-1.09	0.51
					p_{eff}	=	0.26	0.29	-0.31	0.82
					ψ_{int}	=	-3.52	1.01	-5.50	-1.54
					ψ_{grs}	=	-1.10	0.86	-2.78	0.58
					ψ_{ag}	=	0.86	0.85	-0.80	2.51
					ψ_{pdL1}	=	3.45	1.16	1.17	5.73
					ψ_{grsL3}	=	2.88	1.05	0.82	4.93
$p_s\ \psi_{s+pdL2+grsL3}$	536.48	2.39	0.03	8	p_{int}	=	-0.12	0.19	-0.50	0.25
					p_{grs}	=	-1.11	0.66	-2.41	0.18
					p_{ag}	=	-0.28	0.41	-1.09	0.52
					ψ_{int}	=	-2.82	0.86	-4.51	-1.13
					ψ_{grs}	=	-1.86	0.75	-3.32	-0.40
					ψ_{ag}	=	0.10	0.68	-1.23	1.44
					ψ_{pdL2}	=	4.32	1.60	1.18	7.45
					ψ_{grsL3}	=	2.91	1.05	0.86	4.96
$p_{temp}\ \psi_{s+pdL1+grsL3}$	536.56	2.47	0.03	7	p_{int}	=	-0.16	0.42	-0.98	0.66
					p_{temp}	=	-0.01	0.02	-0.05	0.04
					ψ_{int}	=	-3.43	1.02	-5.43	-1.44
					ψ_{grs}	=	-1.53	0.79	-3.08	0.02
					ψ_{ag}	=	0.75	0.84	-0.90	2.40
					ψ_{pdL1}	=	3.49	1.21	1.11	5.87
					ψ_{grsL3}	=	2.84	1.06	0.77	4.91
$p_{day}\ \psi_{s+pdL1+grsL3}$	536.57	2.47	0.03	7	p_{int}	=	-0.35	0.29	-0.92	0.22
					p_{day}	=	0.00	0.01	-0.01	0.02
					ψ_{int}	=	-3.44	1.01	-5.43	-1.45
					ψ_{grs}	=	-1.51	0.79	-3.06	0.03
					ψ_{ag}	=	0.76	0.84	-0.89	2.40

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{pdL1}	=	3.50	1.21	1.13	5.87
					ψ_{grsL3}	=	2.82	1.05	0.76	4.88
$p_{.}\ \psi_{s+pdL1+grsL2}$	536.80	2.71	0.03	6	p_{int}	=	-0.29	0.16	-0.60	0.03
					ψ_{int}	=	-3.25	1.04	-5.28	-1.21
					ψ_{grs}	=	-1.44	0.79	-2.99	0.11
					ψ_{ag}	=	0.78	0.87	-0.93	2.49
					ψ_{pdL1}	=	3.76	1.25	1.31	6.21
					ψ_{grsL2}	=	2.45	1.07	0.35	4.55
$p_s\ \psi_{s+pdL1+grsL2}$	537.33	3.24	0.02	8	p_{int}	=	-0.12	0.19	-0.50	0.25
					p_{grs}	=	-1.09	0.65	-2.36	0.18
					p_{ag}	=	-0.28	0.41	-1.08	0.53
					ψ_{int}	=	-3.32	1.04	-5.35	-1.29
					ψ_{grs}	=	-1.04	0.85	-2.71	0.63
					ψ_{ag}	=	0.88	0.88	-0.85	2.61
					ψ_{pdL1}	=	3.71	1.20	1.35	6.07
					ψ_{grsL2}	=	2.49	1.07	0.39	4.59
$p_{.}\ \psi_{s\times grsL2+pdL1}$	537.53	3.44	0.02	8	p_{int}	=	-0.29	0.16	-0.61	0.03
					ψ_i	=	-3.95	1.39	-6.67	-1.22
					ψ_{grs}	=	3.62	2.59	-1.46	8.71
					ψ_{ag}	=	1.38	1.54	-1.63	4.39
					ψ_{pdL1}	=	4.10	1.36	1.43	6.77
					$\psi_{grsL2*grs}$	=	-2.54	2.62	-7.67	2.59
					$\psi_{grsL2*ag}$	=	2.79	1.77	-0.69	6.27
					$\psi_{grsL2*pd}$	=	3.41	1.58	0.31	6.51
$p_s\ \psi_{s\times grsL2+pdL1}$	538.17	4.08	0.01	10	p_{int}	=	-0.12	0.19	-0.50	0.25
					p_{grs}	=	-1.07	0.63	-2.31	0.17
					p_{ag}	=	-0.29	0.41	-1.10	0.53

…table continued

…table continued

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	-3.96	1.36	-6.63	-1.29
					ψ_{grs}	=	4.15	2.78	-1.30	9.59
					ψ_{ag}	=	1.40	1.51	-1.57	4.37
					ψ_{pdL1}	=	4.02	1.32	1.45	6.60
					$\psi_{grsL2*grs}$	=	-2.73	2.82	-8.25	2.80
					$\psi_{grsL2*ag}$	=	2.88	1.85	-0.74	6.50
					$\psi_{grsL2*pd}$	=	3.36	1.53	0.36	6.36
$p_{.}\ \psi_{s+pdL2+grsL2}$	538.28	4.19	0.01	6	p_{int}	=	-0.30	0.16	-0.62	0.02
					ψ_{int}	=	-2.52	0.88	-4.25	-0.79
					ψ_{grs}	=	-2.24	0.66	-3.54	-0.94
					ψ_{ag}	=	0.01	0.70	-1.36	1.37
					ψ_{pdL2}	=	4.92	1.84	1.32	8.52
					ψ_{grsL2}	=	2.49	1.08	0.38	4.60

Table 2.21. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
ψ_s	1.00
ψ_{act}	1.00
ψ_{pdL1}	0.27
ψ_{pdL2}	0.34
ψ_{pdL3}	0.36
ψ_{grsL1}	0.09
ψ_{grsL2}	0.11
ψ_{grsL3}	0.18

Table 2.22. Covariate estimates ($\hat{\beta}_i$) under the top 26 occupancy models (AIC_c weight [w_i] ≥ 0.01) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{.}\ \psi_{s+act+pdL3}$	394.19	0.00	0.08	6	p_{int}	=	0.18	0.15	-0.12	0.49
					ψ_{int}	=	-0.24	0.80	-1.80	1.33
					ψ_{grs}	=	-4.22	1.27	-6.71	-1.72
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.59	0.78	1.07	4.12
					ψ_{pdL3}	=	-5.18	2.14	-9.37	-0.99
$p_{.}\ \psi_{s+act+pdL2}$	394.61	0.42	0.07	6	p_{int}	=	0.19	0.15	-0.11	0.49
					ψ_{int}	=	-0.16	0.83	-1.77	1.46
					ψ_{grs}	=	-4.33	1.29	-6.87	-1.80
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.61	0.78	1.08	4.13
					ψ_{pdL2}	=	-4.09	1.75	-7.52	-0.66
$p_{eff}\ \psi_{s+act+pdL3}$	394.77	0.58	0.06	7	p_{int}	=	0.08	0.17	-0.25	0.42
					p_{eff}	=	0.38	0.31	-0.23	0.98
					ψ_{int}	=	-0.24	0.80	-1.80	1.32
					ψ_{grs}	=	-4.22	1.27	-6.71	-1.72
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.59	0.77	1.07	4.11
					ψ_{pdL3}	=	-5.18	2.13	-9.35	-1.00
$p_{.}\ \psi_{s+act+pdL1}$	395.01	0.82	0.05	6	p_{int}	=	0.19	0.15	-0.11	0.49
					ψ_{int}	=	0.21	0.95	-1.66	2.08
					ψ_{grs}	=	-4.74	1.38	-7.44	-2.03
					ψ_{ag}	=	*	*	*	*

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{act}	=	2.74	0.78	1.21	4.26
					ψ_{pdL1}	=	-2.92	1.31	-5.49	-0.34
$p.\ \psi_{s+act+pdL3+grsL3}$	395.06	0.87	0.05	7	p_{int}	=	0.19	0.15	-0.11	0.49
					ψ_{int}	=	1.12	1.51	-1.83	4.08
					ψ_{grs}	=	-4.03	1.28	-6.54	-1.53
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.49	0.78	0.96	4.02
					ψ_{pdL3}	=	-6.40	2.51	-11.32	-1.47
					ψ_{grsL3}	=	-1.83	1.69	-5.14	1.48
$p_{eff}\ \psi_{s+act+pdL2}$	395.19	1.00	0.05	7	p_{int}	=	0.09	0.17	-0.25	0.43
					p_{eff}	=	0.38	0.31	-0.23	0.99
					ψ_{int}	=	-0.16	0.82	-1.77	1.46
					ψ_{grs}	=	-4.33	1.29	-6.86	-1.80
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.60	0.78	1.08	4.13
					ψ_{pdL2}	=	-4.09	1.74	-7.51	-0.67
$p.\ \psi_{s+act+pdL1+grsL1}$	395.23	1.04	0.05	7	p_{int}	=	0.20	0.15	-0.10	0.50
					ψ_{int}	=	3.11	2.54	-1.87	8.08
					ψ_{grs}	=	-4.26	1.40	-7.00	-1.51
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.49	0.78	0.97	4.01
					ψ_{pdL1}	=	-5.61	2.63	-10.76	-0.45
					ψ_{grsL1}	=	-3.59	2.82	-9.12	1.94
$p.\ \psi_{s+act+pdL2+grsL2}$	395.38	1.18	0.05	7	p_{int}	=	0.19	0.15	-0.11	0.49
					ψ_{int}	=	1.45	1.71	-1.89	4.79
					ψ_{grs}	=	-4.12	1.30	-6.67	-1.57
					ψ_{ag}	=	*	*	*	*

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{act}	=	2.48	0.79	0.94	4.02
					ψ_{pdL2}	=	-5.51	2.28	-9.98	-1.04
					ψ_{grsL2}	=	-2.09	1.88	-5.78	1.61
$p_{eff}\ \psi_{s+act+pdL1}$	395.59	1.39	0.04	7	p_{int}	=	0.09	0.17	-0.24	0.43
					p_{eff}	=	0.38	0.31	-0.23	0.99
					ψ_{int}	=	0.21	0.95	-1.65	2.07
					ψ_{grs}	=	-4.73	1.38	-7.44	-2.03
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.73	0.78	1.21	4.26
					ψ_{pdL1}	=	-2.92	1.31	-5.49	-0.36
$p_{eff}\ \psi_{s+act+pdL3+grsL3}$	395.64	1.45	0.04	8	p_{int}	=	0.09	0.17	-0.25	0.43
					p_{eff}	=	0.38	0.31	-0.23	0.99
					ψ_{int}	=	1.12	1.51	-1.83	4.07
					ψ_{grs}	=	-4.03	1.28	-6.54	-1.53
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.49	0.78	0.96	4.02
					ψ_{pdL3}	=	-6.40	2.51	-11.31	-1.49
					ψ_{grsL3}	=	-1.83	1.68	-5.13	1.47
$p_{.}\ \psi_{s+act+pdL2+grsL3}$	395.76	1.57	0.04	7	p_{int}	=	0.19	0.15	-0.11	0.49
					ψ_{int}	=	1.00	1.48	-1.90	3.90
					ψ_{grs}	=	-4.18	1.30	-6.72	-1.64
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.53	0.78	0.99	4.06
					ψ_{pdL2}	=	-4.85	1.98	-8.74	-0.96
					ψ_{grsL3}	=	-1.55	1.61	-4.71	1.62
$p_{eff}\ \psi_{s+act+pdL1+grsL1}$	395.84	1.64	0.04	8	p_{int}	=	0.10	0.17	-0.23	0.44
					p_{eff}	=	0.38	0.31	-0.23	0.99

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	3.08	2.53	-1.87	8.03
					ψ_{grs}	=	-4.26	1.40	-7.00	-1.52
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.49	0.77	0.97	4.01
					ψ_{pdL1}	=	-5.59	2.62	-10.72	-0.46
					ψ_{grsL1}	=	-3.56	2.81	-9.06	1.94
$p_{day+eff}\ \psi_{s+act+pdL3}$	395.92	1.72	0.03	8	p_{int}	=	-0.24	0.37	-0.95	0.48
					p_{day}	=	0.01	0.01	-0.01	0.03
					p_{eff}	=	0.49	0.33	-0.16	1.14
					ψ_{int}	=	-0.26	0.79	-1.82	1.30
					ψ_{grs}	=	-4.20	1.27	-6.69	-1.71
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.58	0.77	1.07	4.10
					ψ_{pdL3}	=	-5.11	2.12	-9.26	-0.96
$p_{eff}\ \psi_{s+act+pdL2+grsL2}$	395.97	1.78	0.03	8	p_{int}	=	0.09	0.17	-0.24	0.43
					p_{eff}	=	0.38	0.31	-0.23	0.99
					ψ_{int}	=	1.44	1.70	-1.89	4.78
					ψ_{grs}	=	-4.11	1.30	-6.66	-1.57
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.48	0.78	0.94	4.01
					ψ_{pdL2}	=	-5.51	2.28	-9.97	-1.05
					ψ_{grsL2}	=	-2.08	1.88	-5.77	1.60
$p_{day}\ \psi_{s+act+pdL3}$	396.06	1.87	0.03	7	p_{int}	=	0.05	0.31	-0.56	0.66
					p_{day}	=	0.00	0.01	-0.01	0.02
					ψ_{int}	=	-0.25	0.80	-1.81	1.32
					ψ_{grs}	=	-4.21	1.27	-6.71	-1.72
					ψ_{ag}	=	*	*	*	*

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{act}	=	2.59	0.77	1.07	4.11
					ψ_{pdL3}	=	-5.15	2.13	-9.33	-0.97
$p_{temp}\ \psi_{s+act+pdL3}$	396.13	1.94	0.03	7	p_{int}	=	0.37	0.48	-0.57	1.31
					p_{temp}	=	-0.01	0.02	-0.06	0.04
					ψ_{int}	=	-0.23	0.80	-1.80	1.33
					ψ_{grs}	=	-4.23	1.27	-6.72	-1.73
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.59	0.78	1.07	4.11
					ψ_{pdL3}	=	-5.20	2.14	-9.40	-1.01
$p_{day+eff}\ \psi_{s+act+pdL2}$	396.34	2.14	0.03	8	p_{int}	=	-0.23	0.37	-0.95	0.49
					p_{day}	=	0.01	0.01	-0.01	0.03
					p_{eff}	=	0.49	0.33	-0.16	1.14
					ψ_{int}	=	-0.18	0.82	-1.79	1.43
					ψ_{grs}	=	-4.31	1.29	-6.84	-1.78
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.60	0.77	1.08	4.11
					ψ_{pdL2}	=	-4.03	1.73	-7.43	-0.64
$p_{eff}\ \psi_{s+act+pdL2+grsL3}$	396.35	2.16	0.03	8	p_{int}	=	0.09	0.17	-0.24	0.43
					p_{eff}	=	0.38	0.31	-0.23	0.99
					ψ_{int}	=	0.99	1.48	-1.90	3.89
					ψ_{grs}	=	-4.18	1.30	-6.72	-1.64
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.53	0.78	0.99	4.06
					ψ_{pdL2}	=	-4.86	1.98	-8.74	-0.98
					ψ_{grsL3}	=	-1.55	1.61	-4.70	1.61
$p_{day}\ \psi_{s+act+pdL2}$	396.48	2.29	0.03	7	p_{int}	=	0.05	0.31	-0.56	0.67
					p_{day}	=	0.00	0.01	-0.01	0.02

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	-0.16	0.82	-1.78	1.45
					ψ_{grs}	=	-4.33	1.29	-6.86	-1.79
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.60	0.78	1.08	4.13
					ψ_{pdL2}	=	-4.06	1.74	-7.48	-0.65
$p.\ \psi_{s+act+pdL1+grsL2}$	396.53	2.34	0.03	7	p_{int}	=	0.20	0.15	-0.10	0.50
					ψ_{int}	=	1.19	1.64	-2.02	4.40
					ψ_{grs}	=	-4.61	1.38	-7.32	-1.90
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.67	0.77	1.16	4.19
					ψ_{pdL1}	=	-3.39	1.48	-6.29	-0.48
					ψ_{grsL2}	=	-1.26	1.68	-4.56	2.04
$p_{temp}\ \psi_{s+act+pdL2}$	396.56	2.37	0.03	7	p_{int}	=	0.37	0.48	-0.58	1.31
					p_{temp}	=	-0.01	0.02	-0.06	0.04
					ψ_{int}	=	-0.15	0.83	-1.77	1.47
					ψ_{grs}	=	-4.34	1.29	-6.88	-1.80
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.60	0.78	1.08	4.13
					ψ_{pdL2}	=	-4.10	1.75	-7.53	-0.67
$p.\ \psi_{s+act+pdL1+grsL3}$	396.70	2.51	0.02	7	p_{int}	=	0.20	0.15	-0.10	0.50
					ψ_{int}	=	0.92	1.47	-1.96	3.80
					ψ_{grs}	=	-4.63	1.38	-7.34	-1.92
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.69	0.77	1.17	4.21
					ψ_{pdL1}	=	-3.14	1.37	-5.82	-0.46
					ψ_{grsL3}	=	-0.96	1.51	-3.91	1.99

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{day}\ \psi_{s+act+pdL1}$	396.88	2.68	0.02	7	p_{int}	=	0.06	0.31	-0.55	0.67
					p_{day}	=	0.00	0.01	-0.01	0.02
					ψ_{int}	=	0.20	0.95	-1.66	2.06
					ψ_{grs}	=	-4.72	1.38	-7.43	-2.02
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.73	0.78	1.21	4.25
					ψ_{pdL1}	=	-2.90	1.31	-5.47	-0.33
$p_{temp}\ \psi_{s+act+pdL1}$	396.97	2.78	0.02	7	p_{int}	=	0.37	0.49	-0.58	1.32
					p_{temp}	=	-0.01	0.02	-0.06	0.04
					ψ_{int}	=	0.22	0.95	-1.65	2.08
					ψ_{grs}	=	-4.74	1.38	-7.45	-2.03
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.73	0.78	1.21	4.26
					ψ_{pdL1}	=	-2.92	1.31	-5.50	-0.35
$p_{day+\ day^2}\ \psi_{s+act+pdL3}$	397.20	3.00	0.02	8	p_{int}	=	-0.25	0.44	-1.11	0.60
					p_{day}	=	0.03	0.03	-0.03	0.10
					p_{day^2}	=	0.00	0.00	0.00	0.00
					ψ_{int}	=	-0.25	0.80	-1.81	1.31
					ψ_{grs}	=	-4.21	1.27	-6.70	-1.72
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.59	0.77	1.08	4.11
					ψ_{pdL3}	=	-5.16	2.13	-9.33	-0.98
$p_{.}\ \psi_{s+act}$	398.37	4.17	0.01	5	p_{int}	=	0.17	0.16	-0.14	0.48
					ψ_{int}	=	-1.38	0.65	-2.66	-0.10
					ψ_{grs}	=	-3.17	1.20	-5.52	-0.82
					ψ_{ag}	=	*	*	*	*
					ψ_{act}	=	2.75	0.74	1.31	4.19

* Poor estimation of ψ_{ag} was caused by the lack of detections of burrowing owls on dryland agriculture plots.

Table 2.23. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
ψ_s	1.00
ψ_{pdP}	0.23
ψ_{pdL2}	0.17
ψ_{grsL1}	0.06
ψ_{grsL2}	0.33
ψ_{grsL3}	0.61

Table 2.24. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+day+day^2+eff+wind}$ $\psi_{s\times grsL3}$	797.40	0.00	0.31	13	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.74	0.58	-1.86	0.39
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	0.18	0.69	-1.18	1.55
					ψ_{grs}	=	-6.04	1.94	-9.84	-2.23
					ψ_{ag}	=	-4.55	1.45	-7.39	-1.71
					$\psi_{grsL3*grs}$	=	6.71	2.06	2.68	10.74
					$\psi_{grsL3*ag}$	=	6.62	3.24	0.27	12.96
					$\psi_{grsL3*pd}$	=	0.38	1.15	-1.86	2.63
$p_{s+day+day^2+eff+wind}$ $\psi_{s\times grsL2}$	798.63	1.23	0.17	13	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.76	0.60	-1.93	0.42
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	0.32	0.65	-0.96	1.59
					ψ_{grs}	=	-6.91	2.21	-11.23	-2.58

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{ag}	=	-4.26	1.33	-6.86	-1.65
					$\psi_{grsL2*grs}$	=	7.31	2.32	2.77	11.85
					$\psi_{grsL2*ag}$	=	6.16	3.40	-0.50	12.82
					$\psi_{grsL2*pd}$	=	0.17	1.15	-2.08	2.42
$p_{s+day+\ day^2+eff+wind}\ \psi_{s\times grsL3+pdP}$	798.96	1.56	0.14	14	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.74	0.58	-1.86	0.39
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-0.72	1.30	-3.27	1.83
					ψ_{grs}	=	-5.13	2.23	-9.51	-0.76
					ψ_{ag}	=	-3.64	1.82	-7.21	-0.08
					ψ_{pdP}	=	0.99	1.22	-1.40	3.37
					$\psi_{grsL3*grs}$	=	6.71	2.06	2.68	10.74
					$\psi_{grsL3*ag}$	=	6.62	3.24	0.27	12.96
					$\psi_{grsL3*pd}$	=	0.58	1.16	-1.71	2.86
$p_{s+day+\ day^2+eff+wind}\ \psi_{s\times grsL3+pdL2}$	799.47	2.07	0.11	14	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.73	0.57	-1.85	0.39
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-0.02	0.88	-1.75	1.71
					ψ_{grs}	=	-5.87	1.99	-9.77	-1.97

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{ag}	=	-4.32	1.55	-7.37	-1.28
					ψ_{pdL2}	=	0.52	1.38	-2.18	3.22
					$\psi_{grsL3*grs}$	=	6.74	2.06	2.70	10.78
					$\psi_{grsL3*ag}$	=	6.54	3.20	0.28	12.80
					$\psi_{grsL3*pd}$	=	0.51	1.19	-1.82	2.84
$p_{s+day+\ day^2+eff+wind}\ \psi_{s\times grsL2+pdP}$	800.20	2.81	0.08	14	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.76	0.60	-1.93	0.42
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-0.63	1.33	-3.25	1.98
					ψ_{grs}	=	-5.96	2.49	-10.85	-1.07
					ψ_{ag}	=	-3.31	1.77	-6.77	0.15
					ψ_{pdP}	=	1.00	1.24	-1.43	3.43
					$\psi_{grsL2*grs}$	=	7.31	2.32	2.77	11.85
					$\psi_{grsL2*ag}$	=	6.16	3.40	-0.49	12.81
					$\psi_{grsL2*pd}$	=	0.44	1.18	-1.88	2.76
$p_{s+day+\ day^2+eff+wind}\ \psi_{s\times grsL2+pdL2}$	800.61	3.21	0.06	14	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.75	0.59	-1.91	0.42
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-0.01	0.93	-1.84	1.82

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{grs}	=	-6.67	2.27	-11.11	-2.23
					ψ_{ag}	=	-3.92	1.49	-6.84	-1.00
					ψ_{pdL2}	=	0.71	1.47	-2.18	3.59
					$\psi_{grsL2*grs}$	=	7.40	2.33	2.83	11.97
					$\psi_{grsL2*ag}$	=	6.08	3.34	-0.46	12.62
					$\psi_{grsL2*pd}$	=	0.44	1.27	-2.05	2.92
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1}$	801.58	4.18	0.04	13	p_{int}	=	-1.64	0.40	-2.43	-0.86
					p_{grs}	=	0.52	0.25	0.02	1.01
					p_{ag}	=	-0.66	0.54	-1.72	0.40
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.19	1.12
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	0.46	0.44	-0.40	1.32
					ψ_{grs}	=	-11.45	3.66	-18.63	-4.26
					ψ_{ag}	=	-3.35	0.74	-4.80	-1.90
					$\psi_{grsL1*grs}$	=	11.49	3.79	4.06	18.91
					$\psi_{grsL1*ag}$	=	4.76	2.25	0.35	9.17
					$\psi_{grsL1*pd}$	=	-0.17	1.08	-2.29	1.95
$p_{s+day+eff+wind}\ \psi_{s\times grsL3}$	802.49	5.10	0.02	12	p_{int}	=	-1.12	0.33	-1.77	-0.46
					p_{grs}	=	0.51	0.25	0.02	1.00
					p_{ag}	=	-0.71	0.56	-1.81	0.38
					p_{day}	=	0.04	0.01	0.02	0.05
					p_{eff}	=	1.03	0.25	0.54	1.53
					p_{wind}	=	-0.24	0.07	-0.37	-0.10
					ψ_{int}	=	0.21	0.70	-1.16	1.59
					ψ_{grs}	=	-6.06	1.94	-9.86	-2.26

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{ag}	=	-4.61	1.45	-7.45	-1.77
					$\psi_{grsL3*grs}$	=	6.69	2.05	2.67	10.71
					$\psi_{grsL3*ag}$	=	6.65	3.21	0.36	12.93
					$\psi_{grsL3*pd}$	=	0.34	1.15	-1.92	2.59
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL1+pdP}$	803.22	5.82	0.02	14	p_{int}	=	-1.64	0.40	-2.43	-0.85
					p_{grs}	=	0.51	0.25	0.02	1.01
					p_{ag}	=	-0.66	0.54	-1.72	0.40
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.46	0.33	-0.20	1.11
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-0.57	1.41	-3.34	2.20
					ψ_{grs}	=	-10.41	3.90	-18.06	-2.76
					ψ_{ag}	=	-2.32	1.53	-5.32	0.69
					ψ_{pdP}	=	1.07	1.40	-1.67	3.80
					$\psi_{grsL1*grs}$	=	11.49	3.79	4.06	18.91
					$\psi_{grsL1*ag}$	=	4.75	2.25	0.35	9.16
					$\psi_{grsL1*pd}$	=	0.35	1.27	-2.15	2.84
$p_{s+day+eff+wind}\ \psi_{s\times grsL2}$	803.73	6.33	0.01	12	p_{int}	=	-1.12	0.33	-1.77	-0.47
					p_{grs}	=	0.51	0.25	0.02	1.00
					p_{ag}	=	-0.72	0.58	-1.85	0.40
					p_{day}	=	0.04	0.01	0.02	0.05
					p_{eff}	=	1.03	0.25	0.54	1.53
					p_{wind}	=	-0.24	0.07	-0.37	-0.10
					ψ_{int}	=	0.35	0.66	-0.94	1.63
					ψ_{grs}	=	-6.93	2.20	-11.25	-2.61
					ψ_{ag}	=	-4.31	1.32	-6.89	-1.72

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					$\psi_{grsL2*grs}$	=	7.30	2.31	2.77	11.83
					$\psi_{grsL2*ag}$	=	6.14	3.29	-0.31	12.59
					$\psi_{grsL2*pd}$	=	0.12	1.15	-2.14	2.37
$p_{s+t}\ \psi_{s\times grsL3}$	803.73	6.34	0.01	12	p_{int}	=	0.18	0.24	-0.30	0.65
					p_{grs}	=	0.59	0.25	0.09	1.09
					p_{ag}	=	-0.86	0.58	-1.99	0.26
					p_{t1}	=	-1.83	0.34	-2.49	-1.17
					p_{t2}	=	0.05	0.27	-0.48	0.59
					p_{t3}	=	0.07	0.27	-0.46	0.61
					ψ_{int}	=	0.20	0.71	-1.19	1.58
					ψ_{grs}	=	-6.02	1.94	-9.81	-2.22
					ψ_{ag}	=	-4.70	1.56	-7.75	-1.65
					$\psi_{grsL3*grs}$	=	6.66	2.04	2.65	10.66
					$\psi_{grsL3*ag}$	=	7.29	3.61	0.22	14.37
					$\psi_{grsL3*pd}$	=	0.43	1.17	-1.87	2.73
$p_{s+day+\ day^2+eff+wind}\ \psi_{s+grsL3}$	803.89	6.50	0.01	11	p_{int}	=	-1.67	0.40	-2.46	-0.88
					p_{grs}	=	0.55	0.26	0.05	1.06
					p_{ag}	=	-0.56	0.51	-1.56	0.43
					p_{day}	=	0.12	0.03	0.06	0.18
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.45	0.33	-0.21	1.10
					p_{wind}	=	-0.25	0.07	-0.39	-0.11
					ψ_{int}	=	-1.26	0.54	-2.31	-0.21
					ψ_{grs}	=	-1.43	0.47	-2.35	-0.51
					ψ_{ag}	=	-1.78	0.49	-2.75	-0.82
					ψ_{grsL3}	=	3.06	0.92	1.25	4.87

Table 2.25. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
$\psi_{.}$	0.04
ψ_{s}	0.91
ψ_{pdP}	0.24
ψ_{pdL1}	0.14
ψ_{pdL2}	0.02
ψ_{pdL3}	0.02
ψ_{grsL1}	0.12
ψ_{grsL2}	0.26
ψ_{grsL3}	0.41

Table 2.26. Covariate estimates ($\hat{\beta}_i$) under the top 25 occupancy models (AIC_c weight [w_i] ≥ 0.01) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
$p_{s+day+temp+wind}$ $\psi_{s\times grsL3}$	573.58	0.00	0.11	11	p_{int}	= -0.20	0.53	-1.23	0.83
					p_{grs}	= -0.88	0.36	-1.59	-0.16
					p_{ag}	= -1.65	1.07	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= 0.80	0.78	-0.73	2.33
					ψ_{grs}	= -2.79	2.03	-6.77	1.18
					ψ_{ag}	= -2.94	1.22	-5.33	-0.55
					$\psi_{grsL3*grs}$	= 2.56	2.21	-1.76	6.88
					$\psi_{grsL3*pd}$	= -2.63	1.33	-5.24	-0.03
$p_{s+day+temp+wind}$ $\psi_{s\times grsL3+pdP}$	573.96	0.38	0.09	12	p_{int}	= -0.21	0.53	-1.24	0.83
					p_{grs}	= -0.86	0.37	-1.58	-0.14
					p_{ag}	= -1.63	1.07	-3.72	0.46
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.34	0.09	-0.53	-0.16
					ψ_{int}	= 2.58	1.67	-0.70	5.86
					ψ_{grs}	= -4.57	2.51	-9.49	0.34
					ψ_{ag}	= -4.73	1.92	-8.49	-0.97
					ψ_{pdP}	= -1.92	1.49	-4.85	1.01
					$\psi_{grsL3*grs}$	= 2.55	2.20	-1.77	6.87
					$\psi_{grsL3*pd}$	= -3.03	1.42	-5.82	-0.24

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
$p_{s+day+temp+wind}\ \psi_{s+grsL3}$	574.08	0.50	0.08	10	p_{int}	= -0.18	0.52	-1.20	0.85
					p_{grs}	= -0.97	0.38	-1.71	-0.23
					p_{ag}	= -1.61	1.03	-3.63	0.41
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.54	-0.17
					ψ_{int}	= 0.42	0.71	-0.98	1.82
					ψ_{grs}	= 1.59	0.73	0.15	3.02
					ψ_{ag}	= -2.09	1.01	-4.08	-0.11
					ψ_{grsL3}	= -1.94	1.20	-4.30	0.41
$p_{s+day+temp+wind}\ \psi_{s+grsL2}$	574.20	0.62	0.08	10	p_{int}	= -0.18	0.52	-1.21	0.84
					p_{grs}	= -0.96	0.37	-1.69	-0.22
					p_{ag}	= -1.60	1.02	-3.60	0.41
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.54	-0.17
					ψ_{int}	= 0.31	0.66	-0.98	1.61
					ψ_{grs}	= 1.67	0.76	0.18	3.17
					ψ_{ag}	= -2.09	1.00	-4.05	-0.12
					ψ_{grsL2}	= -1.90	1.18	-4.22	0.42
$p_{s+day+temp+wind}\ \psi_{s\times grsL3+pdL1}$	574.56	0.98	0.06	12	p_{int}	= -0.19	0.53	-1.22	0.84
					p_{grs}	= -0.87	0.37	-1.59	-0.15
					p_{ag}	= -1.64	1.06	-3.73	0.45
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					ψ_{int}	= 1.66	1.17	-0.62	3.95
					ψ_{grs}	= -3.61	2.18	-7.88	0.67
					ψ_{ag}	= -3.81	1.49	-6.74	-0.88
					ψ_{pdL1}	= -1.27	1.17	-3.57	1.03
					$\psi_{grsL3*grs}$	= 2.50	2.20	-1.80	6.81
					$\psi_{grsL3*pd}$	= -2.97	1.40	-5.72	-0.23
$p_{s+day+temp+wind}\ \psi_{s\times grsL2}$	574.71	1.14	0.06	11	p_{int}	= -0.20	0.53	-1.23	0.83
					p_{grs}	= -0.88	0.36	-1.59	-0.16
					p_{ag}	= -1.65	1.07	-3.74	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= 0.54	0.72	-0.87	1.95
					ψ_{grs}	= -2.48	2.13	-6.66	1.69
					ψ_{ag}	= -2.69	1.18	-5.00	-0.37
					$\psi_{grsL2*grs}$	= 2.41	2.27	-2.04	6.86
					$\psi_{grsL2*pd}$	= -2.34	1.31	-4.91	0.23
$p_{s+day+temp+wind}\ \psi_{s\times grsL2+pdP}$	574.75	1.18	0.06	12	p_{int}	= -0.20	0.53	-1.24	0.83
					p_{grs}	= -0.86	0.37	-1.57	-0.14
					p_{ag}	= -1.63	1.07	-3.72	0.46
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.34	0.09	-0.53	-0.16
					ψ_{int}	= 2.56	1.69	-0.76	5.88
					ψ_{grs}	= -4.50	2.62	-9.64	0.64
					ψ_{ag}	= -4.71	1.94	-8.50	-0.92
					ψ_{pdP}	= -2.11	1.52	-5.09	0.86

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					$\psi_{grsL2*grs}$	= 2.40	2.27	-2.04	6.85
					$\psi_{grsL2*pd}$	= -2.91	1.44	-5.73	-0.10
$p_{s+day+temp+wind}\ \psi_{s\times grsL2+pdL1}$	574.90	1.32	0.05	12	p_{int}	= -0.19	0.53	-1.22	0.84
					p_{grs}	= -0.87	0.37	-1.58	-0.15
					p_{ag}	= -1.64	1.06	-3.73	0.45
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.34	0.09	-0.53	-0.16
					ψ_{int}	= 1.86	1.26	-0.62	4.33
					ψ_{grs}	= -3.73	2.34	-8.31	0.86
					ψ_{ag}	= -4.00	1.57	-7.08	-0.92
					ψ_{pdL1}	= -1.72	1.25	-4.17	0.74
					$\psi_{grsL2*grs}$	= 2.33	2.26	-2.10	6.77
					$\psi_{grsL2*pd}$	= -3.11	1.48	-6.01	-0.20
$p_{s+day+temp+wind}\ \psi_{s}$	574.94	1.36	0.05	9	p_{int}	= -0.17	0.52	-1.20	0.86
					p_{grs}	= -0.89	0.37	-1.60	-0.17
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= -0.66	0.26	-1.18	-0.14
					ψ_{grs}	= 0.86	0.47	-0.07	1.78
					ψ_{ag}	= -1.49	0.97	-3.40	0.42
$p_{s+day+eff+temp+wind}\ \psi_{s\times grsL3}$	575.74	2.16	0.04	12	p_{int}	= -0.20	0.53	-1.24	0.83
					p_{grs}	= -0.87	0.36	-1.59	-0.16
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					p_{eff}	= 0.04	0.29	-0.54	0.62
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= 0.79	0.78	-0.73	2.32
					ψ_{grs}	= -2.80	2.03	-6.77	1.18
					ψ_{ag}	= -2.94	1.22	-5.33	-0.56
					$\psi_{grsL3*grs}$	= 2.56	2.20	-1.76	6.88
					$\psi_{grsL3*pd}$	= -2.63	1.33	-5.23	-0.03
$p_{s+day+temp+wind}\ \psi_{s+pdP+grsL1}$	575.88	2.30	0.03	11	p_{int}	= -0.19	0.52	-1.22	0.84
					p_{grs}	= -0.92	0.37	-1.64	-0.19
					p_{ag}	= -1.60	1.04	-3.63	0.43
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= 2.00	1.63	-1.20	5.20
					ψ_{grs}	= 0.24	1.25	-2.20	2.68
					ψ_{ag}	= -3.94	1.79	-7.45	-0.43
					ψ_{pdP}	= -2.43	1.62	-5.60	0.73
					ψ_{grsL1}	= -2.08	1.40	-4.83	0.66
$p_{s+day+temp+wind}\ \psi_{.}$	576.08	2.50	0.03	7	p_{int}	= -0.30	0.54	-1.35	0.75
					p_{grs}	= -0.54	0.33	-1.18	0.09
					p_{ag}	= -3.01	0.55	-4.08	-1.94
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.09	0.03	0.04	0.14
					p_{wind}	= -0.32	0.09	-0.50	-0.13
					ψ_{int}	= -0.33	0.20	-0.74	0.07

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
$p_{s+day+eff+temp+wind}\ \psi_{s\times grsL3+pdP}$	576.13	2.55	0.03	13	p_{int}	= -0.21	0.53	-1.25	0.82
					p_{grs}	= -0.85	0.37	-1.57	-0.13
					p_{ag}	= -1.62	1.06	-3.71	0.46
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{eff}	= 0.05	0.29	-0.52	0.63
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.34	0.09	-0.53	-0.16
					ψ_{int}	= 2.58	1.67	-0.69	5.86
					ψ_{grs}	= -4.58	2.51	-9.49	0.33
					ψ_{ag}	= -4.73	1.92	-8.49	-0.98
					ψ_{pdP}	= -1.92	1.49	-4.85	1.00
					$\psi_{grsL3*grs}$	= 2.56	2.20	-1.76	6.87
					$\psi_{grsL3*pd}$	= -3.03	1.42	-5.82	-0.24
$p_{s+day+temp+wind}\ \psi_{s+pdP}$	576.20	2.62	0.03	10	p_{int}	= -0.17	0.52	-1.19	0.85
					p_{grs}	= -0.88	0.37	-1.59	-0.16
					p_{ag}	= -1.64	1.06	-3.73	0.45
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= 0.33	1.10	-1.82	2.49
					ψ_{grs}	= -0.14	1.17	-2.43	2.15
					ψ_{ag}	= -2.48	1.45	-5.32	0.35
					ψ_{pdP}	= -1.23	1.32	-3.81	1.35
$p_{s+day+temp+wind}\ \psi_{s+grsL1}$	576.23	2.65	0.03	10	p_{int}	= -0.18	0.52	-1.21	0.84
					p_{grs}	= -0.90	0.37	-1.62	-0.18
					p_{ag}	= -1.62	1.05	-3.67	0.43
					p_{day}	= -0.04	0.01	-0.05	-0.02

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.17
					ψ_{int}	= -0.32	0.46	-1.21	0.57
					ψ_{grs}	= 1.52	0.89	-0.21	3.26
					ψ_{ag}	= -1.72	0.99	-3.65	0.21
					ψ_{grsL1}	= -1.03	1.13	-3.26	1.19
$p_{s+day+temp+wind}\ \psi_{s\times grsL1}$	576.25	2.67	0.03	11	p_{int}	= -0.20	0.53	-1.23	0.83
					p_{grs}	= -0.87	0.36	-1.58	-0.16
					p_{ag}	= -1.64	1.07	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= -0.27	0.48	-1.21	0.68
					ψ_{grs}	= -4.64	3.63	-11.75	2.47
					ψ_{ag}	= -1.88	1.05	-3.95	0.18
					$\psi_{grsL1*grs}$	= 5.38	3.83	-2.13	12.90
					$\psi_{grsL1*pd}$	= -1.20	1.23	-3.61	1.21
$p_{s+day+temp+wind}\ \psi_{grsL1}$	576.33	2.75	0.03	8	p_{int}	= -0.22	0.53	-1.25	0.82
					p_{grs}	= -0.72	0.34	-1.39	-0.05
					p_{ag}	= -2.86	0.57	-3.98	-1.73
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.33	0.09	-0.52	-0.15
					ψ_{int}	= -0.80	0.39	-1.56	-0.03
					ψ_{grsL1}	= 0.77	0.57	-0.35	1.88
$p_{s+day+temp+wind}\ \psi_{s+pdL1}$	576.69	3.11	0.02	10	p_{int}	= -0.16	0.52	-1.18	0.86
					p_{grs}	= -0.88	0.36	-1.60	-0.17

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= -0.30	0.63	-1.53	0.93
					ψ_{grs}	= 0.50	0.73	-0.94	1.94
					ψ_{ag}	= -1.85	1.13	-4.05	0.36
					ψ_{pdL1}	= -0.68	1.08	-2.80	1.44
$p_{s+day+temp+wind}\ \psi_{s+pdL2}$	577.06	3.48	0.02	10	p_{int}	= -0.17	0.52	-1.19	0.86
					p_{grs}	= -0.89	0.36	-1.60	-0.17
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= -0.59	0.45	-1.49	0.30
					ψ_{grs}	= 0.79	0.59	-0.36	1.94
					ψ_{ag}	= -1.55	1.04	-3.59	0.48
					ψ_{pdL2}	= -0.26	1.42	-3.04	2.53
$p_{s+day+eff+temp+wind}\ \psi_{s}$	577.08	3.50	0.02	10	p_{int}	= -0.17	0.53	-1.20	0.86
					p_{grs}	= -0.88	0.37	-1.60	-0.17
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{eff}	= 0.03	0.29	-0.55	0.61
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					ψ_{int}	= -0.66	0.26	-1.18	-0.14
					ψ_{grs}	= 0.85	0.47	-0.07	1.77
					ψ_{ag}	= -1.49	0.97	-3.39	0.42
$p_{s+day+temp+wind}\ \psi_{s+pdL3}$	577.09	3.51	0.02	10	p_{int}	= -0.17	0.52	-1.20	0.86
					p_{grs}	= -0.89	0.37	-1.60	-0.17
					p_{ag}	= -1.65	1.06	-3.73	0.44
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.10	0.03	0.05	0.15
					p_{wind}	= -0.35	0.09	-0.53	-0.16
					ψ_{int}	= -0.67	0.42	-1.49	0.16
					ψ_{grs}	= 0.86	0.56	-0.23	1.95
					ψ_{ag}	= -1.49	1.02	-3.49	0.52
					ψ_{pdL3}	= 0.02	1.73	-3.37	3.42
$p_{s+day+temp+wind}\ \psi_{grsL2}$	578.01	4.43	0.01	8	p_{int}	= -0.28	0.54	-1.33	0.77
					p_{grs}	= -0.59	0.34	-1.24	0.07
					p_{ag}	= -2.94	0.57	-4.07	-1.82
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.09	0.03	0.05	0.14
					p_{wind}	= -0.32	0.09	-0.50	-0.14
					ψ_{int}	= -0.56	0.54	-1.61	0.50
					ψ_{grsL2}	= 0.32	0.72	-1.10	1.74
$p_{s+day+temp+wind}\ \psi_{grsL3}$	578.17	4.59	0.01	8	p_{int}	= -0.29	0.54	-1.35	0.76
					p_{grs}	= -0.56	0.33	-1.21	0.10
					p_{ag}	= -2.98	0.57	-4.10	-1.86
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.09	0.03	0.05	0.14
					p_{wind}	= -0.32	0.09	-0.50	-0.13

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$		SE	LCL	UCL
					ψ_{int}	= -0.44	0.58	-1.58	0.70
					ψ_{grsL3}	= 0.15	0.78	-1.39	1.68
$p_{day+temp+wind}\ \psi_s$	578.19	4.61	0.01	7	p_{int}	= -0.72	0.49	-1.68	0.23
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{temp}	= 0.09	0.02	0.04	0.14
					p_{wind}	= -0.31	0.09	-0.49	-0.13
					ψ_{int}	= -0.42	0.29	-0.99	0.15
					ψ_{grs}	= 0.32	0.38	-0.42	1.06
					ψ_{ag}	= -2.35	0.59	-3.50	-1.20
$p_{s+day+eff+temp+wind}\ \psi_{.}$	578.20	4.62	0.01	8	p_{int}	= -0.31	0.54	-1.36	0.75
					p_{grs}	= -0.54	0.33	-1.18	0.10
					p_{ag}	= -3.01	0.55	-4.08	-1.94
					p_{day}	= -0.04	0.01	-0.05	-0.02
					p_{eff}	= 0.02	0.30	-0.55	0.60
					p_{temp}	= 0.09	0.03	0.04	0.14
					p_{wind}	= -0.32	0.09	-0.50	-0.13
					ψ_{int}	= -0.34	0.21	-0.74	0.07

Table 2.27. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
ψ_s	1.0
ψ_{pdL2}	0.04
ψ_{pdL3}	0.96
ψ_{grsL3}	0.26

Table 2.28. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+day+\ day^2+eff+wind}\ \psi_{s+pdL3}$	1286.63	0.00	0.20	11	p_{int}	=	0.21	0.29	-0.35	0.78
					p_{grs}	=	0.53	0.20	0.14	0.93
					p_{ag}	=	-0.29	0.21	-0.70	0.12
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					p_{wind}	=	-0.08	0.05	-0.17	0.02
					ψ_{int}	=	3.03	0.71	1.64	4.43
					ψ_{grs}	=	-0.68	0.74	-2.13	0.76
					ψ_{ag}	=	-2.00	0.73	-3.44	-0.57
					ψ_{pdL3}	=	-8.59	2.36	-13.21	-3.97
$p_{s+day+\ day^2+eff}\ \psi_{s+pdL3}$	1287.02	0.38	0.16	10	p_{int}	=	0.09	0.28	-0.45	0.64
					p_{grs}	=	0.51	0.20	0.12	0.89
					p_{ag}	=	-0.30	0.21	-0.71	0.11
					p_{day}	=	0.06	0.02	0.02	0.10
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					ψ_{int}	=	2.99	0.69	1.64	4.35
					ψ_{grs}	=	-0.65	0.72	-2.06	0.76
					ψ_{ag}	=	-1.96	0.71	-3.36	-0.57
					ψ_{pdL3}	=	-8.48	2.31	-13.00	-3.96

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+day+day^2+wind}\ \psi_{s+pdL3}$	1287.14	0.51	0.15	10	p_{int}	=	0.14	0.28	-0.42	0.70
					p_{grs}	=	0.53	0.20	0.13	0.92
					p_{ag}	=	-0.29	0.21	-0.71	0.12
					p_{day}	=	0.08	0.02	0.05	0.12
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{wind}	=	-0.08	0.05	-0.17	0.02
					ψ_{int}	=	3.05	0.72	1.63	4.47
					ψ_{grs}	=	-0.69	0.75	-2.16	0.77
					ψ_{ag}	=	-2.02	0.74	-3.47	-0.57
					ψ_{pdL3}	=	-8.64	2.38	-13.31	-3.98
$p_{s+day+day^2}\ \psi_{s+pdL3}$	1287.49	0.85	0.13	9	p_{int}	=	0.02	0.27	-0.52	0.56
					p_{grs}	=	0.50	0.20	0.11	0.89
					p_{ag}	=	-0.31	0.21	-0.72	0.10
					p_{day}	=	0.08	0.02	0.04	0.12
					p_{day^2}	=	0.00	0.00	0.00	0.00
					ψ_{int}	=	3.01	0.70	1.64	4.38
					ψ_{grs}	=	-0.66	0.73	-2.08	0.77
					ψ_{ag}	=	-1.97	0.72	-3.38	-0.57
					ψ_{pdL3}	=	-8.53	2.32	-13.08	-3.97
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL3+grsL3}$	1287.88	1.25	0.11	12	p_{int}	=	0.22	0.29	-0.35	0.78
					p_{grs}	=	0.53	0.20	0.14	0.92
					p_{ag}	=	-0.30	0.21	-0.72	0.11
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					p_{wind}	=	-0.08	0.05	-0.17	0.02

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	2.36	0.96	0.49	4.24
					ψ_{grs}	=	-0.88	0.77	-2.38	0.62
					ψ_{ag}	=	-1.62	0.81	-3.20	-0.04
					ψ_{pdL3}	=	-8.16	2.36	-12.78	-3.53
					ψ_{grsL3}	=	1.02	1.06	-1.07	3.11
$p_{s+day+ day^2+eff}\ \psi_{s+pdL3+grsL3}$	1288.18	1.55	0.09	11	p_{int}	=	0.10	0.28	-0.45	0.64
					p_{grs}	=	0.50	0.20	0.11	0.89
					p_{ag}	=	-0.32	0.21	-0.73	0.10
					p_{day}	=	0.06	0.02	0.02	0.10
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					ψ_{int}	=	2.30	0.94	0.47	4.14
					ψ_{grs}	=	-0.85	0.75	-2.33	0.62
					ψ_{ag}	=	-1.57	0.79	-3.12	-0.03
					ψ_{pdL3}	=	-8.05	2.32	-12.59	-3.51
					ψ_{grsL3}	=	1.05	1.06	-1.03	3.13
$p_{s+t}\ \psi_{s+pdL3}$	1289.64	3.01	0.04	10	p_{int}	=	-0.03	0.19	-0.39	0.34
					p_{grs}	=	0.50	0.20	0.11	0.88
					p_{ag}	=	-0.33	0.21	-0.74	0.09
					p_{t1}	=	0.67	0.21	0.26	1.08
					p_{t2}	=	1.26	0.22	0.83	1.68
					p_{t3}	=	0.43	0.20	0.05	0.82
					ψ_{int}	=	3.03	0.71	1.65	4.42
					ψ_{grs}	=	-0.68	0.73	-2.12	0.75
					ψ_{ag}	=	-1.99	0.72	-3.41	-0.57
					ψ_{pdL3}	=	-8.55	2.34	-13.14	-3.96

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+day+day^2+eff+wind}\ \psi_{s\times pdL3}$	1290.60	3.97	0.03	13	p_{int}	=	0.21	0.29	-0.36	0.77
					p_{grs}	=	0.54	0.20	0.14	0.94
					p_{ag}	=	-0.28	0.21	-0.70	0.14
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					p_{wind}	=	-0.08	0.05	-0.17	0.02
					ψ_{int}	=	3.21	0.86	1.53	4.90
					ψ_{grs}	=	-0.87	0.95	-2.74	0.99
					ψ_{ag}	=	-2.24	0.90	-4.01	-0.48
					$\psi_{pdL3*grs}$	=	-8.05	8.17	-24.07	7.96
					$\psi_{pdL3*ag}$	=	-4.17	7.43	-18.74	10.39
					$\psi_{pdL3*pd}$	=	-9.23	2.84	-14.80	-3.66
$p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3+pdL3}$	1290.81	4.18	0.02	14	p_{int}	=	0.21	0.29	-0.36	0.77
					p_{grs}	=	0.53	0.20	0.13	0.92
					p_{ag}	=	-0.30	0.21	-0.71	0.12
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.87
					p_{wind}	=	-0.08	0.05	-0.17	0.02
					ψ_{int}	=	1.48	1.20	-0.88	3.83
					ψ_{grs}	=	-0.81	2.08	-4.89	3.27
					ψ_{ag}	=	-0.39	1.30	-2.94	2.17
					ψ_{pdL3}	=	-7.56	2.34	-12.15	-2.97

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					$\psi_{grsL3*grs}$	=	1.98	2.12	-2.18	6.14
					$\psi_{grsL3*ag}$	=	-0.26	1.42	-3.04	2.52
					$\psi_{grsL3*pd}$	=	2.42	1.92	-1.34	6.19
$p_{s+day+day^2+eff}\ \psi_{s\times grsL3+pdL3}$	1291.05	4.42	0.02	13	p_{int}	=	0.09	0.28	-0.46	0.63
					p_{grs}	=	0.50	0.20	0.11	0.89
					p_{ag}	=	-0.31	0.21	-0.72	0.10
					p_{day}	=	0.06	0.02	0.02	0.10
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					ψ_{int}	=	1.44	1.18	-0.88	3.75
					ψ_{grs}	=	-0.77	2.07	-4.82	3.28
					ψ_{ag}	=	-0.35	1.29	-2.87	2.17
					ψ_{pdL3}	=	-7.48	2.31	-11.99	-2.96
					$\psi_{grsL3*grs}$	=	1.99	2.12	-2.16	6.13
					$\psi_{grsL3*ag}$	=	-0.25	1.42	-3.05	2.54
					$\psi_{grsL3*pd}$	=	2.44	1.89	-1.27	6.14
$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL2}$	1291.20	4.57	0.02	11	p_{int}	=	0.21	0.29	-0.36	0.78
					p_{grs}	=	0.54	0.20	0.14	0.93
					p_{ag}	=	-0.29	0.21	-0.70	0.13
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					p_{wind}	=	-0.08	0.05	-0.17	0.02

….table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	3.03	0.78	1.50	4.57
					ψ_{grs}	=	-0.76	0.82	-2.36	0.83
					ψ_{ag}	=	-2.05	0.80	-3.63	-0.48
					ψ_{pdL2}	=	-6.20	1.92	-9.96	-2.44
$p_{s+day+\ day^2+eff+wind}\ \psi_{s+pdL2+grsL3}$	1291.96	5.32	0.01	12	p_{int}	=	0.21	0.29	-0.36	0.78
					p_{grs}	=	0.53	0.20	0.14	0.93
					p_{ag}	=	-0.30	0.21	-0.72	0.12
					p_{day}	=	0.06	0.02	0.02	0.11
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{eff}	=	0.39	0.24	-0.08	0.86
					p_{wind}	=	-0.08	0.05	-0.17	0.02
					ψ_{int}	=	2.23	0.99	0.30	4.17
					ψ_{grs}	=	-1.01	0.85	-2.66	0.65
					ψ_{ag}	=	-1.59	0.87	-3.29	0.10
					ψ_{pdL2}	=	-5.84	1.92	-9.60	-2.08
					ψ_{grsL3}	=	1.23	1.05	-0.82	3.29

Table 2.29. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
ψ_s	1.0
ψ_{pdL2}	0.33
ψ_{pdL3}	0.67
ψ_{grsL2}	0.07
ψ_{grsL3}	0.91

Table 2.30. Covariate estimates ($\hat{\beta}_i$) under the top 12 occupancy models (AIC_c weight [w_i] ≥ 0.01) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (*K*), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL3}$	828.10	0.00	0.21	11	p_{int}	=	-1.34	0.45	-2.22	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	3.38	1.19	1.05	5.70
					ψ_{grs}	=	-3.89	1.77	-7.35	-0.43
					ψ_{ag}	=	-2.51	1.27	-5.00	-0.02
					ψ_{pdL3}	=	-12.20	3.27	-18.62	-5.79
					$\psi_{grsL3*grs}$	=	-0.06	1.59	-3.17	3.04
					$\psi_{grsL3*ag}$	=	-1.16	1.29	-3.69	1.38
					$\psi_{grsL3*pd}$	=	-4.69	1.61	-7.85	-1.54
$p_{day+\ day^2}\ \psi_{s\times grsL3+pdL3}$	828.97	0.87	0.14	10	p_{int}	=	-1.78	0.39	-2.53	-1.02
					p_{day}	=	0.09	0.03	0.04	0.14
					p_{day^2}	=	0.00	0.00	0.00	0.00
					ψ_{int}	=	3.34	1.17	1.05	5.63
					ψ_{grs}	=	-3.85	1.75	-7.29	-0.41
					ψ_{ag}	=	-2.47	1.25	-4.92	-0.01
					ψ_{pdL3}	=	-12.18	3.27	-18.58	-5.77
					$\psi_{grsL3*grs}$	=	-0.06	1.58	-3.17	3.04
					$\psi_{grsL3*ag}$	=	-1.17	1.29	-3.70	1.36
					$\psi_{grsL3*pd}$	=	-4.65	1.59	-7.76	-1.54

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{day+\ day^2+temp}\ \psi_{s+pdL3+grsL3}$	829.12	1.01	0.13	9	p_{int}	=	-1.34	0.45	-2.23	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	1.64	0.67	0.32	2.97
					ψ_{grs}	=	-0.50	0.50	-1.48	0.48
					ψ_{ag}	=	-0.53	0.55	-1.60	0.54
					ψ_{pdL3}	=	-10.71	2.93	-16.45	-4.97
					ψ_{grsL3}	=	-2.04	0.80	-3.60	-0.47
$p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL2}$	829.45	1.34	0.11	11	p_{int}	=	-1.34	0.45	-2.23	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	3.60	1.25	1.14	6.05
					ψ_{grs}	=	-4.17	1.81	-7.71	-0.63
					ψ_{ag}	=	-2.74	1.33	-5.36	-0.13
					ψ_{pdL2}	=	-9.38	2.55	-14.39	-4.38
					$\psi_{grsL3*grs}$	=	-0.08	1.59	-3.20	3.05
					$\psi_{grsL3*ag}$	=	-1.29	1.28	-3.80	1.23
					$\psi_{grsL3*pd}$	=	-4.76	1.63	-7.96	-1.56
$p_{day+\ day^2+temp+wind}\ \psi_{s\times grsL3+pdL3}$	830.23	2.12	0.07	12	p_{int}	=	-1.32	0.46	-2.22	-0.42
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.01
					p_{wind}	=	-0.02	0.07	-0.16	0.13

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{int}	=	3.39	1.19	1.05	5.72
					ψ_{grs}	=	-3.90	1.77	-7.36	-0.43
					ψ_{ag}	=	-2.52	1.27	-5.02	-0.02
					ψ_{pdL3}	=	-12.22	3.28	-18.65	-5.79
					$\psi_{grsL3*grs}$	=	-0.06	1.59	-3.17	3.04
					$\psi_{grsL3*ag}$	=	-1.16	1.29	-3.69	1.37
					$\psi_{grsL3*pd}$	=	-4.71	1.61	-7.87	-1.54
$p_{day+\ day^2}\ \psi_{s\times grsL3+pdL2}$	830.28	2.18	0.07	10	p_{int}	=	-1.78	0.39	-2.53	-1.02
					p_{day}	=	0.09	0.03	0.04	0.14
					p_{day^2}	=	0.00	0.00	0.00	0.00
					ψ_{int}	=	3.57	1.24	1.14	5.99
					ψ_{grs}	=	-4.14	1.80	-7.66	-0.62
					ψ_{ag}	=	-2.71	1.32	-5.30	-0.12
					ψ_{pdL2}	=	-9.37	2.55	-14.36	-4.38
					$\psi_{grsL3*grs}$	=	-0.08	1.59	-3.20	3.04
					$\psi_{grsL3*ag}$	=	-1.30	1.28	-3.81	1.22
					$\psi_{grsL3*pd}$	=	-4.72	1.62	-7.89	-1.55
$p_{day+\ day^2+temp}\ \psi_{s+pdL2+grsL3}$	830.39	2.29	0.07	9	p_{int}	=	-1.34	0.45	-2.23	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	1.81	0.71	0.42	3.21
					ψ_{grs}	=	-0.70	0.53	-1.75	0.34
					ψ_{ag}	=	-0.73	0.59	-1.88	0.42
					ψ_{pdL2}	=	-8.06	2.21	-12.38	-3.74
					ψ_{grsL3}	=	-2.08	0.80	-3.65	-0.51

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{day+temp}\ \psi_{s\times grsL3+pdL3}$	830.58	2.48	0.06	10	p_{int}	=	-0.74	0.34	-1.39	-0.08
					p_{day}	=	0.04	0.01	0.03	0.06
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	3.40	1.20	1.06	5.74
					ψ_{grs}	=	-3.91	1.77	-7.38	-0.44
					ψ_{ag}	=	-2.54	1.28	-5.04	-0.04
					ψ_{pdL3}	=	-12.24	3.29	-18.68	-5.80
					$\psi_{grsL3*grs}$	=	-0.06	1.58	-3.17	3.04
					$\psi_{grsL3*ag}$	=	-1.14	1.29	-3.67	1.40
					$\psi_{grsL3*pd}$	=	-4.72	1.62	-7.89	-1.55
$p_{day}\ \psi_{s\times grsL3+pdL3}$	831.50	3.39	0.04	9	p_{int}	=	-1.17	0.23	-1.63	-0.71
					p_{day}	=	0.04	0.01	0.02	0.05
					ψ_{int}	=	3.36	1.18	1.05	5.67
					ψ_{grs}	=	-3.87	1.76	-7.32	-0.42
					ψ_{ag}	=	-2.50	1.26	-4.97	-0.03
					ψ_{pdL3}	=	-12.21	3.28	-18.64	-5.78
					$\psi_{grsL3*grs}$	=	-0.06	1.58	-3.17	3.04
					$\psi_{grsL3*ag}$	=	-1.15	1.29	-3.68	1.38
					$\psi_{grsL3*pd}$	=	-4.67	1.60	-7.80	-1.55
$p_{day+\ day^2+temp}\ \psi_{s+pdL2+grsL2}$	831.56	3.45	0.04	9	p_{int}	=	-1.34	0.45	-2.23	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	1.74	0.72	0.33	3.16
					ψ_{grs}	=	-0.68	0.54	-1.74	0.38
					ψ_{ag}	=	-0.77	0.61	-1.96	0.42

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					ψ_{pdL2}	=	-8.35	2.22	-12.71	-3.99
					ψ_{grsL2}	=	-1.95	0.82	-3.55	-0.34
$p_{day+\ day^2+temp}\ \psi_{s\times grsL2+pdL2}$	831.91	3.81	0.03	11	p_{int}	=	-1.34	0.45	-2.22	-0.45
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	3.39	1.25	0.95	5.84
					ψ_{grs}	=	-3.50	1.90	-7.24	0.23
					ψ_{ag}	=	-2.68	1.31	-5.25	-0.12
					ψ_{pdL2}	=	-9.89	2.59	-14.96	-4.81
					$\psi_{grsL2*grs}$	=	-0.59	1.72	-3.95	2.77
					$\psi_{grsL2*ag}$	=	-0.89	1.25	-3.34	1.56
					$\psi_{grsL2*pd}$	=	-4.38	1.62	-7.56	-1.20
$p_{day+\ day^2+temp}\ \psi_{s+pdL3}$	833.73	5.62	0.01	8	p_{int}	=	-1.33	0.45	-2.22	-0.44
					p_{day}	=	0.10	0.03	0.04	0.15
					p_{day^2}	=	0.00	0.00	0.00	0.00
					p_{temp}	=	-0.03	0.02	-0.07	0.00
					ψ_{int}	=	0.37	0.44	-0.49	1.23
					ψ_{grs}	=	-0.96	0.46	-1.87	-0.06
					ψ_{ag}	=	0.13	0.47	-0.79	1.06
					ψ_{pdL3}	=	-10.14	2.92	-15.86	-4.41

Table 2.31. Cumulative AIC_c weight (Σw_i) of top occupancy model parameters for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Top models are those with AIC_c weight ≥ 0.01. Explanation and coding of model parameters are provided in Table 2.4.

Model parameter	Σw_i
$\psi_{.}$	0.28
ψ_{s}	0.05
ψ_{pdP}	0.05
ψ_{pdL1}	0.19
ψ_{pdL2}	0.09
ψ_{pdL3}	0.08
ψ_{grsL1}	0.21
ψ_{grsL2}	0.09
ψ_{grsL3}	0.08

Table 2.32. Covariate estimates ($\hat{\beta}_i$) under the top 17 occupancy models (AIC_c weight [w_i] ≥ 0.01) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 2.4.

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+eff+temp}\ \psi_{.}$	1153.46	0.00	0.20	6	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.81	-0.04
					p_{ag}	=	-0.24	0.21	-0.64	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.35	0.35	2.67	4.03
$p_{s+eff+temp}\ \psi_{pdL1}$	1154.83	1.37	0.10	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.44	0.20	-0.82	-0.05
					p_{ag}	=	-0.25	0.21	-0.65	0.15
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.55	0.45	2.68	4.42
					ψ_{pdL1}	=	-0.95	1.06	-3.02	1.12
$p_{s+eff+temp}\ \psi_{grsL1}$	1155.22	1.76	0.08	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.82	-0.04
					p_{ag}	=	-0.24	0.21	-0.64	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.11	0.51	2.11	4.11
					ψ_{grsL1}	=	0.55	0.97	-1.35	2.44
$p_{s+eff+temp}\ \psi_{pdL2}$	1155.32	1.86	0.08	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.82	-0.05
					p_{ag}	=	-0.24	0.21	-0.65	0.16

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.45	0.42	2.63	4.27
					ψ_{pdL2}	=	-1.00	1.93	-4.78	2.78
$p_{s+eff+temp}\ \psi_{grsL2}$	1155.36	1.90	0.08	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.81	-0.04
					p_{ag}	=	-0.24	0.21	-0.64	0.17
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.08	0.66	1.78	4.38
					ψ_{grsL2}	=	0.51	1.14	-1.72	2.75
$p_{s+eff+temp}\ \psi_{pdL3}$	1155.42	1.95	0.07	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.82	-0.05
					p_{ag}	=	-0.24	0.21	-0.65	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.43	0.41	2.62	4.24
					ψ_{pdL3}	=	-1.04	2.61	-6.15	4.06
$p_{s+eff+temp}\ \psi_{grsL3}$	1155.52	2.06	0.07	7	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.81	-0.04
					p_{ag}	=	-0.24	0.21	-0.64	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.21	0.74	1.76	4.66
					ψ_{grsL3}	=	0.25	1.20	-2.11	2.61

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+eff+temp}\ \psi_{pdL1+grsL1}$	1156.85	3.39	0.04	8	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.44	0.20	-0.82	-0.05
					p_{ag}	=	-0.24	0.21	-0.65	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.38	0.69	2.04	4.73
					ψ_{pdL1}	=	-0.81	1.14	-3.04	1.42
					ψ_{grsL1}	=	0.32	1.07	-1.78	2.42
$p_{s+eff+temp}\ \psi_{pdP+grsL1}$	1156.98	3.52	0.03	8	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.44	0.20	-0.82	-0.05
					p_{ag}	=	-0.24	0.21	-0.65	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.34	0.67	2.03	4.64
					ψ_{pdP}	=	-0.50	0.83	-2.14	1.13
					ψ_{grsL1}	=	0.39	1.05	-1.66	2.44
$p_{s+temp}\ \psi_{.}$	1157.09	3.63	0.03	5	p_{int}	=	2.31	0.30	1.73	2.90
					p_{grs}	=	-0.44	0.20	-0.82	-0.06
					p_{ag}	=	-0.25	0.20	-0.65	0.15
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.35	0.35	2.66	4.03
$p_{temp}\ \psi_{.}$	1158.12	4.66	0.02	3	p_{int}	=	2.06	0.26	1.55	2.57
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.38	0.35	2.68	4.07
$p_{s+temp}\ \psi_{pdL1}$	1158.42	4.96	0.02	6	p_{int}	=	2.31	0.30	1.73	2.90
					p_{grs}	=	-0.45	0.20	-0.83	-0.06
					p_{ag}	=	-0.26	0.20	-0.66	0.14

…table continued

…table continued

Model	AIC$_c$	Δ AIC$_c$	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.55	0.45	2.68	4.43
					ψ_{pdL1}	=	-0.96	1.06	-3.03	1.11
$p_{s+temp}\ \psi_{grsL1}$	1158.83	5.37	0.01	6	p_{int}	=	2.31	0.30	1.73	2.89
					p_{grs}	=	-0.44	0.20	-0.83	-0.06
					p_{ag}	=	-0.25	0.20	-0.65	0.15
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.11	0.51	2.11	4.11
					ψ_{grsL1}	=	0.55	0.97	-1.35	2.46
$p_{s+eff+temp}\ \psi_{s+pdL1}$	1159.02	5.56	0.01	9	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.44	0.20	-0.82	-0.05
					p_{ag}	=	-0.24	0.21	-0.65	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.72	1.68	0.42	7.02
					ψ_{grs}	=	-0.08	1.79	-3.59	3.43
					ψ_{ag}	=	-0.28	1.78	-3.77	3.22
					ψ_{pdL1}	=	-1.20	2.53	-6.16	3.77
$p_{s+eff+temp}\ \psi_{s+grsL1}$	1159.03	5.57	0.01	9	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.43	0.20	-0.82	-0.04
					p_{ag}	=	-0.24	0.21	-0.65	0.17
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	2.69	0.87	0.98	4.40
					ψ_{grs}	=	-0.22	2.23	-4.59	4.16
					ψ_{ag}	=	0.59	0.89	-1.16	2.34
					ψ_{grsL1}	=	1.23	2.92	-4.49	6.96

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+eff+temp}\ \psi_{s+pdP}$	1159.21	5.75	0.01	9	p_{int}	=	2.21	0.30	1.63	2.80
					p_{grs}	=	-0.44	0.20	-0.82	-0.05
					p_{ag}	=	-0.25	0.21	-0.65	0.16
					p_{eff}	=	0.43	0.19	0.07	0.80
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.68	3.11	-2.42	9.78
					ψ_{grs}	=	-0.06	3.19	-6.30	6.19
					ψ_{ag}	=	-0.24	3.17	-6.46	5.98
					ψ_{pdP}	=	-0.78	3.52	-7.67	6.12
$p_{temp}\ \psi_{pdL1}$	1159.60	6.14	0.01	4	p_{int}	=	2.06	0.26	1.55	2.57
					p_{temp}	=	-0.04	0.01	-0.07	-0.02
					ψ_{int}	=	3.55	0.44	2.68	4.42
					ψ_{pdL1}	=	-0.87	1.08	-2.99	1.26

Table 2.33. Estimated occupancy probabilities ($\hat{\psi}_i$) under the highest ranking model ($\Delta AIC_c = 0$) for eight grassland bird species in eastern Colorado in 2005. Each model's AIC_c weight (w_i) and number of parameters (K) are shown. Estimates with 95% confidence intervals are shown for three strata – prairie dog colony (pd), grassland (grs), and dryland agriculture (ag) – where appropriate. Occupancy estimates were calculated using stratum-specific means for individual covariates. Explanation, coding, and mean values of model parameters are provided in Table 2.4.

Species	Model	w_i	K	$\hat{\psi}_i$		LCL	UCL
Mountain plover	$p.\ \psi_{s \times grsL3+pdL1}$	0.11	8	ψ_{pd}	0.50	0.36	0.64
				ψ_{grs}	0.07	0.03	0.15
				ψ_{ag}	0.13	0.07	0.23
Burrowing owl	$p.\ \psi_{s+act+pdL3}$	0.08	6	$\psi_{act\ pd}$	0.80	0.66	0.89
				$\psi_{inact\ pd}$	0.23	0.07	0.53
				ψ_{grs}	0.01	0.00	0.07
				ψ_{ag}	0.00	0.00	0.00
Horned lark	$p.\ \psi.$	0.49	2	$\psi.$	1.00	0.98	1.00
Cassin's sparrow	$p_{s+day+day^2+eff+wind}\ \psi_{s \times grsL3s}$	0.31	13	ψ_{pd}	0.60	0.48	0.71
				ψ_{grs}	0.46	0.35	0.57
				ψ_{ag}	0.08	0.03	0.19
Lark sparrow	$p_{s+day+temp+wind}\ \psi_{s \times grsL3}$	0.11	11	ψ_{pd}	0.33	0.22	0.46
				ψ_{grs}	0.54	0.36	0.72
				ψ_{ag}	0.10	0.02	0.42

…table continued

…table continued

Species	Model	w_i	K	$\hat{\psi}_i$		LCL	UCL
Lark bunting	$p_{s+day+day^2+eff+wind}\ \psi_{s+pdL3}$	0.20	11	ψ_{pd}	0.80	0.66	0.89
				ψ_{grs}	0.90	0.82	0.95
				ψ_{ag}	0.72	0.61	0.81
Grasshopper sparrow	$p_{day+day^2+temp}\ \psi_{s\times grsL3+pdL3}$	0.21	11	ψ_{pd}	0.17	0.09	0.29
				ψ_{grs}	0.31	0.22	0.41
				ψ_{ag}	0.60	0.49	0.70
Western meadowlark	$p_{s+eff+temp}\ \psi_{.}$	0.20	6	$\psi_{.}$	0.97	0.94	0.98

Table 2.34. Estimated detection ($\hat{p}_i$) and occupancy ($\hat{\psi}_i$) probabilities for eight grassland bird species in three strata – prairie dog colony (pd), grassland (grs), and dryland agriculture (ag) – in eastern Colorado in 2005. Estimates were generated in program MARK under a general strata model ($p_s\,\psi_s$) and do not represent top model parameter estimates as indicated by ΔAIC_c and AIC_c weights (w_i). Standard errors (SE) and 95% confidence intervals of parameter estimates are also shown.

Species	$\{p_s\,\psi_s\}$ [a] ΔAIC_c	$\{p_s\,\psi_s\}$ [a] w_i	$\hat{p}_i$		SE	LCL	UCL	$\hat{\psi}_i$		SE	LCL	UCL
Mountain plover	12.11	0.00	p_{pd}	0.46	0.05	0.37	0.56	ψ_{pd}	0.51	0.06	0.39	0.63
			p_{grs}	0.23	0.11	0.09	0.50	ψ_{grs}	0.11	0.05	0.04	0.25
			p_{ag}	0.41	0.09	0.26	0.58	ψ_{ag}	0.15	0.04	0.08	0.25
Burrowing owl [a]	19.54	0.00	p_{pd}	0.54	0.04	0.47	0.62	ψ_{pd}	0.69	0.06	0.57	0.79
			p_{grs}	0.54	0.04	0.47	0.62	ψ_{grs}	0.01	0.01	0.00	0.07
			p_{ag}	0.54	0.04	0.47	0.62	ψ_{ag}	0.00	0.00	0.00	0.00
Horned lark	4.02	0.07	p_{pd}	0.97	0.01	0.95	0.99	ψ_{pd}	1.00	0.00	0.00	1.00
			p_{grs}	0.96	0.01	0.93	0.97	ψ_{grs}	0.99	0.01	0.93	1.00
			p_{ag}	0.97	0.01	0.95	0.98	ψ_{ag}	1.00	0.00	1.00	1.00
Cassin's sparrow	66.32	0.00	p_{pd}	0.48	0.04	0.40	0.56	ψ_{pd}	0.63	0.06	0.50	0.74
			p_{grs}	0.58	0.04	0.50	0.65	ψ_{grs}	0.49	0.05	0.39	0.59
			p_{ag}	0.32	0.10	0.15	0.54	ψ_{ag}	0.13	0.05	0.06	0.24
Lark sparrow	30.82	0.00	p_{pd}	0.45	0.06	0.33	0.57	ψ_{pd}	0.33	0.06	0.23	0.45
			p_{grs}	0.35	0.05	0.26	0.46	ψ_{grs}	0.43	0.06	0.31	0.56
			p_{ag}	0.15	0.13	0.02	0.56	ψ_{ag}	0.10	0.08	0.02	0.39

…table continued

…table continued

Species	$\{p_s\,\psi_s\}$ [a] ΔAIC_c	$\{p_s\,\psi_s\}$ [a] w_i		$\hat{p}_i$	SE	LCL	UCL		$\hat{\psi}_i$	SE	LCL	UCL
Lark bunting	51.79	0.00	p_{pd}	0.63	0.03	0.56	0.69	ψ_{pd}	0.75	0.05	0.64	0.84
			p_{grs}	0.73	0.02	0.68	0.78	ψ_{grs}	0.90	0.03	0.82	0.94
			p_{ag}	0.55	0.03	0.48	0.62	ψ_{ag}	0.72	0.05	0.61	0.81
Grasshopper sparrow	64.81	0.00	p_{pd}	0.54	0.07	0.41	0.67	ψ_{pd}	0.25	0.05	0.17	0.36
			p_{grs}	0.45	0.05	0.35	0.56	ψ_{grs}	0.33	0.05	0.24	0.44
			p_{ag}	0.54	0.04	0.47	0.62	ψ_{ag}	0.60	0.06	0.49	0.70
Western meadowlark	15.23	0.00	p_{pd}	0.82	0.02	0.78	0.86	ψ_{pd}	0.95	0.02	0.88	0.98
			p_{grs}	0.75	0.02	0.70	0.79	ψ_{grs}	0.97	0.02	0.91	0.99
			p_{ag}	0.79	0.02	0.74	0.83	ψ_{ag}	0.97	0.02	0.90	0.99

[a] Stratum-specific detection probabilities were unestimable for burrowing owl due to low numbers of detections on grassland and dryland agriculture plots. Model results and parameters estimates shown were generated under model $p_{.}\,\psi_s$.

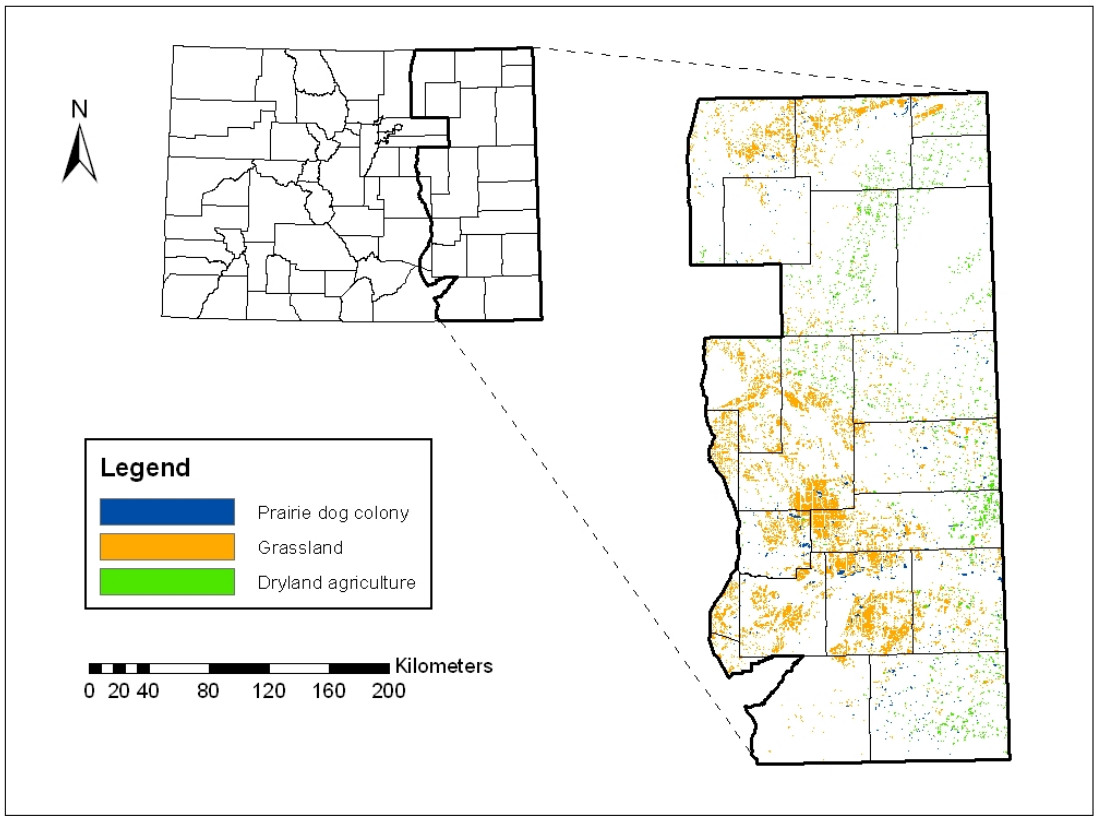


Figure 2.1. Study area and stratified sampling frame of a grassland avifauna study conducted in 2005 on three different habitat types in shortgrass prairie in eastern Colorado, USA.

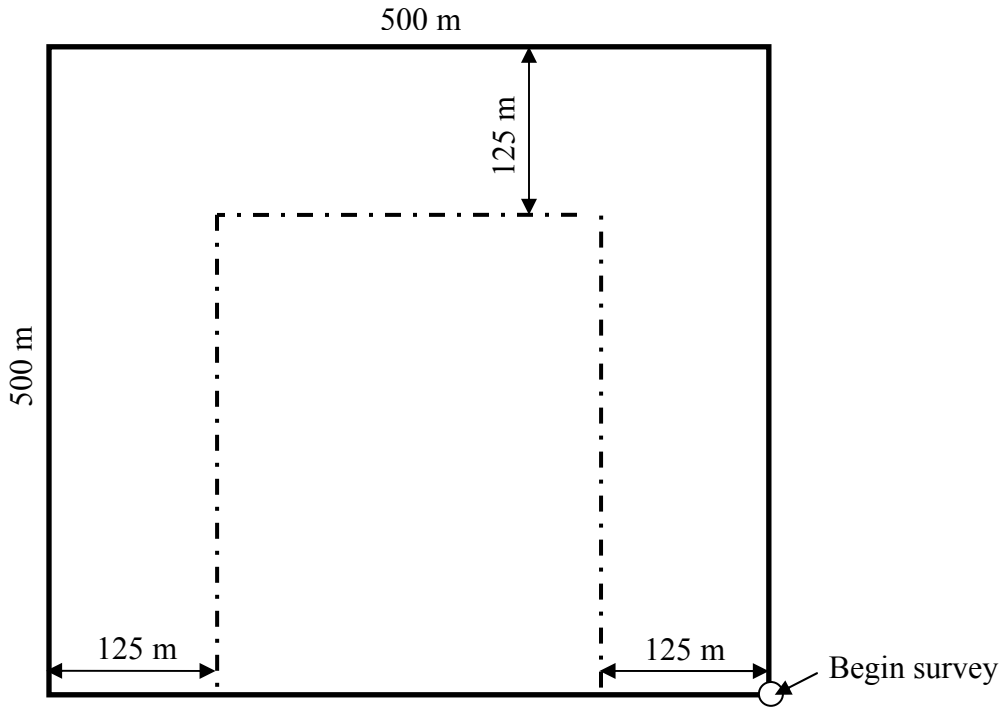


Figure 2.2. Diagram of survey "transect" walked by observers during occupancy surveys conducted on randomly selected 500-m × 500-m plots in eastern Colorado in 2005.

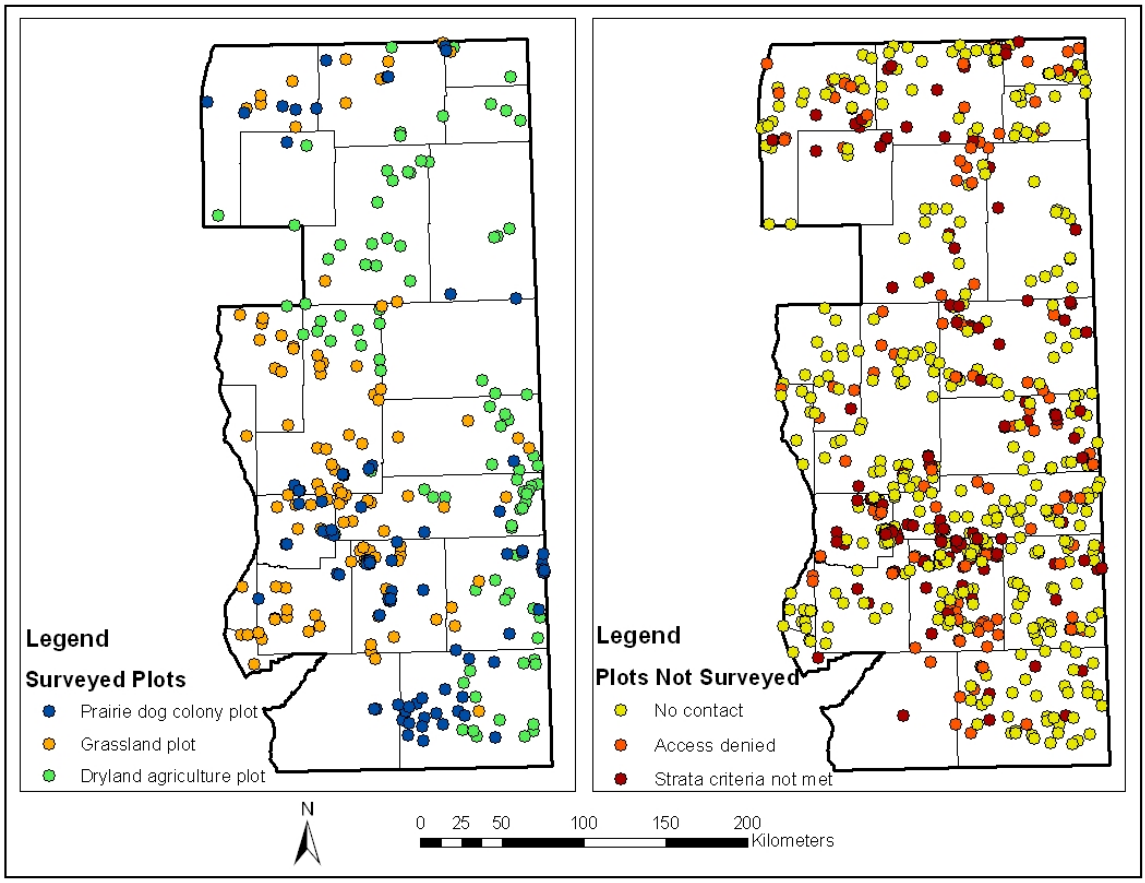
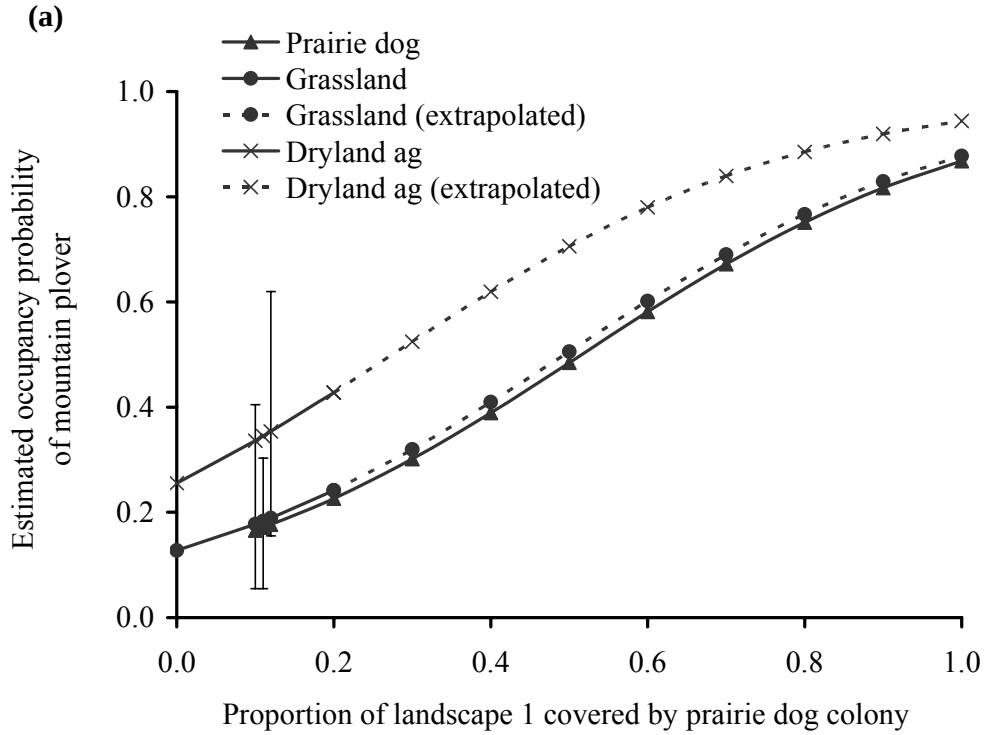


Figure 2.3. Fates of plots selected in a grassland avifauna study conducted in 2005 in shortgrass prairie in eastern Colorado, USA. Locations are shown for surveyed plots in three strata – prairie dog colony, grassland, and dryland agriculture – and plots not surveyed due to inability to contact the landowner (no contact), access denied by the landowner or lessee, or if strata criteria were not met.

Figure 2.4. Effect of the landscape variable 'pdL1' on estimated mountain plover (*Charadrius montanus*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s \times grsL3+pdL1}$) and allowed to vary by the proportion of prairie dog colony in landscape 1 (pdL1) while holding the effect of the variable 'grsL3' constant at either: a) the overall variable mean (0.58), or b) the individual stratum means (pd = 0.57, grassland = 0.85, ag = 0.29). Landscape 1 was defined as the area of a plot and its 500 m buffer. The variable 'grsL3' was defined as the proportion of grassland in landscape 3, defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals.


(a)
Prairie dog
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of mountain plover
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 1 covered by prairie dog colony

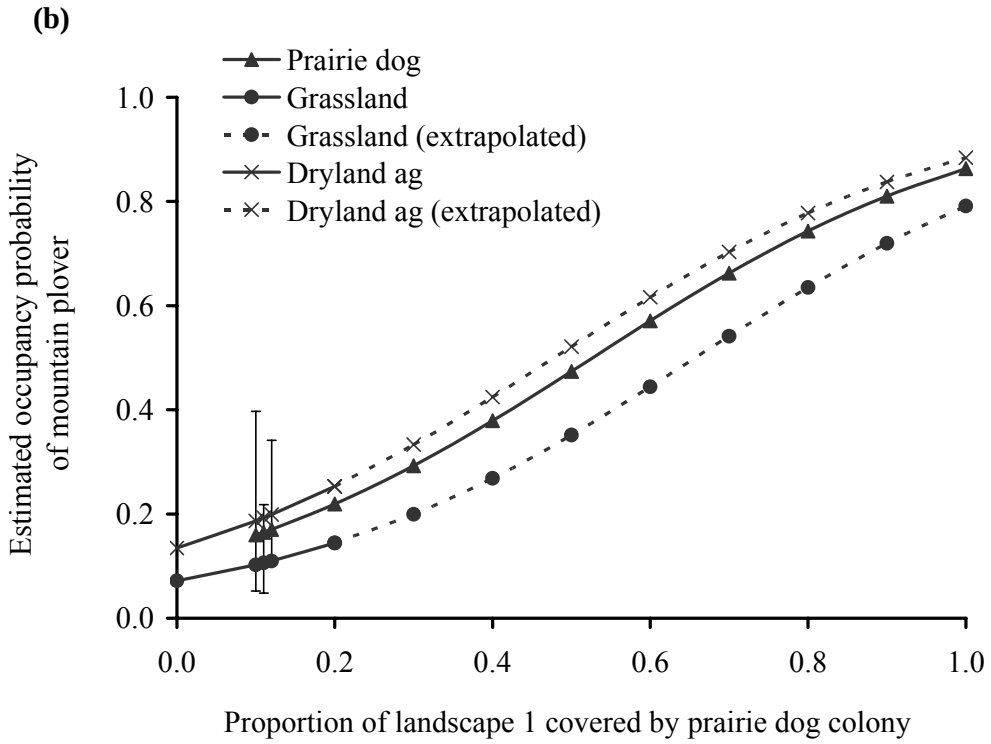
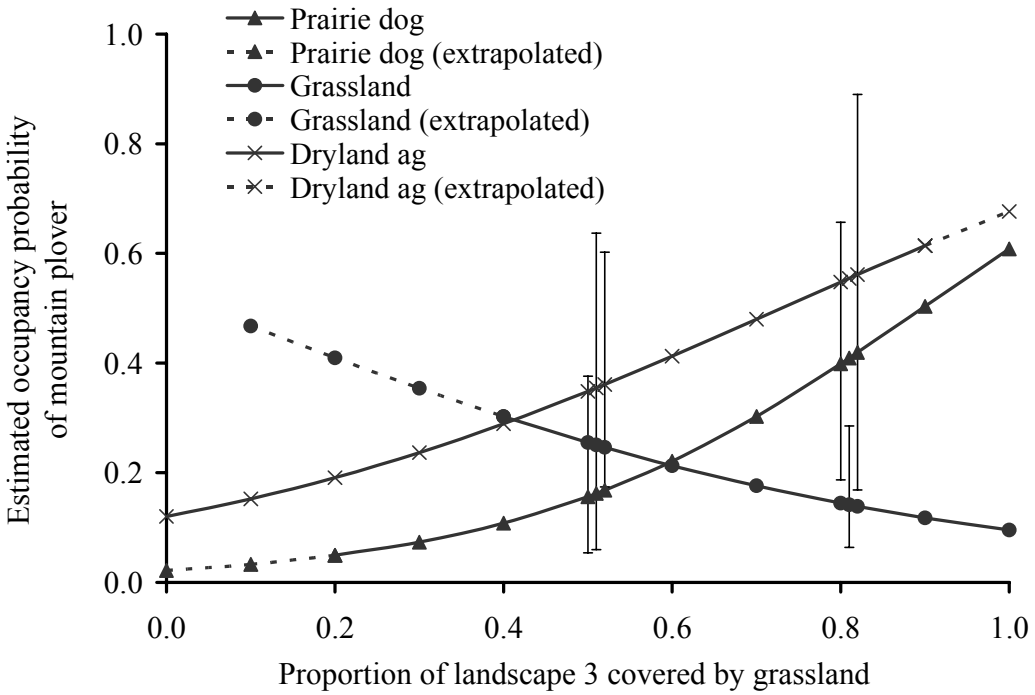
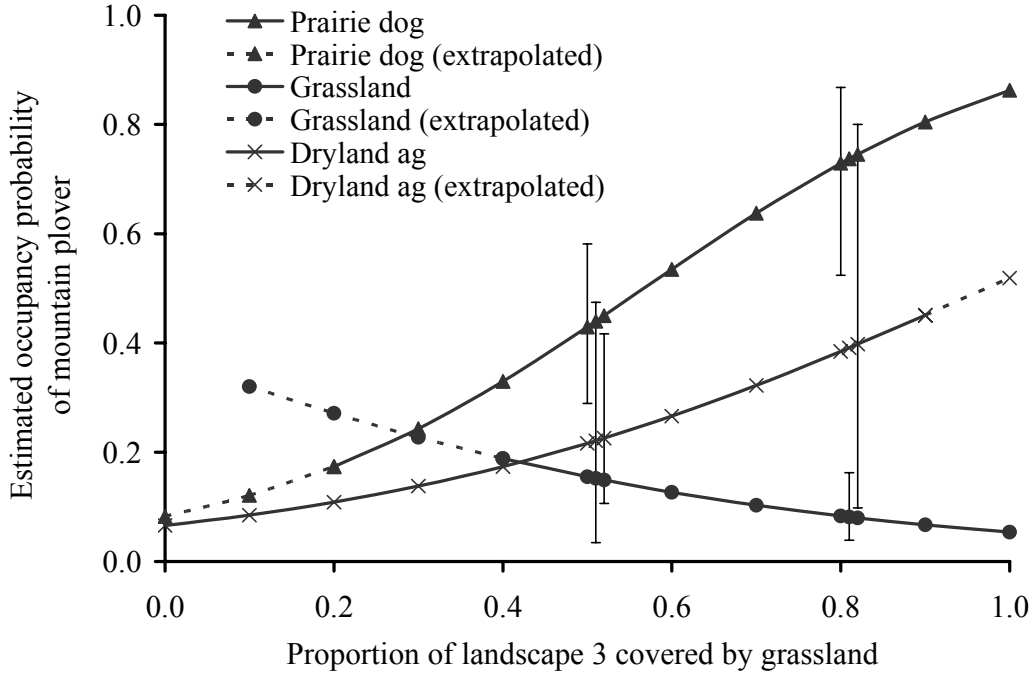

(b)
Prairie dog
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of mountain plover
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 1 covered by prairie dog colony

Figure 2.5. Effect of the landscape variable 'grsL3' on estimated mountain plover (*Charadrius montanus*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s \times grsL3+pdL1}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3) while holding the effect of the variable 'pdL1' constant at either: a) the overall variable mean (0.17), or b) the individual stratum means (pd = 0.53, grassland = 0.01, ag = 0.00). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'pdL1' was defined as the proportion of prairie dog colony in landscape 1, defined as the area of a plot and its 500 m buffer. Error bars represent 95% confidence intervals.

(a)


Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of mountain plover
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by grassland

(b)


Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of mountain plover
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by grassland

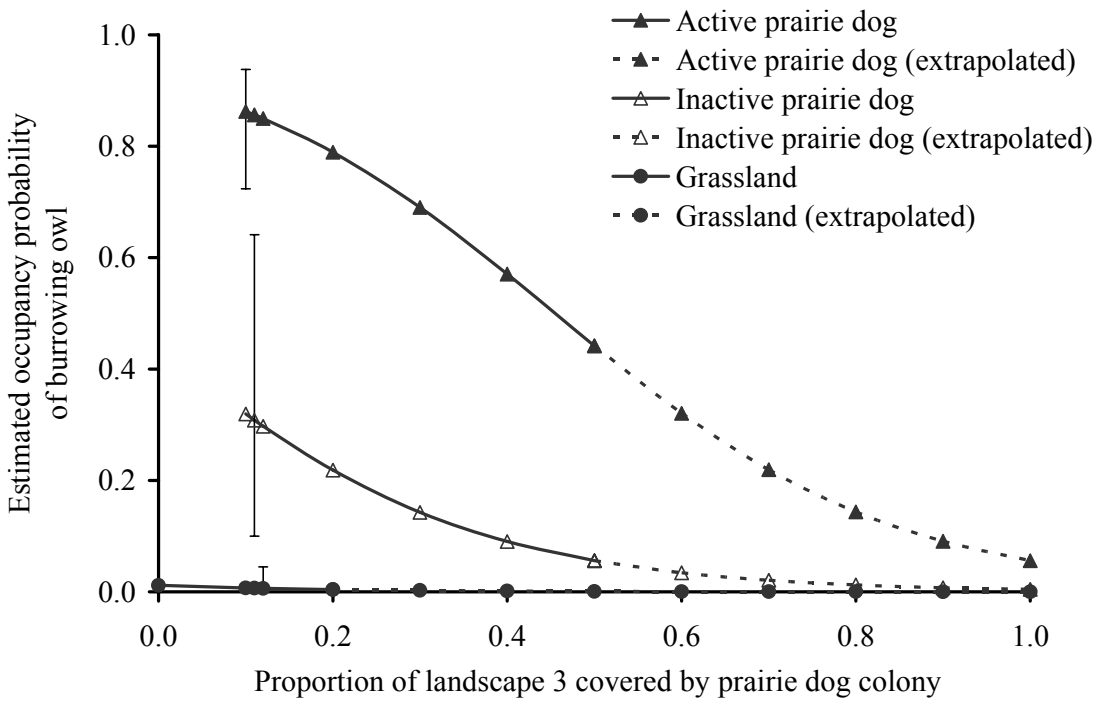


Figure 2.6. Effect of the landscape variable 'pdL3' on estimated burrowing owl (*Athene cunicularia hypugaea*) occupancy probabilities in two strata – prairie dog colony and grassland – in eastern Colorado in 2005. Prairie dog colony plots were further characterized as active or inactive. Occupancy was estimated under the highest ranking model ($p_{.}\ \psi_{s+act+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals. Because estimated occupancy probability of burrowing owl on dryland agriculture plots was 0.00 (95% CI = 0.00, 0.00), regardless of the amount of prairie dog colony in the surrounding landscape, these data are not shown.

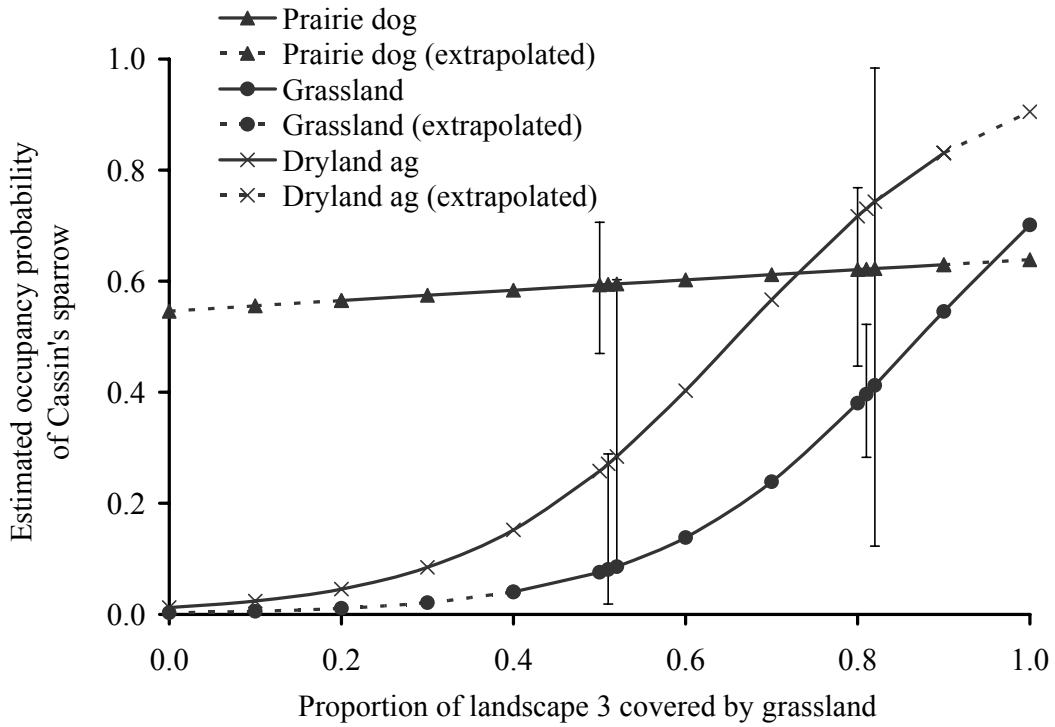


Figure 2.7. Effect of the landscape variable 'grsL3' on estimated Cassin's sparrow (*Aimophila cassinii*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+day^2+eff+wind}\ \psi_{s\times grsL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals.

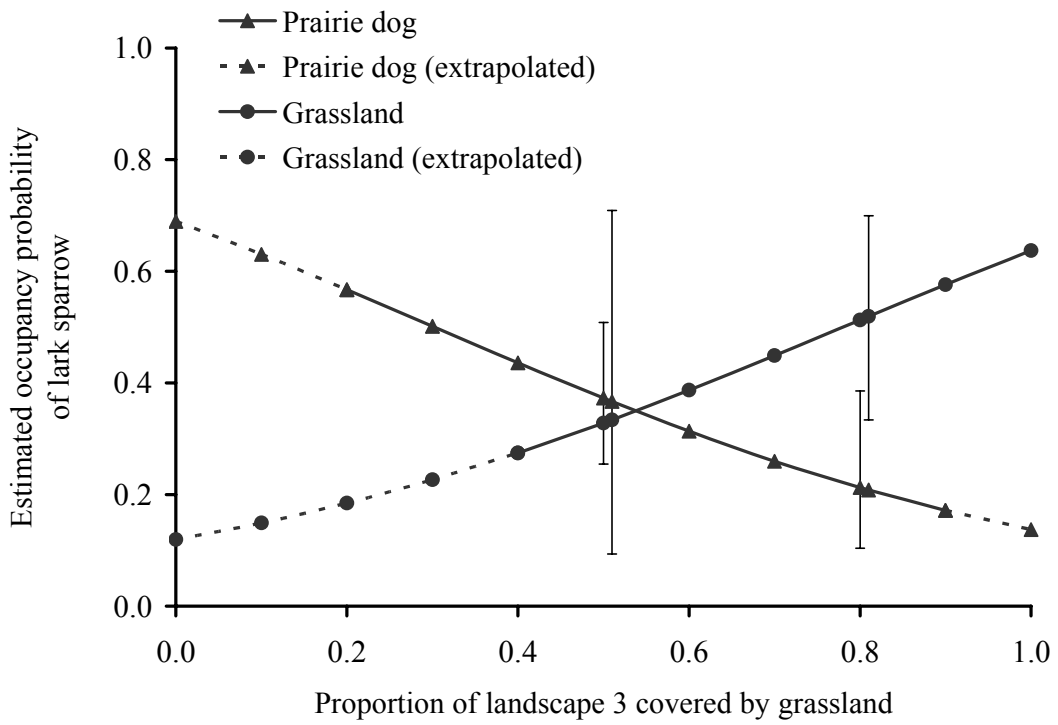


Figure 2.8. Effect of the landscape variable 'grsL3' on estimated lark sparrow (*Chondestes grammacus*) occupancy probabilities in two strata – prairie dog colony and grassland – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+temp+wind}\ \psi_{s\times grsL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals. The low number of detections in dryland agriculture prevented modeling a covariate effect in addition to a stratum effect.

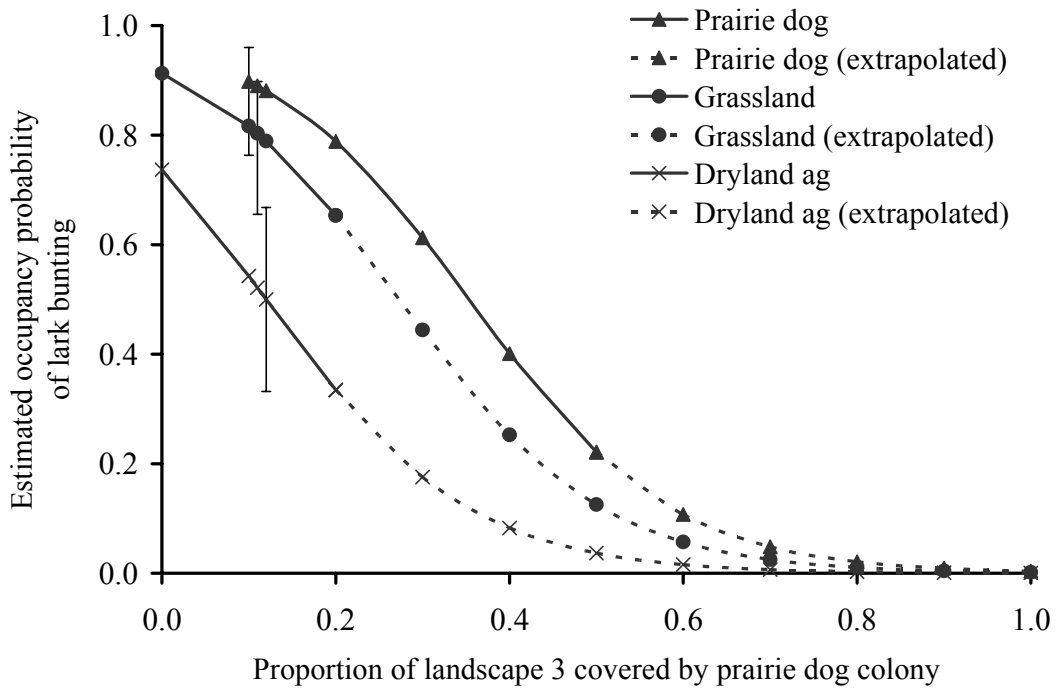
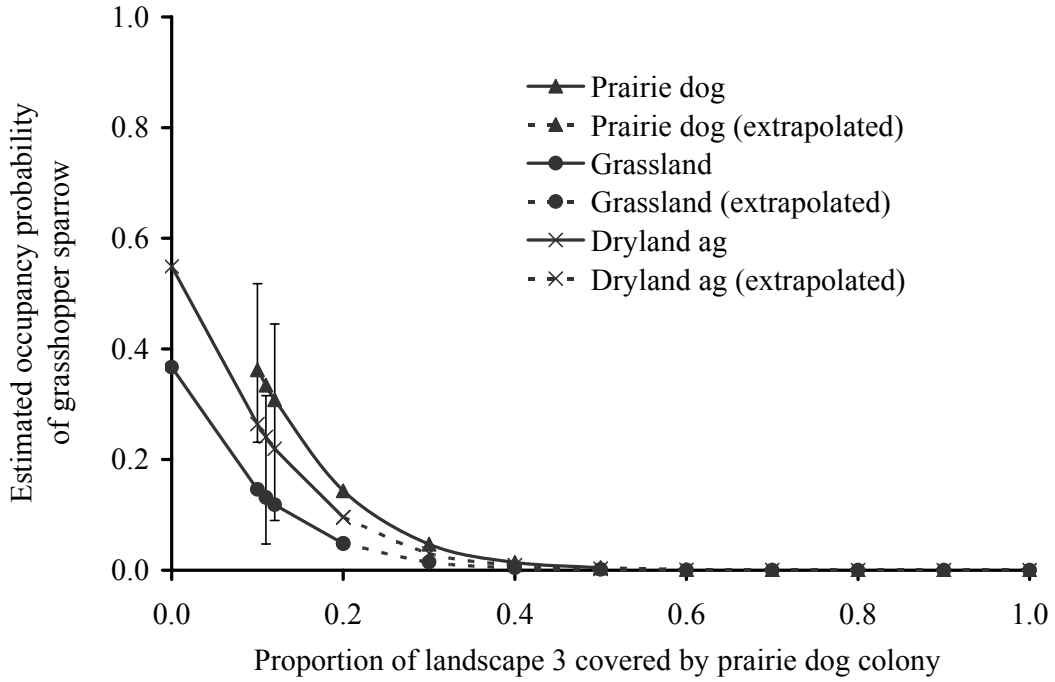


Figure 2.9. Effect of the landscape variable 'pdL3' on estimated lark bunting (*Calamonspiza melanocorys*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{s+day+\ day^2+eff+wind}\ \psi_{s+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3). Landscape 3 was defined as the area of a plot and its 2250 m buffer. Error bars represent 95% confidence intervals.

Figure 2.10. Effect of the landscape variable 'pdL3' on estimated grasshopper sparrow (*Ammodramus savannarum*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL3}$) and allowed to vary by the proportion of prairie dog colony in landscape 3 (pdL3) while holding the effect of the variable 'grsL3' constant at either: a) the overall variable mean (0.58), or b) the individual stratum means (pd = 0.57, grassland = 0.85, ag = 0.29). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'grsL3' was defined as the proportion of grassland in landscape 3. Error bars represent 95% confidence intervals.

(a)


1.0
0.8
0.6
0.4
0.2
0.0
Estimated occupancy probability of grasshopper sparrow
Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by prairie dog colony

(b)

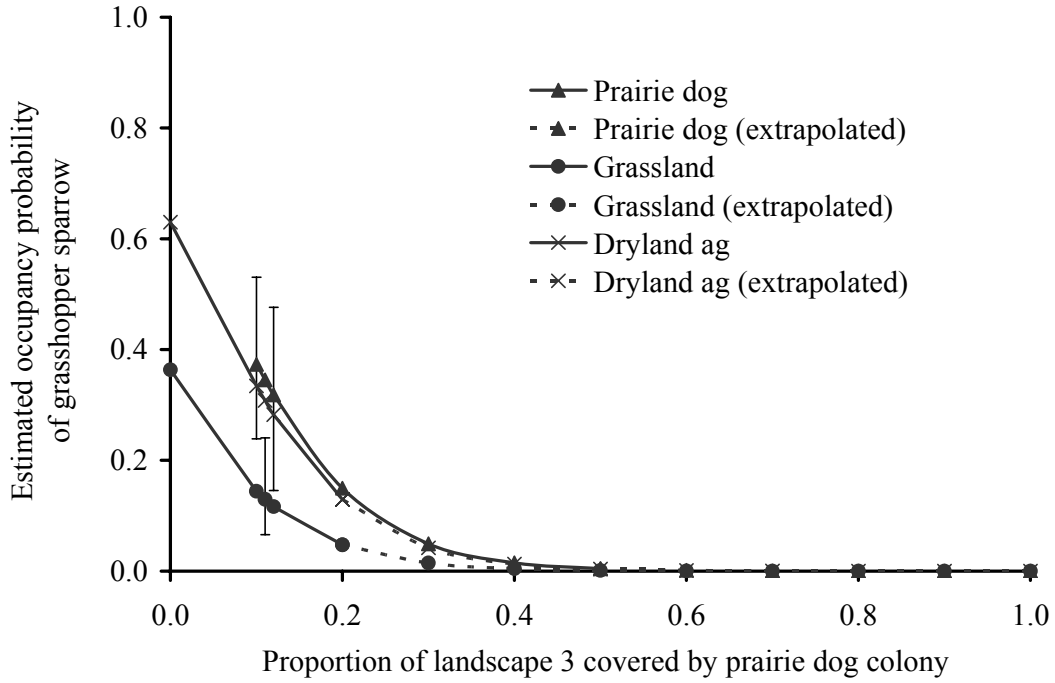
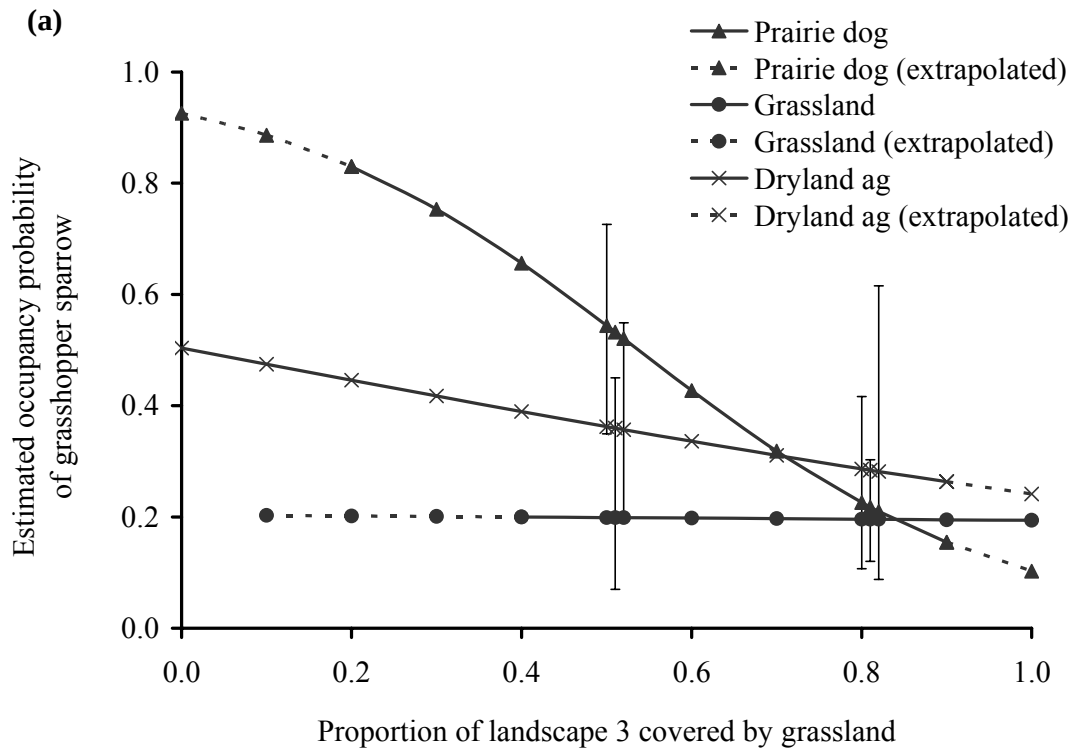
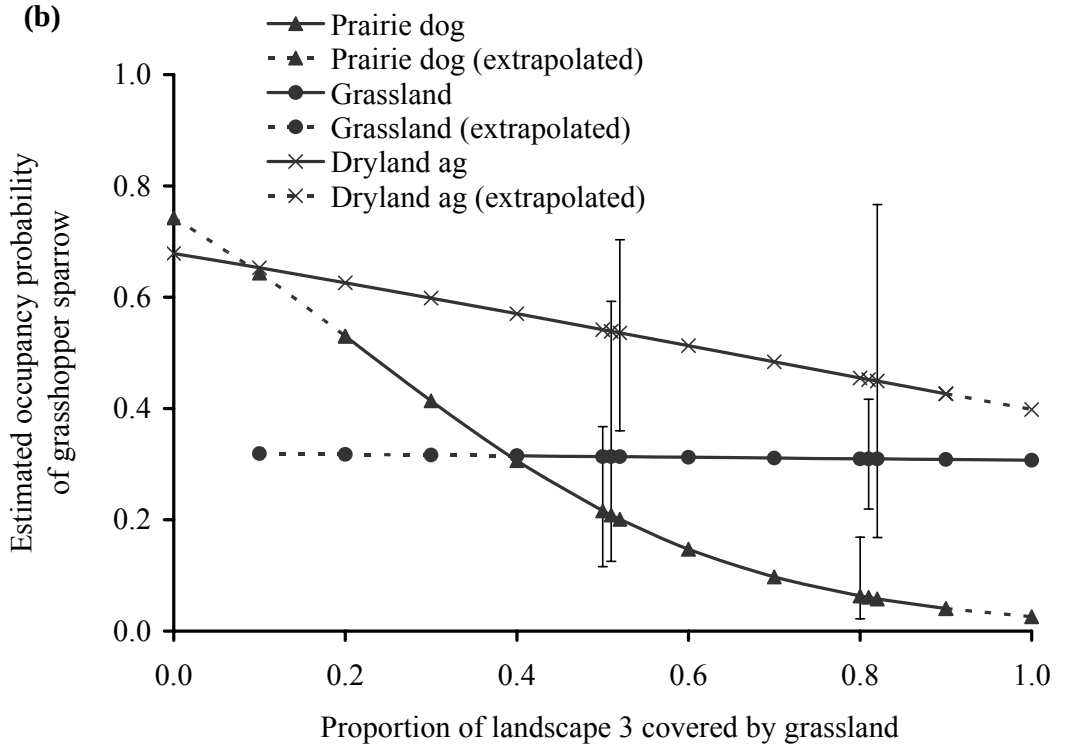

1.0
0.8
0.6
0.4
0.2
0.0
Estimated occupancy probability of grasshopper sparrow
Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by prairie dog colony

Figure 2.11. Effect of the landscape variable 'grsL3' on estimated grasshopper sparrow (*Ammodramus savannarum*) occupancy probabilities in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Occupancy was estimated under the highest ranking model ($p_{day+\ day^2+temp}\ \psi_{s\times grsL3+pdL3}$) and allowed to vary by the proportion of grassland in landscape 3 (grsL3) while holding the effect of the variable 'pdL3' constant at either: a) the overall variable mean (0.07), or b) the individual stratum means (pd = 0.19, grassland = 0.02, ag = 0.01). Landscape 3 was defined as the area of a plot and its 2250 m buffer. The variable 'pdL3' was defined as the proportion of prairie dog colony in landscape 3. Error bars represent 95% confidence intervals.


(a)
Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of grasshopper sparrow
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by grassland


(b)
Prairie dog
Prairie dog (extrapolated)
Grassland
Grassland (extrapolated)
Dryland ag
Dryland ag (extrapolated)
Estimated occupancy probability of grasshopper sparrow
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of landscape 3 covered by grassland

CHAPTER 3

ABUNDANCE AND DENSITY OF COLORADO BREEDING GRASSLAND BIRDS: ESTIMATION AND HABITAT CORRELATIONS

INTRODUCTION

Native grasslands have been altered to a greater extent than any other biome in North America (Samson et al. 2004), resulting in the conversion of the once diverse prairie landscape into a collection of homogenous grassland fragments interspersed with agricultural fields (Lomolino et al. 2001, Brockway et al. 2002, Brennan and Kuvlesky 2005). Part of this alteration has been caused by the attempted eradication of the black-tailed prairie dog (*Cynomys ludovicianus*, hereafter simply referred to as prairie dog) which has resulted in extensive declines in both prairie dog numbers and colony acreage (Knopf 1994, Benedict et al. 1996, Miller and Cully 2001, Sidle et al. 2001b). A recent survey of Colorado's shortgrass prairie indicates that prairie dogs occupy approximately 2,554 km^2 (1.94%) of the eastern plains (White et al. 2005) – only 5.3% of current potentially suitable habitat and 2.6% of the species' historic state range (Colorado Division of Wildlife 2003b).

The prairie dog creates large areas of grazed vegetation, bare soil, and burrows which are essential components of breeding habitat for grassland birds such as the mountain plover (*Charadrius montanus,* Knopf 1996b) and the western burrowing owl (*Athene cunicularia hypugaea,* Haug et al. 1993). In addition, grasshoppers and beetles,

the primary food items of grassland birds, require >10% of an area to be bare ground in order to lay eggs (Knopf 1996b), and thus benefit from prairie dog grazing and burrowing activities. Some researchers have suggested that the combination of these effects produces increased avian species occupancy, density, and richness observed on colonized versus uncolonized areas (Agnew et al. 1986, Barko et al. 1999, Smith and Lomolino 2004). The decline of prairie dogs, together with land conversion and grassland homogenization, has possibly resulted in the reduction of some species from the shortgrass prairie ecosystem as suggested by Breeding Bird Survey (BBS) analyses (Knopf 1994, 1996b, Sauer et al. 2003, Smith and Lomolino 2004). Concerns over declines in mountain plover and burrowing owl specifically, and grassland birds as a whole, have spurred the development of conservation plans, such as the *Conservation Plan for Grassland Species in Colorado* (Colorado Division of Wildlife 2003b), which focus on improving our knowledge of the ecology and status of grassland species.

Current and past research of mountain plover in Colorado focus on the species' use of shortgrass prairie habitats, including agricultural fields and prairie dog colonies, for nesting (Knopf and Miller 1994, Shackford and Leslie 1994, Knopf and Rupert 1999, Shackford et al. 1999, Dreitz 2005, Dreitz et al. 2005). While mountain plovers are strongly associated with prairie dog colonies in Montana (Knowles et al. 1982, Olson and Edge 1985, Dinsmore et al. 2003, Dinsmore et al. 2005), the nature of this relationship in Colorado is not yet well understood (Knopf 1996a, Colorado Division of Wildlife 2003b, Dreitz et al. 2005, Dreitz et al. 2006). Preliminary results indicate that prairie dogs maintain suitable plover habitat as compared with surrounding grassland (U.S. Fish and Wildlife Service 1999, Dreitz et al. 2005, Dreitz et al. 2006).

Burrowing owls in Colorado also seem to favor prairie dog colonies (80% of sightings in one 1999 survey, VerCauteren et al. 2001). This habitat preference has been corroborated in other states where researchers have found higher burrowing owl counts on prairie dog colonies than other areas (South Dakota, Agnew et al. 1986, Nebraska, Desmond and Savidge 1996, Oklahoma, Barko et al. 1999, Smith and Lomolino 2004, New Mexico, Arrowood et al. 2001). Burrowing owls have also been highly associated with active prairie dog colonies as compared with inactive colonies (Toombs 1997, Desmond et al. 2000, Sidle et al. 2001a).

Studies have also been conducted investigating the effects of prairie dog colonies on avian assemblages as a whole in shortgrass and mixed-grass prairie (Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004). While some species (e.g., horned larks, *Eremophila alpestris*) were found to be positively associated with prairie dog colonies, others (e.g., Cassin's sparrows, *Aimophila cassinii*, lark buntings, *Calamospiza melanocorys*, and grasshopper sparrows, *Ammodramus savannarum*) appeared to be associated with uncolonized sites (Agnew et al. 1986, Winter et al. 2003, Smith and Lomolino 2004). Mixed results for some species (e.g., response of lark sparrows, *Chondestes grammacus*, and western meadowlarks, *Sturnella neglecta*; Agnew et al. 1986, Barko et al. 1999, Winter et al. 2003, Smith and Lomolino 2004) may be due to differences in study area, spatial extent, duration, climatic conditions, and methodologies. Additionally, landscape factors (e.g., grassland habitat area) likely influence avian distributions, and the effect of both small- and large-scale habitat factors should be considered in conjunction with species-specific

perceptual/functional ranges (Orth and Kennedy 2001, Lueders 2002, Valiulis 2003, Cunningham and Johnson 2006, Hamer et al. 2006).

To rigorously investigate habitat and landscape effects on grassland birds, and to inform conservation actions of agencies, attention needs to be paid to the statistical methods employed. Obtaining unbiased estimates of abundance is important so that biologists can effectively monitor changes in population size, land managers can make sound management decisions and evaluations, and policy makers can make informed decisions on species conservation issues.

Methodologies widely used to estimate grassland bird population parameters have lacked at least one of two important considerations – attention to a probability-based sampling scheme and incorporation of detection probability into population estimates (Nichols 1999, Pollock et al. 2002). Previous surveys of grassland birds, such as the BBS (Sauer et al. 2003), Northern Region Landbird Monitoring Program (NRLMP, Hutto and Young 2002), and others (Hanni 2002, Conway and Simon 2003, Hanni 2003), have employed a "convenience sampling" scheme, where data are collected along roads or trails. Evaluating bias of such estimates is difficult, and problems arise when extrapolating these estimates to larger areas of interest (other than roads). Methods incorporating a probability-based approach, and applicable to large-scale survey projects, have been recently developed. Specifically, a spatially balanced sampling design (Theobald et al. in press) allows for improved coverage of a study area while avoiding some of the drawbacks associated with simple random or systematic sampling schemes.

Bias also arises from failure to detect individuals and the subsequent failure to adjust the count statistic accordingly (Lancia et al. 1994, Borchers et al. 2002, Thompson

2002, Williams et al. 2002). Methods incorporating detection probabilities into demographic estimation (Williams et al. 2002) have not been extensively used in the shortgrass prairie ecosystem or have not been applied properly (e.g., distance transects along roads, Hanni 2002, 2003). Recently, an observation-based estimation method, grounded in mark-recapture techniques, has been developed which employs "double observers" (Nichols et al. 2000).

My objectives were to employ and evaluate these recently developed methodologies for estimating grassland bird species abundance over large areas and to increase understanding of grassland bird ecology in the shortgrass prairie ecosystem of eastern Colorado. Specifically, I tested predictions concerning variation in abundance and detection of grassland birds across three habitat strata – prairie dog colonies, native grassland not occupied by prairie dogs (hereafter simply referred to as grassland), and dryland agriculture – as well as predictions concerning the surrounding landscape at multiple spatial scales. I identified the mountain plover and burrowing owl as species of primary interest, for which the design of this study was most influenced. In addition, data were available to estimate abundance for the following six grassland species: horned lark, Cassin's sparrow, lark sparrow, lark bunting, grasshopper sparrow, and western meadowlark.

STUDY AREA

In Colorado, shortgrass prairie spreads east from the foothills of the southern Rocky Mountains. The study area consisted of all areas (privately and publicly owned) in Colorado located ~48 km east of Interstate 25, excluding lands owned by the

Department of Defense (Figure 3.1). This area encompasses approximately 81,200 km^2 in 20 counties and was defined to include most of the shortgrass prairie in Colorado while avoiding urban and ex-urban areas, and high-security areas which could not be accessed.

METHODS

Sampling Design

I determined land cover types within the study area using 30-m vegetation classification data (Colorado Division of Wildlife 2003a) into which I incorporated all available Conservation Reserve Program (CRP), road, and prairie dog colony data using the Geographic Information System (GIS), ArcGIS 9.0. A detailed explanation of all GIS procedures is provided in Appendix I.

The sampling frame consisted of 500-m × 500-m (25 ha) grid cells categorized as prairie dog colony, grassland, or dryland agriculture (Figure 3.1). For each stratum, I chose sample plots from the frame using a spatially balanced sampling tool (Theobald 2004) employing a Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. in press), similar to the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen 2004). Based on the randomly assigned survey order, my field crew and I contacted land owners and lessees by phone or in person in order to obtain access. For those plots where we obtained access, I based final plot selection and stratum designation on qualitative vegetative assessments, determined in the field, accdording to the following criteria: 1) surveyed grassland and dryland agricultural plots had 100% coverage of the appropriate cover type, and 2) surveyed prairie dog colony plots had a minimum of 25% coverage by an active or recently

inactive prairie dog colony. If the observed vegetative cover did not meet strata criteria, the plot was not surveyed. Plots which included portions of major (paved or graded) roads or active structures were also not surveyed.

Field Data Collection

We conducted double-observer surveys (Nichols et al. 2000) of each plot from 19 May to 6 June 2005. This timing was designed to avoid migration periods and to coincide with the peak breeding season of most study species. The distance from the southern border of Colorado to the northern border is approximately 445 km. Because the phenology of avian breeding activity is believed to begin earlier in the south, I chose to survey plots from south to north. Morning and evening surveys were primarily conducted between the hours of sunrise and 1100 and between 1830 and sunset, respectively. Surveys were generally not conducted under unacceptable weather conditions which included temperatures above 27° C (~80° F), wind speeds above 6.0 mps (~13.5 mph), and fog or precipitation which reduced visibility to less than 125 m.

Double-observer surveys were conducted following protocol described by Nichols et al. (2000). For these surveys, field observers were divided into exclusive two-person survey teams. Survey team assignments attempted to create similar and complementary skill sets among the teams. For each survey employing the double-observer method, one team of two observers was present, with one person designated as the "primary" observer and the other as the "secondary" observer. The survey "transect" described below was walked and individual adult birds observed within the plot boundary were recorded by

species and detection type (visual or auditory observation) with care taken not to double count individuals.

Surveys of each plot began at the plot's southeast corner. When navigating to this point, care was taken not to cross or disturb the study plot prior to beginning the survey. All double-observer surveys were conducted by two observers using binoculars, Garmin 12 Global Positioning System (GPS) unit, Bushnell rangefinder, declinated compass, field guide, Brunton digital temperature and wind meter, and datasheets. At the start of the survey, time and weather conditions were recorded. Beginning from the southeast corner, observers walked west along the plot's south boundary approximately 125 m, turned north and walked approximately 375 m, turned west and walked approximately 250 m, and finally turned south and walked approximately 375 m to the plot's south boundary (Figure 3.2). Walking this transect ensured observers were no more than ~125 m from any location in the study plot, an assumed maximum distance for positive species identification. If terrain or other environmental factors required, observers altered this transect in order to see the entire plot or positively identify birds.

Following Nichols et al. (2000), while walking the survey transect single file, the primary observer identified all birds seen or heard within the study plot and communicated each individual detection, including species, detection type, and approximate location, to the secondary observer who recorded the information. In addition, the secondary observer surveyed the plot, recording any observed individuals not detected by the primary observer. Various techniques (e.g., maintaining a minimum distance, faking observations) were employed to prevent the secondary observer from affecting individual detections by the primary observer. Transects were walked slowly

with occasional stops such that each survey typically lasted 30-65 minutes. At the end of the survey, time and weather data were again recorded and the data totaled by species, detection type, and observer. The roles of primary and secondary observer within the survey teams were alternated on consecutive surveys.

Model Set and Selection

I developed *a priori* hypotheses for detection probabilities and habitat correlations based on existing literature regarding individual species' breeding ecology and vegetation preferences, preliminary results from my pilot study conducted in 2004, and personal communications with biologists familiar with the study area and species, as well as my own personal observations. Detection-related hypotheses examined the effect of plot stratum, observer team, and survey weather conditions on species detection probabilities.

For variables of interest, I first examined the available variance and correlation. Initially, I chose nine visit-specific variables which I thought would have the greatest effect on detection probability: survey date (day), start time, survey duration, temperature (measured as a survey average and a maximum), wind speed (average and maximum), and cloud cover (average and maximum). Survey duration was similar for the majority of surveys and therefore I did not use it as a covariate. As expected, average and maximum values of temperature, wind, and cloud cover were highly correlated (Table 3.1), so only average values of weather variables were used as individual covariates in my analyses. In addition, survey day and temperature were negatively correlated (r^2 = -0.48, Table 3.1), corresponding to the passage of a cold front through the study area during the second half of the survey period. Based on these exploratory results, I selected

four visit-specific and one plot-level covariate to model detection probabilities (Table 3.2).

I estimated plot-level detection probabilities (*p*) and abundances (*N*) using Huggins closed captures models (Huggins 1989, 1991) in program MARK (White and Burnham 1999). Huggins models allow modeling of individual covariates and can perform better when sample sizes are likely to be low, as in the case of my focal species. I developed candidate model sets for detection probability based on my *a priori* hypotheses for each species (Table 3.3). I modeled *p* as either constant (.), or as a function of selected visit-specific covariates (Table 3.2), plot stratum (s), or an additive combination of these variables. Probability of recapture (*c*) was set to zero for all models to simulate a removal model based on the double-observer methodology used.

Because avian behavior differs by breeding activity (e.g., birds are generally less detectable when nesting compared with breeding displays and brood-rearing periods), I predicted that survey date (day) would affect *p* relative to each species' breeding phenology within the 2 ½-week survey period (Table 3.3). In addition, since observers likely varied in survey ability and experience despite the training they received, I predicted observer team would affect *p*, and that the relative effect may vary between species (Table 3.3). Observer team 1 included a field crew member who had substantially less experience than the other crew members, and I predicted that team 1 would have a lower *p*. For all species, I hypothesized that increases in average survey temperature and wind speed would both negatively affect detection due to a decrease in bird activity and, in the case of wind, the opportunity for auditory detections, especially for smaller sparrow species. In contrast, I predicted that the effect of plot stratum on *p*

would vary by species (Table 3.3). Stratum may effect detection due to visibility differences created by vegetation height and structure coupled with species behavior or vocalizations.

The number of models among species model sets varied according to species-specific hypotheses (Table 3.3) as well as the degree of model uncertainty, with greater uncertainty necessitating a larger number of models. I used Akaike's Information Criterion with small sample size correction (AIC_c) to rank models (Burnham and Anderson 2002). The beta parameter ($\hat{\beta}$) for each detection covariate was also estimated.

Using the derived abundance estimates generated under the highest ranking ($\Delta AIC_c = 0$) model for each species, I calculated stratum-specific densities based on the area surveyed in each stratum. I then extrapolated calculated densities to obtain species population estimates for my study area. Area of prairie dog colonies, grassland, and dryland agriculture within my study area were estimated using results from a 2002 prairie dog aerial survey (White et al. 2005) and the baseline vegetation classification data (Colorado Division of Wildlife 2003a) used in sampling design (Appendix I).

I extrapolated my calculated density estimates in three different ways based on how non-sampled plots are viewed. My most "liberal" estimates extrapolate to my entire sampling frame of prairie dog colonies, grassland, and dryland agriculture within my study area. Due to access issues and stratum misclassification, this is not warranted from a statistical point of view. The most statistically valid extrapolation, and the one in which I am most confident, does not include plots not surveyed due to inability to contact the landowner (hereafter referred to as no contact), access denied by the landowner or lessee,

or if strata criteria were not met (Table 3.4). I term this my "conservative" extrapolation. I also performed a "moderate" extrapolation where I assumed that "no contact" plots did not differ significantly from surveyed plots and thus extrapolated to a larger area (Table 3.4), but not to area corresponding to plots where access was denied or strata criteria were not met.

Habitat Factors Affecting Abundance

During the field season, observers recorded data to characterize each plot, including whether prairie dogs were currently active at colonies. I later identified prairie dog colonies within 2250 m of surveyed plot boundaries using digital aerial photography taken during the field season. I digitized these data in ArcGIS 9.0 and combined the resulting prairie dog colony layer with the baseline 30-m vegetation classification data (Colorado Division of Wildlife 2003a) to obtain percent cover of prairie dog colony and grassland at three spatial scales - a plot plus its 500-m, 1500-m, or 2250-m buffer, hereafter referred to as landscape 1, landscape 2, and landscape 3, respectively (Appendix I).

To investigate avian-habitat associations, I wanted to test the effect of the amount of prairie dog colony and grassland in the surrounding landscape on species abundance at the three spatial scales defined above. I examined the correlation of the resulting six landscape variables plus two additional plot-level variables – prairie dog activity status and the amount of prairie dog colony inside plot boundaries. As expected, nested variables (e.g., amount of prairie dog colony in the plot and landscapes 1, 2, and 3) were highly positively correlated (Tables 3.5). Due to the high correlation of nested variables,

I decided to examine habitat effects singly and selected three plot-level and six landscape-level covariates to use in models examining underlying process variance of species abundance (Table 3.6).

For each species, I conducted a variance components analysis in program MARK (White et al. 2002) to estimate the ability of these habitat covariates to explain process variance in abundance estimates. Total variance is made up of two components – sampling variance and process variance. Sampling variance is a measure of within-site variability arising from the inexactness of counts. Process variance reflects variability in population size among sites. I used variance components analysis to focus on explaining the biological process variance, and not to confound this analysis with the sampling variance or the sampling covariance between the plot abundance estimates induced by modeling detection probability with some commonality across plots. Analyses were conducted on derived abundance estimates generated under the highest ranking model of *p* for each species.

I hypothesized plot stratum would affect species abundance (Table 3.7), with species' responses based on their respective habitat/vegetation preferences (Chapter 1, Table 1.3). For mountain plovers and burrowing owls, I predicted that the presence of prairie dogs would have a strong positive effect on species abundance (Table 3.7). I did not consider activity status as an important covariate for other study species. For all species, I hypothesized that landscapes containing more native grassland may translate to higher-quality breeding habitat. Thus, I predicted a positive relationship between grassland landscape variables and species abundance (Table 3.7). Hypotheses related to the effect of prairie dog colony area on abundance were species-specific based on

individual species' breeding ecology. For the mountain plover, burrowing owl, and horned lark, I predicted a positive effect of increasing amounts of prairie dog colony in the landscape on species abundance. In contrast, a number of grassland birds, sparrow species in particular, often prefer areas of taller grasses within the shortgrass prairie as well as landscapes with varied structure. Based on these habitat preferences, I predicted there would be a negative effect of increasing amounts of prairie dog colony, both within plot boundaries and the surrounding landscape, on abundance of Cassin's sparrow, lark sparrow, lark bunting, grasshopper sparrow, and western meadowlark (Table 3.7).

On occupied sites, species abundance may be more affected by smaller-scale (local) habitat factors than by characteristics of the larger landscape. That is, species' responses may be closely tied to home-range/breeding territory size. Considering my plot size (25 ha) in relation to home-range sizes of my study species, I hypothesized that, among nested habitat variables, smaller-scale variables would explain more variance in abundance estimates than larger-scales variables.

Because abundance (N) is not part of the likelihood in Huggins models, models examining the effect of habitat factors on abundance could not be compared using AIC_c. Therefore, a mean model (model with no explanatory covariates; intercept only) was run to obtain an estimate of overall process variance. The estimate of process variance for each habitat factor (i.e., remaining process variance) was then compared to this overall estimate and the difference interpreted as the amount of variance explained by the habitat covariate. The beta parameter ($\hat{\beta}$) for each habitat covariate was also estimated.

Estimating Latent Abundance from Occupancy Data

There is a connection between occupancy and abundance. Royle and Nichols (2003) developed a statistical method for analyzing occupancy (presence-apparent absence) data to draw inferences on site-specific abundance. Dreitz et al. (2006) tested the patch occupancy method to estimate mountain plover latent abundance in eastern Colorado and found it was feasible, at least in areas of high plover concentrations. Given that my occupancy data collection (Chapter 2) fell within the field protocols of this method, I analyzed my occupancy data to derive estimates of latent abundance for my focal species – mountain plover and burrowing owl. Because this estimation procedure does not perform well when more than a few individuals are observed on a plot, I did not estimate latent abundance for my other study species. Latent abundance was estimated using the Royle/Nichols (RN) heterogeneity model (Royle and Nichols 2003) as implemented in program PRESENCE (Hines 2006).

RESULTS

I surveyed a total of 278 plots, consisting of 87 in prairie dog colonies, 100 in grassland, and 91 in dryland agriculture (Figure 3.3). Exploratory analyses of survey covariates suggested the presence of outliers, and records from six surveys were not included in further analyses due to the surveys being conducted under unacceptable survey conditions (i.e., temperatures too high or too low). Thus, abundance analyses were conducted on 272 mark-recapture plots – 84 prairie dog colony plots, 98 grassland plots, and 90 dryland agriculture plots. Throughout the survey period, a total of 7,316 adults of my eight study species were observed on 271 of these 272 plots. Among all

strata, horned lark were the most common species observed, followed by lark bunting (Table 3.8). Due to low numbers of detections in certain strata (Table 3.8) and by some observer teams, the effect of plot stratum and/or observer team on detection probability (p) could not be estimated for some species. Below I detail results for each species.

Mountain Plover

A total of 59 mountain plovers were detected on 31 of the 272 surveyed plots included in analyses – 45 plovers on 21 prairie dog colony plots, 4 plovers on 3 grassland plots, and 10 plovers on 7 dryland agriculture plots (Table 3.8). Due to low numbers of detections on grassland and agriculture plots, models in which p varied by stratum were not possible. Models in which p was modeled as a function of observer team (obs1 ≠ obs2-5) consistently ranked higher than models where p was modeled as constant (.) or allowed to vary by other visit-specific covariates (Table 3.9). There was some evidence of a negative effect of the variable 'obs1' on detection, as I had predicted ($\hat{\beta}$ = -3.91, Table 3.10). Effects of other visit-specific covariates (day, temp, and wind) on p were considerably smaller, and 95% confidence intervals (CI's) for all variables overlapped zero (Table 3.10).

Mountain plover densities were calculated using derived abundance estimates generated under model $p_{obs1}\, N_{plot}$. On occupied plots, the estimated number of mountain plovers ranged from 1 to 4 birds per plot (Table 3.11). Plover density on prairie dog colony plots ($\hat{D}$ = 0.023 birds/ha, 95% CI = 0.022, 0.051) was significantly higher than densities on either grassland ($\hat{D}$ = 0.0023, 95% CI = 0.0017, 0.018) or dryland agriculture plots ($\hat{D}$ = 0.0045, 95% CI = 0.0044, 0.0053, Figure 3.4). The most conservative

extrapolation of these densities to my study area estimated the total mountain plover population at 8,577 individuals with a 95% CI of 7,511 to 35,130 birds (Tables 3.12 and 3.13).

Results of variance components analysis suggest that the amount of prairie dog colony in landscape 1 (pdL1) explained the most process variance in mountain plover abundance estimates on sampled plots (11.32%, Table 3.14). The amount of prairie dog colony in the plot (pdP) and in landscapes 2 (pdL2) and 3 (pdL3) also explained some process variance (6.60%, 8.49%, and 2.83%, respectively, Table 3.14). While plot stratum (s) and prairie dog activity status (act) each explained 4.72% of the process variance, the amount of grassland in the landscape at any scale (grsL1, grsL2, and grsL3) explained very little, if any, of the process variance.

β estimates for the effect of stratum on estimated mountain plover abundance on sampled plots reflect the same relationship suggested by estimated mean abundances (pd > grassland > ag, Tables 3.11 and 3.14). β estimates for all prairie dog habitat covariates suggest a positive relationship with plover abundance (Table 3.14). Likewise, active prairie dog colonies (~82% of prairie dog colony plots surveyed) also positively affected abundance estimates (Table 3.14).

The estimate of mountain plover latent abundance over all sampled plots obtained using occupancy data ($\hat{N}$ = 153.39, 95% CI = 122.47, 184.31) was much larger than the abundance estimate obtained using double-observer data ($\hat{N}$ = 63.08, 95% CI = 59.17, 162.64), although 95% CI's do overlap (Table 3.15). However, the RN model used to estimate latent abundance fit the data poorly (ΔAIC_c = 1011.75) when compared with the constant detection model ($p_.$, ΔAIC_c = 0) in program PRESENCE.

Burrowing Owl

A total of 60 burrowing owls were detected on 35 of the 272 surveyed plots included in analyses – 59 owls on 34 prairie dog colony plots, 1 owl on 1 grassland plot, and 0 owls in dryland agriculture (Table 3.8). Due to low numbers of detections on grassland and agriculture plots, and by observer teams 3 and 4, models in which *p* varied by stratum or observer team were not possible. The model in which *p* was modeled as constant (.) ranked higher than models where *p* was allowed to vary by visit-specific covariates (Table 3.16). The effect of all variables on *p* were contrary to my predictions (some evidence of a negative effect of 'day' and positive effects of 'temp' and 'wind'), although β estimates were small and all 95% CI's overlapped zero (Table 3.17).

Burrowing owl densities were calculated using derived abundance estimates generated under model $p_{.}N_{plot}$. On occupied plots, the estimated number of burrowing owls ranged from 1 to 6 birds per plot (Table 3.11). Results of variance components analysis suggest that none of the measured covariates explained underlying process variance in burrowing owl abundance estimates on sampled plots (Table 3.18). Owl density on prairie dog colony plots ($\hat{D}$ = 0.030 birds/ha, 95% CI = 0.028, 0.069) was significantly higher than densities on either grassland ($\hat{D}$ = 0.00044, 95% CI = 0.00041, 0.0012) or dryland agriculture plots ($\hat{D}$ = 0.00, 95% CI = 0.00, 0.00, Figure 3.5). The most conservative extrapolation of these densities to my study area estimated the total burrowing owl population at 3,554 individuals with a 95% CI of 3,298 to 8,445 birds (Tables 3.12 and 3.13).

The estimate of burrowing owl latent abundance over all sampled plots obtained using occupancy data ($\hat{N}$ = 108.34, 95% CI = 89.60, 127.08) was much larger than the

abundance estimate obtained using double-observer data ($\hat{N}$ = 64.98, 95% CI = 60.31, 148.36), although 95% CI's do overlap (Table 3.15). However, the RN model used to estimate latent abundance fit the data poorly (ΔAIC_c = 943.10) when compared with the constant detection model ($p_.$, ΔAIC_c = 0) in program PRESENCE.

Horned Lark

A total of 4,395 horned larks were detected on 264 of the 272 surveyed plots included in analyses – 1,269 larks on 83 prairie dog colony plots, 1,812 larks on 94 grassland plots, and 1,314 larks on 87 dryland agriculture plots (Table 3.8). The model in which *p* was modeled as an additive combination of observer team (obs) and average survey temperature (temp) and wind speed (wind) ranked higher than models where *p* was modeled as constant (.) or allowed to vary by plot stratum (s), single visit-specific covariates, or reduced additive models (Table 3.19).

The effect of observer team on detection reflected the same pattern (team 4 > team 5 ≥ team 2 > team 1 > team 3) among models which included the variable (Table 3.20). Effects of other visit-specific variables on *p* were small (≤0.07) but generally exhibited predicted relationships with the exception of the variable 'wind' (positive effect, Table 3.20). β estimates for a stratum effect on *p* suggest that detection probability on grassland plots is higher than in other strata ($\hat{\beta}$ = 0.35, 95% CI = 0.11, 0.60), although this model ranked low (ΔAIC_c = 43.60) compared with models incorporating an observer team effect (Table 3.20).

Horned lark densities were calculated using derived abundance estimates generated under model $p_{obs+temp+wind}N_{plot}$. On occupied plots, the estimated number of

horned larks ranged from 1 to 70 birds per plot (Table 3.11). Horned lark density on grassland plots ($\hat{D}$ = 0.76 birds/ha, 95% CI = 0.74, 0.87) was significantly higher than densities on either prairie dog colony ($\hat{D}$ = 0.62, 95% CI = 0.61, 0.75) or dryland agriculture plots ($\hat{D}$ = 0.61, 95% CI = 0.59, 0.73, Figure 3.6). The most conservative extrapolation of these densities to my study area estimated the total horned lark population at 1,615,556 individuals with a 95% CI of 1,578,820 to 1,885,093 birds (Tables 3.12 and 3.13).

Results of variance components analyses suggest that plot stratum (s) explained the most process variance in horned lark abundance estimates on sampled plots, although percent of variation explained was low (2.19%, Table 3.21). The amount of prairie dog colony in the plot (pdP) and grassland in landscape 1 (grsL1) also explained small amounts of process variance (0.05% and 0.55%, respectively, Table 3.21). Covariates measuring the amount of prairie dog colony or grassland in larger landscapes (pdL1, pdL2, pdL3, grsL2, and grsL3) did not explain any process variance in horned lark estimated abundance.

β estimates for the effect of stratum on estimated horned lark abundance on sampled plots reflect the same relationship suggested by estimated mean abundances (grassland > pd > ag, Tables 3.11 and 3.21). β estimates for all prairie dog habitat covariates suggest a negative relationship with horned lark abundance (Table 3.21). In contrast, the effect of grassland habitat covariates on horned lark abundance was positive (Table 3.21).

Cassin's Sparrow

A total of 237 Cassin's sparrows were detected on 68 of the 272 surveyed plots included in analyses – 94 sparrows on 30 prairie dog colony plots, 135 sparrows on 34 grassland plots, and 8 sparrows on 4 dryland agriculture plots (Table 3.8). Due to low numbers of detections by observer team 2, models in which *p* varied by observer team were not possible. The model in which *p* was modeled as a function of stratum (s) ranked higher than models where *p* was constant (.) or varied by visit-specific covariates, whether modeled alone or in an additive combination with plot stratum (Table 3.22). The effect of stratum on detection reflected the same pattern (grassland > pd > ag) among models which included the variable (Table 3.23). Effects of visit-specific variables (day, temp, and wind) on *p* were small with 95% CI's overlapping zero (Table 3.23).

Cassin's sparrow densities were calculated using derived abundance estimates generated under model $p_s N_{plot}$. On occupied plots, the estimated number of Cassin's sparrows ranged from 1 to 12 birds per plot (Table 3.11). Sparrow density on grassland plots ($\hat{D}$ = 0.056 birds/ha, 95% CI = 0.055, 0.073) was significantly higher than density on dryland agriculture plots ($\hat{D}$ = 0.0056, 95% CI = 0.0037, 0.036) but not prairie dog colony plots ($\hat{D}$ = 0.045, 95% CI = 0.045, 0.65, Figure 3.7). The most conservative extrapolation of these densities to my study area estimated the total Cassin's sparrow population at 92,725 individuals with a 95% CI of 90,641 to 140,719 birds (Tables 3.12 and 3.13).

Results of variance components analysis suggest that the amount of grassland in landscape 3 (grsL3) explained the most process variance in Cassin's sparrow abundance estimates on sampled plots (Table 3.24). However, the percent of variation explained by

the variable 'grsL3' was low (1.36%) and not much higher than the percent of process variation explained by plot stratum (s, 0.75%), the amount of prairie dog colony in the plot (pdP, 0.90%), or the amount of grassland in landscape 2 (grsL2, 1.05%, Table 3.24). Covariates measuring the amount of prairie dog colony in landscapes 1, 2, or 3 (pdL1, pdL2, and pdL3, respectively) did not explain any process variance in Cassin's sparrow estimated abundance.

β estimates for the effect of stratum on estimated Cassin's sparrow abundance on sampled plots reflect the same relationship suggested by estimated mean abundances (grassland > pd > ag, Tables 3.11 and 3.24). β estimates for all prairie dog habitat covariates suggest a negative relationship with sparrow abundance (Table 3.24). In contrast, the effect of grassland habitat covariates on sparrow abundance was positive (Table 3.24).

Lark Sparrow

A total of 155 lark sparrows were detected on 33 of the 272 surveyed plots included in analyses – 85 sparrows on 16 prairie dog colony plots, 67 sparrows on 15 grassland plots, and 3 sparrows on 2 dryland agriculture plots (Table 3.8). Due to low numbers of detections by observer team 2, models in which *p* varied by observer team were not possible. Models in which *p* was modeled as a function of average survey wind speed (wind) consistently ranked higher than models where *p* was constant (.) or varied by stratum (s) or other visit-specific covariates (Table 3.25).

The variable 'wind' had a negative effect on detection as I had predicted ($\hat{\beta}$ = -0.63, 95% CI = -1.22, -0.04, Table 3.26). Effects of other visit-specific covariates (day and temp) on *p* were considerably smaller (≤0.08) with 95% CI's overlapping zero, but exhibited predicted relationships (Table 3.26). The effect of stratum on detection reflected the same pattern (pd > grassland > ag) among models which included the variable (Table 3.26).

Lark sparrow densities were calculated using derived abundance estimates generated under model $p_{wind}\,N_{plot}$. On occupied plots, the estimated number of lark sparrows ranged from 1 to 19 birds per plot (Table 3.11). Sparrow density on prairie dog colony plots ($\hat{D}$ = 0.045 birds/ha, 95% CI = 0.041, 0.083) was significantly higher than density on dryland agriculture plots ($\hat{D}$ = 0.0014, 95% CI = 0.0013, 0.0028) but not grassland plots ($\hat{D}$ = 0.031, 95% CI = 0.028, 0.062, Figure 3.8). The most conservative extrapolation of these densities to my study area estimated the total lark sparrow population at 52,989 individuals with a 95% CI of 47,250 to 104,092 birds (Tables 3.12 and 3.13).

Results of variance components analysis suggest that the amount of prairie dog colony in landscape 1 (pdL1) explained the most process variance in lark sparrow abundance estimates on sampled plots (8.38%, Table 3.27). Measures of the amount of prairie dog colony at other scales (pdP, pdL2, and pdL3) also explained some process variance (2.04%, 5.08%, and 4.82%, respectively, Table 3.27). However, neither plot stratum (s) nor the amount of grassland in the landscape at any scale (grsL1, grsL2, and grsL3) explained any process variance in lark sparrow estimated abundance. β estimates for the effect of stratum on estimated lark sparrow abundance on sampled plots reflect the

same relationship suggested by estimated mean abundances (pd > grassland > ag, Tables 3.11 and 3.27). β estimates for all prairie dog habitat covariates suggest a positive relationship with sparrow abundance (Table 3.27).

Lark Bunting

A total of 1,564 lark buntings were detected on 171 of the 272 surveyed plots included in analyses – 499 buntings on 52 prairie dog colony plots, 818 buntings on 77 grassland plots, and 247 buntings on 42 dryland agriculture plots (Table 3.8). The model in which *p* was modeled as an additive combination of observer team (obs) and average survey temperature (temp) and wind speed (wind) ranked higher than models where *p* was modeled as constant (.) or allowed to vary by plot stratum (s), single visit-specific covariates, or reduced additive models (Table 3.28).

The effect of observer team on detection reflected the same general pattern (team 4 > team 2 > team 5 ≈ team 1 > team 3) among models which included the variable (Table 3.29). Effects of other visit-specific variables on *p* were small. The variable 'temp' had a small negative effect on *p* ($\hat{\beta}$ = -0.05, 95% CI = -0.09, -0.01), while the 'wind' had a small positive effect ($\hat{\beta}$ = 0.14, 95% CI = 0.00, 0.28, Table 3.29). The effect of the variable 'day' varied depending on model structure (Table 3.29). β estimates for a stratum effect on *p* reflected the same general pattern (grassland > pd > ag) among models which included the variable, although these models ranked relatively low ($\Delta AIC_c \geq 14.82$, Table 3.29).

Lark bunting densities were calculated using derived abundance estimates generated under model $p_{obs+temp+wind} N_{plot}$. On occupied plots, the estimated number of

lark buntings ranged from 1 to 57 birds per plot (Table 3.11). Lark bunting density on grassland plots ($\hat{D}$ = 0.34 birds/ha, 95% CI = 0.34, 0.42) was significantly higher than densities on either prairie dog colony ($\hat{D}$ = 0.25, 95% CI = 0.24, 0.31) or dryland agriculture plots ($\hat{D}$ = 0.12, 95% CI = 0.11, 0.17, Figure 3.9). The most conservative extrapolation of these densities to my study area estimated the total lark bunting population at 623,171 individuals with a 95% CI of 606,806 to 781,335 birds (Tables 3.12 and 3.13).

Results of variance components analysis suggest that the amount of prairie dog colony in landscape 3 (pdL3) explained the most process variance in lark bunting abundance estimates on sampled plots (4.34%, Table 3.30). Other landscape-level covariates (pdL1, pdL2, grsL1, grsL2, and grsL3) also explained some process variance (0.04-2.69%, Table 3.30). However, the amount of prairie dog colony at the plot level (pdP) failed to explain any process variance in estimated abundances on sampled plots. Plot stratum (s) explained 2.02% of process variance of lark bunting abundance estimates (Table 3.30). β estimates for the effect of stratum on estimated lark bunting abundance on sampled plots reflect the same relationship suggested by estimated mean abundances (grassland > pd > ag, Tables 3.11 and 3.30). β estimates for all other habitat covariates suggest a positive relationship with lark bunting abundance (Table 3.30).

Grasshopper Sparrow

A total of 197 grasshopper sparrows were detected on 54 of the 272 surveyed plots included in analyses – 35 sparrows on 11 prairie dog colony plots, 51 sparrows on 13 grassland plots, and 111 sparrows on 30 dryland agriculture plots (Table 3.8). The

model in which p was modeled as an additive combination of observer team (obs) and average survey temperature (temp) and wind speed (wind) ranked higher than models where p was modeled as constant (.) or allowed to vary by plot stratum (s), single visit-specific covariates, or reduced additive models (Table 3.31).

The effect of observer team on detection varied slightly among models but suggested a general pattern (team 4 ≈ team 1 > team 2 > team 5 ≈ team 3, Table 3.32). Effects of other visit-specific variables on p were small but exhibited predicted relationships with the exception of 'day' which had a small positive effect (Table 3.32). β estimates for a stratum effect on p indicated a positive effect of grassland and a negative effect of dryland agriculture, although p_s models ranked low in the model set (Tables 3.32). Confidence intervals for all variables overlapped zero (Table 3.32).

Grasshopper sparrow densities were calculated using derived abundance estimates generated under model $p_{obs+temp+wind} N_{plot}$. On occupied plots, the estimated number of grasshopper sparrows ranged from 1 to 17 birds per plot (Table 3.11). Results of variance components analysis suggest that none of the measured covariates explained underlying process variance in grasshopper sparrow abundance estimates on sampled plots (Table 3.33). Sparrow density on dryland agriculture plots ($\hat{D}$ = 0.066 birds/ha, 95% CI = 0.052, 0.17) was significantly higher than density on prairie dog colony plots ($\hat{D}$ = 0.018, 95% CI = 0.017, 0.038) but not grassland plots ($\hat{D}$ = 0.025, 95% CI = 0.021, 0.065, Figure 3.10). The most conservative extrapolation of these densities to my study area estimated the total grasshopper sparrow population at 83,407 individuals with a 95% CI of 68,356 to 218,877 birds (Tables 3.12 and 3.13).

Western Meadowlark

A total of 649 western meadowlarks were detected on 219 of the 272 surveyed plots included in analyses – 235 meadowlarks on 73 prairie dog colony plots, 238 meadowlarks on 76 grassland plots, and 176 meadowlarks on 70 dryland agriculture plots (Table 3.8). Models in which p was modeled as a function of observer team (obs) consistently ranked higher than models where p was modeled as constant (.) or allowed to vary by stratum (s) or other visit-specific covariates alone (Table 3.34).

The effect of observer team on detection reflected the same pattern (team 4 > team 5 > team 2 > team 3 > team 1) among models which included the variable (Table 3.35). Effects of other visit-specific variables on p were small (≤0.09) with 95% CI's overlapping zero (Table 3.35). β estimates for a stratum effect on p suggest that detection probability on prairie dog colony plots was lower than in other strata, although this model ranked very low among the model set (Table 3.35).

Western meadowlark densities were calculated using derived abundance estimates generated under model $p_{obs}\, N_{plot}$. On occupied plots, the estimated number of western meadowlark ranged from 1 to 11 birds per plot (Table 3.11). Meadowlark density was highest on prairie dog colony plots ($\hat{D}$ = 0.12 birds/ha, 95% CI = 0.11, 0.17) but not significantly higher than densities on either grassland ($\hat{D}$ = 0.10, 95% CI = 0.10, 0.14) or dryland agriculture plots ($\hat{D}$ = 0.08, 95% CI = 0.08, 0.13, Figure 3.11). The most conservative extrapolation of these densities to my study area estimated the total western meadowlark population at 215,690 individuals with a 95% CI of 210,811 to 320,406 birds (Tables 3.12 and 3.13).

Results of variance components analysis suggest that plot stratum (s) explained the most process variance in western meadowlark abundance estimates on sampled plots, although percent of variation explained was low (0.97%, Table 3.36). The amount of grassland in landscape 3 (grsL3) also explained a small amount of process variance (0.39%, Table 3.36). Other habitat covariates failed to explain any process variance in meadowlark estimated abundance. β estimates for the effect of stratum on estimated western meadowlark abundance on sampled plots reflect the same relationship suggested by estimated mean abundances (pd > grassland > ag, Tables 3.11 and 3.36). There was some evidence of a negative relationship between the amount of grassland in landscape 3 and meadowlark abundance (Table 3.36).

DISCUSSION

My results suggest that double-observer methods are feasible for monitoring abundance of grassland bird species over large areas. Field protocols were fairly easy to teach/learn and could be easily applied in the open grassland habitat. This methodology is especially promising for species such as mountain plovers and burrowing owls which occur in low numbers on individual plots and whose movements are easy to track during surveys. Species which occur at higher densities present a greater challenge due to the possibility of double counting. In addition, limitations may exist to the extension of this methodology to other habitat types, such as forests, where bird movement is more difficult to track. To ameliorate such circumstances, plot sizes could be reduced, survey duration shortened, or other survey design changes made to improve the resulting abundance estimates.

Double-observer methodology is more cost- and time-efficient than physical mark-recapture techniques and allows modeling of time-varying and habitat variables into species detection probabilities. Proper implementation of double-observer survey methods also promises to avoid bias associated with violation of at least two assumptions important to distance sampling: 1) all individuals on the line or point are detected with probability equal to 1, and 2) individuals do not move in response to the observer before being detected. Because these assumptions can be difficult to meet in field conditions (Rosenstock et al. 2002), the use of double-observer methodology may result in improved estimates of grassland bird abundance.

My results also suggest that probability-based sampling schemes can be used effectively in large-scale studies and demonstrate that statistical rigor need not be sacrificed to obtain large sample sizes. My study was the first avian-specific study to demonstrate the feasibility of a spatially balanced sampling design across such a large study area encompassing both public and private lands. I believe that this spatially balanced approach is useful for those instances when good coverage of the study area is desired, including studies investigating spatial variation of a response variable. The RRQRR algorithm allowed me to construct a survey order of plots that allowed substitution when I encountered conditions in the field that did not allow surveying to occur. In my study, this proved especially useful when large numbers of selected prairie dog plots did not meet stratum criteria.

Abundance and Density Estimation

Prior to this study, statistically rigorous population estimates did not exist for any of my study species for the extent of my study area. These results (Tables 3.12 and 3.13) are the first to provide unbiased information on the status of Colorado's grassland avifauna throughout the eastern plains and should be useful for assessing avian conservation needs. My conservative extrapolated population estimate for mountain plovers (8,577 breeding individuals, Table 3.13) is larger than the previous statewide estimate (7,000 individuals, Colorado Division of Wildlife 2003b) and represents a large portion of the estimated global population (8,000-12,000 individuals, U.S. Fish and Wildlife Service 1999, 11,000-14,000 individuals, revised by Plumb et al. 2005). The species may be more abundant than previously thought. Population estimates for the burrowing owl are not as encouraging. My conservative extrapolated population estimate (3,554 individuals, Table 3.13) is on the low end of the current statewide estimate (1,000-10,000 breeding pairs, Colorado Division of Wildlife 2003b).

Extrapolated species population estimates for eastern Colorado were estimated using calculated species densities for my three strata. When comparing these density estimates for mountain plovers and burrowing owls with estimates from other portions of their ranges, calculated average densities in my study area were low. On surveyed prairie dog colony plots, I calculated mountain plover density to be 0.023 birds/ha (2.3[1] birds/km^2), with an average density of 0.0093 birds/ha (0.93[1] birds/km^2) on surveyed plots across all strata. This is much lower than the 7.9 birds/km^2 average density which Wunder et al. (2003) estimated in South Park, Colorado and the 2.0-4.7 birds/km^2

[1] These corrected estimates (birds/km^2) were incorporated February 19, 2007 (after thesis publication). Previous incorrect estimates were caused by a mistake converting birds/ha to birds/km^2 – birds/ha was incorrectly multiplied by 0.01 instead of 100.

observed on the Pawnee National Grassland in the northeastern portion of the state (1990-1994, Knopf 1996a). Similar densities have been observed on prairie dog colonies in Montana (1.28-6.80 birds/km^2, 1991 to 1995, Knopf 1996a), appearing to vary with seasonal climatic conditions. Higher densities have been found on known breeding locales in Wyoming (average 4.47 birds/km^2, Plumb et al. 2005). Of these estimates, only those from South Park and Wyoming were adjusted for detection error.

My calculated density estimates for burrowing owl were equally low – 0.030 birds/ha (3.0[1] birds/km^2) – on surveyed prairie dog colony plots, with an average density of 0.0096 birds/ha (0.96[1] birds/km^2) on surveyed plots across all strata. Hughes (1993) observed densities of 0.02-14.50 owls/ha on prairie dog colonies in northeastern Colorado, although her counts were not adjusted for detection error. Desmond and Savidge (1996) found 0.10-30.0 owls/ha on prairie dog colonies in the Nebraska panhandle (counts not adjusted for detection error), with density varying by colony size. Conway and Simon (2003) estimated burrowing owl density to be 0.15-0.22 birds/km^2 along roads in Wyoming based on point counts and driving surveys of owl nesting locations. Although the latter estimate was adjusted for detection, its inference is limited due to the convenience-sampling methods employed.

Likewise, differences between my study results and previous density estimates may be due to the sampling scheme used. Whereas most previous surveys were conducted only in known occupied areas and/or areas of higher concentrations, my study employed a probability-based sampling design in which all areas meeting strata criteria were open to sampling, including unoccupied areas and areas of low concentrations. This

[1] These corrected estimates (birds/km^2) were incorporated February 19, 2007 (after thesis publication). Previous incorrect estimates were caused by a mistake converting birds/ha to birds/km^2 – birds/ha was incorrectly multiplied by 0.01 instead of 100.

certainly resulted in lower calculated densities than had I only surveyed areas where each species was known to occur in high numbers.

Estimates of mountain plover latent abundance have been obtained using indirect methods. Dreitz et al. (2006) estimated latent abundance on three strata in Colorado's shortgrass prairie. Although their estimates cannot be extrapolated to provide a statewide abundance estimate, their results do suggest that mountain plover density is greater on prairie dog colonies than on dryland agriculture fields and native shortgrass without prairie dogs. In my study, latent abundance estimates for both the mountain plover and burrowing owl were much larger than derived species abundance estimates on sampled plots obtained using double-observer methodology, although 95% CI's overlapped (Table 3.15). This comparison suggests that the latent abundance model assumption of closure was violated to a stronger extent than with the double-observer methods. This is not unreasonable given that the occupancy data were collected over a two-month period per plot, whereas the double-observer data were collected in a single visit typically lasting less than one hour. Latent abundance could be better estimated by decreasing time between visits, adjusting plot size based on individual species' breeding territories/home-ranges, or using a robust design.

On the other hand, larger latent abundance estimates may indicate that double-observer counts were too conservative in their attempt not to double-count individuals. While this was likely a concern for abundant species (e.g., horned lark), it is unlikely that this was a problem with less common species such as mountain plover and burrowing owl. This potential drawback of double-observer surveys could be ameliorated by

decreasing plot size which would subsequently decrease survey duration and, hopefully, the amount of bird movement.

The RN model, which relies upon the Poisson distribution to estimate latent abundance, fit both the mountain plover and burrowing owl data poorly. Poor model fit was likely due to the large number of zeros in the data (more than are warranted under the Poisson distribution) representing plots on which the species was never detected. When estimating abundance using a latent-occupancy approach in areas of low concentration or over large scales, models which take many "zeros" into account would be useful and should be investigated. Additional methodological developments might focus on combining sources of data from double-observer methods and occupancy methods to obtain the best abundance estimates possible.

Effects on Detection Probabilities

The effect of observer team on detection probability was found in highest-ranking models for all species for which an observer effect could be modeled (mountain plover, horned lark, lark bunting, grasshopper sparrow, and western meadowlark) following my *a priori* hypothesis. In addition, the relative effect of observer team varied by species. These results suggest the importance of adjusting species counts for observer differences, and that generalizations may be unwise, particularly for multi-species studies.

Other visit-specific variables (day, temp, and wind) had small effects on species detection probabilities, although the direction of these effects was not always in support of my *a priori* hypotheses. Effects of survey day for some species (mountain plover, burrowing owl, grasshopper sparrow, and western meadowlark) were contrary to my

predictions, potentially indicating shifts in the timing of breeding activities (e.g., courtship, nesting, brood rearing). This is not unreasonable given that breeding phenology may vary between years in response to climatic conditions on wintering and breeding grounds. For many species, increases in temperature and/or wind speed apparently increased detection probability, contrary to my *a priori* hypotheses. Although I cannot explain why increased wind speed would aid detection, the positive effect of temperature may be related to the overall cooler temperatures experienced due to the cold front passage during the latter part of the survey period.

Model selection results suggest that plot stratum appreciably affected detection probability for only one species (Cassin's sparrow). However, for species for which a stratum effect could be modeled, there generally appeared to be a positive effect of grassland on detection probability and a negative effect of dryland agriculture (with the exception of western meadowlark). Based on my pilot study results, I hypothesized that detection probabilities on prairie dog colony plots would be as high, or higher than, detection probabilities on grassland plots. Although β estimates for differences between these strata were generally small, contrary results may be due to differences among study years and areas resulting from changing habitat conditions and caused by differences in seasonal precipitation and temperature.

Effects on Abundance and Density

Plot-level effects

My study results suggest that the abundance and density of grassland birds are affected by plot-level habitat factors, and that these effects vary by species. Potential

avian-habitat associations are suggested by stratum-specific abundance and density estimates. Estimated mean abundance of four species (mountain plover, burrowing owl, lark sparrow, and western meadowlark) on sampled plots was higher on prairie dog colony plots than on plots in other strata, following my hypotheses (Tables 3.7 and 3.11). This is similar to the results of Smith and Lomolino (2004) which indicate positive associations with prairie dog habitat for burrowing owl, lark sparrow, and western meadowlark in the Oklahoma panhandle. Mountain plover and burrowing owl were also found to be positively associated with prairie dog colonies in southeastern Colorado and southwestern Kansas (Winter et al. 2003). My results also show that calculated densities of these two species were significantly higher on prairie dog colony plots than on grassland or dryland agriculture plots (Figures 3.4 and 3.5).

Other species (horned lark, Cassin's sparrow, and lark bunting) were more abundant on grassland plots (Table 3.11), where calculated densities of horned lark and lark bunting were significantly higher than on prairie dog colony or dryland agriculture plots (Figures 3.6 and 3.9). These species results generally followed my hypotheses (Table 3.7) with the exception of horned lark which I predicted would be more abundant on dryland agriculture, based on my pilot study results. While these results are similar to those of Agnew et al. (1986), Winter et al. (2003), and Smith and Lomolino (2004) for Cassin's sparrows and lark buntings, their results indicate that horned lark were more abundant on prairie dog colonies than other habitats.

Dissimilar results may be due to different study areas, spatial extents, sampling design (e.g., road bias), and methodologies (including whether counts were adjusted for detection error) as well as differences in habitat conditions resulting from variation

among study areas and years. Yearly differences in the amount of seasonal precipitation and spring/summer temperatures typically result in significant differences in vegetation height and cover even within eastern Colorado. In years with less precipitation and higher temperatures, vegetation height and cover will be less across all habitat types; in wetter, cooler years, the opposite is true. Prairie dog colony attributes considered favorable for some species (e.g., lower vegetation height, concentrated prey species, structural diversity in the landscape) result from differences in vegetation between colonized and uncolonized areas which may be most dramatic during summer (i.e., the breeding/growing season). In drought years, these effects would not be as great, while differences between colonized and uncolonized areas (and avian response to those differences) may be much more striking in wet years (Barko et al. 1999, Winter et al. 2003).

In my study, only grasshopper sparrows were found in higher abundance and at higher densities (although not significantly so) on dryland agriculture plots than on plots in other strata (Table 3.11 and Figure 3.10). This result is similar to results of previous research which suggest a negative association with prairie dog colonies (Agnew et al. 1986, Winter et al. 2003, Smith and Lomolino 2004). My results indicate that relative abundance and density of my eight study species combined was highest on grassland plots than on plots of other strata. This result corresponds to findings by Winter et al. (2003) in southeastern Colorado and southwestern Kansas, but differs from study results from Agnew et al. (South Dakota, 1986), Barko et al. (Oklahoma panhandle, 1999), and Smith and Lomolino (Oklahoma panhandle, 2004).

In addition to stratum effects illustrated by species abundance and density estimates, results of variance components analysis suggest that activity status ('act') of prairie dog colony plots positively affected mountain plover abundance, although this was not the case for burrowing owl (Tables 3.14 and 3.18). The failure of activity status to explain any variance in owl abundance estimates may be a result of the relatively high percentage of plots with active prairie dogs. While 64.5% of plots occupied by mountain plover were considered active, 91.4% of plots occupied by burrowing owl had active prairie dogs, leaving little variance to be explained by this variable.

Landscape-level effects

Landscape variables, specifically the proportion of area covered by prairie dog colonies or grassland, failed to explain much process variance in abundance estimates on surveyed plots for many of my study species. Contrary to my hypotheses, variance components analyses for the burrowing owl and grasshopper sparrow suggest that none of the measured habitat factors affected estimated species abundance on occupied plots when compared with the mean model (Tables 3.18 and 3.33). This result for burrowing owl contrasts results Orth and Kennedy (2001) found in northeastern Colorado which suggest a negative relationship with percent cover by shortgrass over areas comparable to my landscapes 2 and 3.

For other species (horned lark, Cassin's sparrow, and western meadowlark), only one or two grassland landscape variables explained any process variance in plot abundance estimates for each species, and percent of variation explained was low (≤1.36%, Tables 3.21, 3.24, and 3.36). For the remaining three species (mountain plover,

lark sparrow, and lark bunting), prairie dog colony landscape variables explained larger amounts of process variance than did grassland landscape variables (Tables 3.14, 3.27, and 3.30).

Variance components analysis of mountain plover abundance estimates on occupied plots indicates a positive relationship with the amount of prairie dog colony in the landscape, following my hypotheses. The variable 'pdL1' (amount of prairie dog colony in landscape 1) explained the most process variation in estimated plover abundance (11.32%, Table 3.14). Landscape 1 encompasses an average brood-rearing territory as observed by Knopf and Rupert (1996). Process variation was also explained by other prairie dog colony habitat variables (6.60% by 'pdP', 8.49% by 'pdL2', and 2.83% by 'pdL3'), although caution should be used when interpreting these results due to the known correlation of nested habitat variables (Table 3.5).

The overall lack of explanatory power of measured habitat covariates suggests that other, unaccounted-for variables are causing between-plot variation in species abundance estimates. These may include smaller, patch- or plot-level variables such as vegetation characteristics, microclimates, and prey availability which can operate as limiting factors to local species abundance and density. In addition, habitat fragmentation, which can be expressed in measures of patch size and shape, and habitat degradation may also limit avian abundance despite the total amount of habitat in a landscape. Thus, measures of habitat quality and structure may also be necessary to describe variation in estimated abundance.

Limitations on Inference

Caution should be used when interpreting results of variance components analyses with respect to landscape habitat variables due to correlations of nested variables, particularly when drawing conclusions about large-scale effects. Inference is also limited by the short time span of my study. A single-year study cannot consider the changing habitat conditions in eastern Colorado which result from fluctuations in precipitation and temperature. Therefore, replication and longer-term studies are desirable to obtain additional information on species-habitat associations.

In addition, extrapolation of my study results to all of eastern Colorado is limited by the proportion of plots that I could not include in my sampling frame (Table 3.4). For example, I was not able to survey 294 prairie dog colony plots (154 no contact, 34 access denied, 106 stratum criteria not met). Thus, the most conservative extrapolation of my study results is limited to only 51.0% of prairie dog colony habitat in eastern Colorado, and "liberal" abundance estimates must be adjusted accordingly. If it can be reasonably assumed that "no contact" plots did not differ significantly from surveyed plots, extrapolation could be extended to 74.3% of prairie dog habitat in the study area to obtain more "moderate" estimates. This problem of limited inference could be lessened in future studies by decreasing the number of plots not surveyed. This could be achieved by allowing for additional time to contact landowners and lessees, and, in the case of prairie dog habitat specifically, improving prairie dog location data or limiting data used to only the most recent (e.g., collected within the previous 2-3 years).

I also note that my species abundance estimates are stratum-specific and thus dependent on my estimates of habitat coverage within my study area. If different habitat

information is used (e.g., different estimates of prairie dog acreage or different GIS vegetation layers), the resulting abundance estimates may vary greatly from those presented here (Tables 3.12 and 3.13). In addition, my extrapolated species population estimates do not include those portions of populations using other habitat types not included in my study (e.g., irrigated agriculture, shrublands) which make up approximately 27% of the study area. Thus, for those species that utilize such habitats, my extrapolated abundance estimates likely underestimate the breeding population in eastern Colorado.

In addition to the usefulness of grassland bird population estimates, results from my study will be useful in the planning of future studies (Chapter 4). Estimated detection probabilities (Table 3.37) can be used when designing double-observer surveys in similar habitats. The spatially balanced sampling design can also be used and adjusted to incorporate unequal sampling probabilities if desired.

LITERATURE CITED

Agnew, W., D. W. Uresk, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. Journal of Range Management 39:135-139.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Barko, V. A., J. H. Shaw, and D. M. Leslie. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwestern Naturalist 44:484-489.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies - mammals. Pages 149-166 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Borchers, D. L., S. T. Buckland, and W. Zucchini. 2002. Estimating Animal Abundance – Closed Populations. Springer, New York, New York, USA.

Brennan, L. A., and W. P. Kuvlesky. 2005. North American grassland birds: An unfolding conservation crisis? Journal of Wildlife Management 69:1-13.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: Initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference - A Practical Information-Theoretic Approach. Springer, New York, New York, USA.

Colorado Division of Wildlife. 2003a. Colorado Vegetation Classification Project. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Colorado Division of Wildlife. 2003b. Conservation Plan for Grassland Species in Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Conway, C. J., and J. C. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501-511.

Cunningham, M. A., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Applications 16:1062-1075.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: A 7 year analysis. Journal of Wildlife Management 64:1067-1075.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2003. Annual survival and population estimates of mountain plovers in southern Phillips County, Montana. Ecological Applications 13:1013-1026.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2005. Mountain plover population responses to black-tailed prairie dogs in Montana. Journal of Wildlife Management 69:1546-1553.

Dreitz, V. J. 2005. Resolving conflicts of Mountain Plovers (*Charadrius montanus*) breeding on agricultural lands in Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado, USA.

Dreitz, V. J., P. M. Lukacs, and F. L. Knopf. 2006. Monitoring low density avian populations: an example using Mountain Plover. Condor 108:700-706.

Dreitz, V. J., M. B. Wunder, and F. L. Knopf. 2005. Movements and home ranges of Mountain Plovers raising broods in three Colorado landscapes. Wilson Bulletin 117:128-132.

Hamer, T. L., C. H. Flather, and B. R. Noon. 2006. Factors associated with grassland bird species richness: the relative roles of grassland area, landscape structure, and prey. Landscape Ecology 21:569-583.

Hanni, D. 2002. A comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Hanni, D. 2003. Section-based monitoring of breeding birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington, D.C., USA.

Hines, J. E. 2006. Program PRESENCE v 2.0. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA. Online at <http://www.mbr-pwrc.usgs.gov/software/presence.html>.

Huggins, R. M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133-140.

Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. Biometrics 47:725-732.

Hughes, A. J. 1993. Breeding density and habitat preference of the burrowing owl in northeastern Colorado. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Hutto, R. L., and J. S. Young. 2002. Regional landbird monitoring: Perspectives from the northern Rocky Mountains. Wildlife Society Bulletin 30:738-750.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

Knopf, F. L. 1996a. Mountain Plover (*Charadrius montanus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 211. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Knopf, F. L. 1996b. Prairie legacies - birds. Pages 135-148 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Knopf, F. L., and B. J. Miller. 1994. *Charadrius montanus* - montane, grassland, or bare-ground plover? Auk 111:504-506.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

Knopf, F. L., and J. R. Rupert. 1999. The use of crop fields by breeding Mountain Plovers. Studies in Avian Biology 19:81-86.

Knowles, C. J., C. J. Stoner, and S. P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland, USA.

Lomolino, M. V., R. Channell, D. R. Perault, and G. A. Smith. 2001. Downsizing nature: Anthropogenic dwarfing of species and ecosystems. Pages 223-243 *in* J. L. Lockwood and M. L. McKinney, editors. Biotic Homogenization. Kluwer, New York, New York, USA.

Lueders, A. S. 2002. Influences of vegetative structure on avian populations under grazing regimes in North Dakota mixed-grass prairie. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Miller, S. D., and J. F. Cully. 2001. Conservation of black-tailed prairie dogs (*Cynomys ludovicianus*). Journal of Mammalogy 82:889-893.

Nichols, J. D. 1999. Monitoring is not enough: On the need for a model-based approach to migratory bird management. *In* R. Bonney, D. N. Pashley, R. J. Cooper, and L. Niles, editors. Strategies for Bird Conservation: The Partners in Flight Planning Process. Cornell Lab of Ornithology, Cape May, New Jersey, USA. Online at <http://birds.cornell.edu/pifcapemay>.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393-408.

Olson, S. L., and D. Edge. 1985. Nest site selection by mountain plovers in northcentral Montana. Journal of Range Management 38:280-282.

Orth, P. B., and P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by burrowing owls (*Athene cunicularia hypugaea*) in northeastern Colorado? Canadian Journal of Zoology-Revue Canadienne de Zoologie 79:1038-1045.

Plumb, R. E., F. L. Knopf, and S. H. Anderson. 2005. Minimum population size of Mountain Plovers breeding in Wyoming. Wilson Bulletin 117:15-22.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105-119.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: Current practices and an alternative. Auk 119:46-53.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin 32:6-15.

Sauer, J. R., J. E. Fallon, and R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for bird conservation regions. Journal of Wildlife Management 67:372-389.

Shackford, J. S., and D. M. Leslie. 1994. Mountain Plover breeding activity on cultivated fields. Federal aid project E-26-1. Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma, USA.

Shackford, J. S., D. M. Leslie, and W. D. Harden. 1999. Range-wide use of cultivated fields by Mountain Plovers during the breeding season. Journal of Field Ornithology 70:114-120.

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, D. N. Svingen. 2001a. Occurrence of Burrowing Owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research 35:316-321.

Sidle, J. G., D. H. Johnson, and B. R. Euliss. 2001b. Estimated areal extent of colonies of black-tailed prairie dogs in the northern Great Plains. Journal of Mammalogy 82:928-936.

Smith, G. A., and M. V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138:592-602.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Theobald, D. T. 2004. GIS - RRQRR: Spatially balanced sampling tool. ArcGIS v.9.0 extension. Language: Python. Operating System: Windows XP. Software Application ESRI ArcGIS v.9.0. Colorado State University, Fort Collins, Colorado, USA.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

Thompson, W. L. 2002. Towards reliable bird surveys: Accounting for individuals present but not detected. Auk 119:18-25.

Toombs, T. P. 1997. Burrowing owl nest-site selection in relation to soil texture and prairie dog colony attributes. Thesis, Colorado State University, Fort Collins, Colorado, USA.

U.S. Fish and Wildlife Service. 1999. Proposed threatened status for the Mountain Plover. Pages 7587-7601 *in* Federal Register Volume 64, Number 30, Washington D.C., USA.

Valiulis, J. 2003. The use of continuous and categorical measures of landscape structure in predicting biotic response: An example using grassland birds. Thesis, Colorado State University, Fort Collins, Colorado, USA.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46, Supplement, 120-138.

White, G. C., K. P. Burnham, and D. R. Anderson. 2002. Advanced features of program MARK. Pages 368-377 *in* R. Fields, editor. Integrating People and Wildlife for a Sustainable Future, Proceedings of the Second International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA.

White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265-272.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Vertebrate Populations. Academic Press, San Diego, California, USA.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2003. Breeding season avifauna of prairie dog colonies and non-colonized areas in shortgrass prairie. Transactions of the Kansas Academy of Science 106:129-138.

Wunder, M. B., F. L. Knopf, and C. A. Pague. 2003. The high-elevation population of Mountain Plovers in Colorado. Condor 105:654-662.

Table 3.1. Correlation matrix for 9 visit-specific variables recorded during double-observer surveys of 278 plots in eastern Colorado in 2005. 'Day' is an assigned value representing date of visit within the survey season. 'StartTime' is the time of day at which the survey began. 'SurvDur' is the survey duration in minutes. 'AvgTemp' is the mean of recorded start and end temperatures, measured in °C. 'MaxTemp' is the higher of the recorded start or end temperatures. 'AvgWind' is the mean of recorded start and end wind speeds, measured in meters per second. 'MaxWind' is the greater of the recorded start or end wind speeds. 'AvgCloud' is the mean of recorded start and end cloud cover, estimated visually and coded as 1-4 representing 0-25%, 26-50%, 51-75% and >75% cover, respectively. 'MaxCloud' is the greater of the recorded start or end cloud cover.

	Day	StartTime	SurvDur	AvgTemp	MaxTemp	AvgWind	MaxWind	AvgCloud	MaxCloud
Day	1.00								
StartTime	-0.06	1.00							
SurvDur	-0.15	0.02	1.00						
AvgTemp	-0.48	0.32	-0.05	1.00					
MaxTemp	-0.49	0.33	0.00	0.99	1.00				
AvgWind	-0.02	0.19	-0.05	0.03	0.01	1.00			
MaxWind	-0.05	0.23	-0.03	0.05	0.04	0.97	1.00		
AvgCloud	0.07	0.02	-0.09	-0.31	-0.33	0.21	0.20	1.00	
MaxCloud	0.05	0.04	-0.07	-0.27	-0.29	0.21	0.20	0.98	1.00

Table 3.2. Variables used as covariates in models estimating detection probabilities (*p)* of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown.

Visit-specific variable	Definition	Value range	Mean ± SD
day	Assigned value representing date of visit within the survey season (2 May – 29 Jun, during which abundance surveys were conducted 20 May – 6 Jun) where 'day' = 19 indicates 20 May 2005	19 – 36	27.03 ± 5.05
obs	Categorical designation of observer team (1-5) that conducted survey	N/A	N/A
temp	Average temperature during each plot visit, calculated as the mean of recorded start and end temperatures measured in degrees Celsius	4.60 – 30.55	18.35 ± 5.47
wind	Average wind speed during each plot visit, calculated as the mean of recorded start and end wind speeds measured in meters per second	0.00 – 5.95	2.26 ± 1.54
Plot-level variable			
s	Categorical designation of plot stratum – prairie dog colony, grassland, or dryland agriculture	N/A	N/A

Table 3.3. Predicted results of covariate-modeled detection probabilities based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific detection probabilities. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species detection probability. Explanation and coding of model parameters are provided in Table 3.2.

	Species							
Visit-specific covariate	Mountain plover	Burrowing owl	Horned lark	Cassin's sparrow	Lark sparrow	Lark bunting	Grasshopper sparrow	Western meadowlark
day	+	+	+	–	–	–	–	–
obs	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5	1 ≠ 2 ≠ 3 ≠ 4 ≠ 5
temp	–	–	–	–	–	–	–	–
wind	–	–	–	–	–	–	–	–
Plot-level covariate								
s	pd = ag > grass	pd > grass = ag	pd > grass = ag	pd = grass > ag	pd = grass > ag	NE	NE	pd > grass > ag

Table 3.4. Area of extrapolation for estimates of grassland bird abundance under three scenarios – (a) conservative, (b) moderate, and (c) liberal – in eastern Colorado in 2005. Estimated total acreage of three habitat types – prairie dog colonies, grassland, and dryland agriculture –within the study area is shown. For each extrapolation scenario, the percent of this area that may be extrapolated to and the corresponding acreage are also shown. The conservative scenario adjusts for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. The moderate scenario adjusts only for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact"' plots do not differ from surveyed plots). The liberal scenario includes no adjustment.

		Extrapolation scenario					
		Conservative		Moderate		Liberal	
Stratum	Study Area ha	%	ha	%	ha	%	ha
Prairie dog colony	185,653	51.0	94,683	74.3	137,940	100.0	185,653
Grassland	3,966,710	38.4	1,523,217	79.1	3,137,668	100.0	3,966,710
Dryland agriculture	1,760,405	37.7	663,673	82.5	1,452,334	100.0	1,760,405
Combined total	5,912,768	44.9	2,654,833	77.7	4,594,221	100.0	5,912,768

Table 3.5. Correlation matrix for 8 plot-level variables representing habitat characteristics of 278 mark-recapture plots in eastern Colorado in 2005. 'ActPlot' is an indicator variable representing prairie dog activity within a plot. 'PdP' is the proportion of a plot occupied by prairie dog colony, measured in GIS. 'PdL1' is the proportion of landscape 1, defined as the area of a plot and its 500-m buffer, occupied by prairie dog colony. 'PdL2' is the proportion of landscape 2, defined as the area of a plot and its 1500-m buffer, occupied by prairie dog colony. 'PdL3' is the proportion of landscape 3, defined as the area of a plot and its 2250-m buffer, occupied by prairie dog colony. 'GrsL1' is the proportion of landscape 1 occupied by grassland, measured in GIS. 'GrsL2' is the proportion of landscape 2 occupied by grassland. 'GrsL3' is the proportion of landscape 3 occupied by grassland.

	actPlot	pdP	pdL1	pdL2	pdL3	grsL1	grsL2	grsL3
actPlot	1.00							
pdP	0.81	1.00						
pdL1	0.72	0.93	1.00					
pdL2	0.57	0.80	0.92	1.00				
pdL3	0.51	0.73	0.86	0.98	1.00			
grsL1	-0.24	-0.31	-0.35	-0.32	-0.28	1.00		
grsL2	-0.08	-0.10	-0.13	-0.15	-0.14	0.92	1.00	
grsL3	-0.04	-0.04	-0.06	-0.08	-0.08	0.87	0.98	1.00

Table 3.6. Habitat variables used in models examining underlying process variance of derived abundance estimates of grassland bird species in eastern Colorado in 2005. Variable name, definition, value range, and mean ± standard deviation (SD) are shown. Values are presented for all plots combined as well as for prairie dog colony (PD), grassland (Grass), and dryland agriculture (Ag) plots separately. In variable definitions, "landscape 1" refers to a plot plus its 500-m buffer, "landscape 2" refers to a plot plus its 1500-m buffer, and "landscape 3" refers to a plot plus its 2250-m buffer.

Plot-level variable	Definition	Value range	Mean ± SD
s	Categorical designation of plot stratum – prairie dog colony, grassland or dryland agriculture	N/A	N/A
act	Indicator variable representing prairie dog activity within a plot, assessed throughout the survey season	N/A	N/A
pdP	Proportion of plot occupied by prairie dog colony for all plots and for prairie dog colony plots alone	All plots = 0.00 – 1.00 PD plots = 0.38 – 1.00	All plots = 0.26 ± 0.40 PD plots = 0.82 ± 0.19
Landscape-level variable			
pdL1	Proportion of landscape 1 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.07 – 1.00 Grass plots = 0.00 – 0.15 Ag plots = 0.00 – 0.15	All plots = 0.17 ± 0.28 PD plots = 0.54 ± 0.24 Grass plots = 0.01 ± 0.03 Ag plots = 0.00 ± 0.02
pdL2	Proportion of landscape 2 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 0.67 PD plots = 0.02 – 0.67 Grass plots = 0.00 – 0.16 Ag plots = 0.00 – 0.19	All plots = 0.09 ± 0.16 PD plots = 0.26 ± 0.18 Grass plots = 0.02 ± 0.03 Ag plots = 0.01 ± 0.03

…table continued

...table continued

Landscape-level variable	Definition	Value range	Mean ± SD
pdL3	Proportion of landscape 3 occupied by prairie dog colony for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 0.57 PD plots = 0.01 – 0.57 Grass plots = 0.00 – 0.19 Ag plots = 0.00 – 0.22	All plots = 0.07 ± 0.12 PD plots = 0.19 ± 0.14 Grass plots = 0.02 ± 0.03 Ag plots = 0.01 ± 0.03
grsL1	Proportion of landscape 1 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.00 – 0.92 Grass plots = 0.67 – 1.00 Ag plots = 0.00 – 0.77	All plots = 0.49 ± 0.39 PD plots = 0.33 ± 0.22 Grass plots = 0.94 ± 0.08 Ag plots = 0.14 ± 0.17
grsL2	Proportion of landscape 2 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.14 – 0.97 Grass plots = 0.47 – 1.00 Ag plots = 0.00 – 0.94	All plots = 0.57 ± 0.31 PD plots = 0.53 ± 0.21 Grass plots = 0.88 ± 0.13 Ag plots = 0.26 ± 0.19
grsL3	Proportion of landscape 3 occupied by grassland for all plots combined as well as for prairie dog colony, grassland, and dryland agriculture plots separately	All plots = 0.00 – 1.00 PD plots = 0.16 – 0.96 Grass plots = 0.40 – 1.00 Ag plots = 0.00 – 0.91	All plots = 0.58 ± 0.29 PD plots = 0.57 ± 0.21 Grass plots = 0.85 ± 0.14 Ag plots = 0.29 ± 0.18

Table 3.7. Predicted results of habitat covariate effects on underlying process variance of derived abundance estimates based on *a priori* hypotheses for eight grassland bird species in eastern Colorado in 2005. Predicted effects of plot stratum are represented as a ranking of stratum-specific mean abundance. Other predicted results are represented as having either a positive (+) or negative (−) effect, or no effect (NE), on species abundance. Explanation and coding of model parameters are provided in Table 3.6.

	Species							
Plot-level variable	Mountain plover	Burrowing owl	Horned lark	Cassin's sparrow	Lark sparrow	Lark bunting	Grasshopper sparrow	Western meadowlark
s	pd > ag >> grass	pd >> grass = ag	ag > pd > grass	pd = grass > ag	pd = grass > ag	grass > pd > ag	grass > ag > pd	pd > grass > ag
act	+	+	NE	NE	NE	NE	NE	NE
pdP	+	+	+	−	−	−	−	−
Landscape-level variable[a]								
pdL1	+	+	+	−	−	−	−	−
pdL2	+	+	+	−	−	−	−	−
pdL3	+	+	+	−	−	−	−	−
grsL1	+	+	+	+	+	+	+	+
grsL2	+	+	+	+	+	+	+	+
grsL3	+	+	+	+	+	+	+	+

[a] Among each landscape-level variable group (measuring amounts of prairie dog colony or grassland habitat), I predicted smaller-scale variables would have a larger effect on species abundance (i.e., explain more process variance) than larger-scale variables across all species. For example, I predicted the effect of the variable 'pdL1' would be greater than the effect of 'pdL2' which in turn I predicted would have a greater effect on species abundance than variable 'pdL3'.

Table 3.8. Number of adults (*N*) of 8 grassland bird species detected on 272 mark-recapture plots in 3 strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Number of plots where each species was detected is also shown. Species counts were recorded by double observers on a single plot visit.

Species	Stratum						Total	
	Prairie dog colony		Grassland		Dryland agriculture			
	N	No. of plots	*N*	No. of plots	*N*	No. of plots	*N*	No. of plots
Mountain plover	45	21	4	3	10	7	59	31
Burrowing owl	59	34	1	1	0	0	60	35
Horned lark	1,269	83	1,812	94	1,314	87	4,395	264
Cassin's sparrow	94	30	135	34	8	4	237	68
Lark sparrow	85	16	67	15	3	2	155	33
Lark bunting	499	52	818	77	247	42	1,564	171
Grasshopper sparrow	35	11	51	13	111	30	197	54
Western meadowlark	235	73	238	76	176	70	649	219

Table 3.9. Model selection results for nine models of detection probability (p) and abundance (N) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{obs1}\, N_{plot}$	27.94	0.00	0.33	1.00	2	23.84
$p_{obs1+day}\, N_{plot}$	28.05	0.10	0.32	0.95	3	21.84
$p_{temp}\, N_{plot}$	30.45	2.51	0.10	0.29	2	26.35
$p_{.}\, N_{plot}$	31.29	3.34	0.06	0.19	1	29.25
$p_{day}\, N_{plot}$	31.29	3.35	0.06	0.19	2	27.19
$p_{day+temp}\, N_{plot}$	31.88	3.94	0.05	0.14	3	25.67
$p_{temp+wind}\, N_{plot}$	32.36	4.42	0.04	0.11	3	26.15
$p_{wind}\, N_{plot}$	33.33	5.39	0.02	0.07	2	29.23
$p_{day+wind}\, N_{plot}$	33.39	5.45	0.02	0.07	3	27.18

Table 3.10. Covariate estimates ($\hat{\beta}_i$) under nine models of detection probability (p) and abundance (N) for mountain plover (*Charadrius montanus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
p_{obs1} N_{plot}	27.94	0.00	0.33	2	p_{int}	=	3.22	0.75	1.75	4.69
					p_{obs1}	=	-3.91	2.84	-9.48	1.65
$p_{obs1+day}$ N_{plot}	28.05	0.10	0.32	3	p_{int}	=	10.27	5.66	-0.83	21.38
					p_{obs1}	=	-3.88	2.26	-8.31	0.56
					p_{day}	=	-0.26	0.20	-0.65	0.13
p_{temp} N_{plot}	30.45	2.51	0.10	2	p_{int}	=	-1.04	2.31	-5.57	3.50
					p_{temp}	=	0.21	0.14	-0.06	0.49
$p_{.}$ N_{plot}	31.29	3.34	0.06	1	p_{int}	=	2.55	0.56	1.45	3.64
p_{day} N_{plot}	31.29	3.35	0.06	2	p_{int}	=	8.31	4.77	-1.03	17.65
					p_{day}	=	-0.22	0.17	-0.56	0.13
$p_{day+temp}$ N_{plot}	31.88	3.94	0.05	3	p_{int}	=	3.23	5.79	-8.13	14.58
					p_{day}	=	-0.13	0.17	-0.47	0.20
					p_{temp}	=	0.17	0.15	-0.12	0.46
$p_{temp+wind}$ N_{plot}	32.36	4.42	0.04	3	p_{int}	=	-1.41	3.41	-8.09	5.27
					p_{temp}	=	0.26	0.25	-0.23	0.74
					p_{wind}	=	-0.24	0.71	-1.63	1.16
p_{wind} N_{plot}	33.33	5.39	0.02	2	p_{int}	=	2.45	0.82	0.85	4.05
					p_{wind}	=	0.05	0.34	-0.62	0.72
$p_{day+wind}$ N_{plot}	33.39	5.45	0.02	3	p_{int}	=	8.41	5.01	-1.40	18.22
					p_{day}	=	-0.22	0.18	-0.57	0.13
					p_{wind}	=	-0.03	0.39	-0.78	0.73

Table 3.11. Summary statistics of derived abundance estimates ($\hat{N}$) for eight grassland bird species in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Abundance estimates were generated under the highest ranking model for detection probability for each species. Mean number of birds per 25 ha plot ($\overline{\hat{N}}$) ± standard deviation (SD) and value range of abundance estimates are shown for plots on which the species was detected.

	Stratum			
Species	Prairie dog colony	Grassland	Dryland agriculture	Range of estimates
Mountain plover	2.26 ± 1.17	1.87 ± 0.12	1.43 ± 0.54	1.00 - 4.01
Burrowing owl[a]	1.88 ± 1.14	1.08[a]	0.00[a]	1.08 - 6.50
Horned lark	15.77 ± 9.19	35.82 ± 13.15	15.65 ± 10.68	1.00 - 70.17
Cassin's sparrow	3.18 ± 2.42	4.01 ± 2.77	3.13 ± 1.80	1.01 - 12.12
Lark sparrow	5.91 ± 5.16	5.13 ± 3.64	1.56 ± 0.74	1.01 - 19.30
Lark bunting	9.93 ± 13.13	10.91 ± 10.03	6.27 ± 6.75	1.00 - 57.43
Grasshopper sparrow	3.53 ± 2.49	4.66 ± 4.43	4.97 ± 3.59	1.00 - 17.67
Western meadowlark	3.32 ± 2.57	3.21 ± 2.50	2.58 ± 1.59	1.00 - 11.23

[a] Burrowing owls were only detected on one grassland plot and were not detected on any dryland agriculture plots.

Table 3.12. Extrapolated stratum-specific abundance estimates ($\hat{N}$) for eight grassland bird species under three scenarios – (a) conservative, (b) moderate, and (c) liberal – in eastern Colorado in 2005. Conservative estimates have been adjusted for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. Moderate estimates have only been adjusted for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact" plots do not differ from surveyed plots). Liberal estimates have not been adjusted. Extrapolated abundance estimates and 95% confidence intervals are presented for three strata – prairie dog colony, grassland, and dryland agriculture. Abundance estimates were extrapolated from density estimates calculated from derived abundance estimates generated under the highest ranking model for detection probability for each species.

(a) Conservative estimates

	Stratum								
	Prairie dog colony			Grassland			Dryland agriculture		
Species	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL
Mountain plover	2,140	2,034	4,856	3,483	2,528	26,766	2,954	2,950	3,508
Burrowing owl	2,881	2,674	6,552	673	624	1,893	0	0	0
Horned lark	59,029	57,489	70,954	1,154,823	1,131,282	1,329,949	401,705	390,050	484,191
Cassin's sparrow	4,299	4,240	6,107	84,739	83,959	110,664	3,687	2,442	23,948
Lark sparrow	4,261	3,882	7,888	47,809	42,482	94,367	919	886	1,837
Lark bunting	23,273	22,622	29,161	522,269	510,599	638,525	77,629	73,585	113,649
Grasshopper sparrow	1,749	1,594	3,592	37,702	32,294	99,696	43,956	34,468	115,589
Western meadowlark	10,921	10,618	16,420	151,543	148,218	219,788	53,226	51,975	84,199

…table continued

…table continued

(b) Moderate estimates

	Stratum								
	Prairie dog colony			Grassland			Dryland agriculture		
Species	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL
Mountain plover	3,118	2,963	7,074	7,176	5,207	55,135	6,464	6,455	7,678
Burrowing owl	4,197	3,895	9,545	1,387	1,285	3,900	0	0	0
Horned lark	85,997	83,753	103,370	2,378,815	2,330,324	2,739,556	879,062	853,557	1,059,569
Cassin's sparrow	6,263	6,178	8,898	174,553	172,947	227,956	8,069	5,343	52,406
Lark sparrow	6,208	5,655	11,492	98,482	87,509	194,386	2,010	1,939	4,020
Lark bunting	33,906	32,957	42,484	1,075,819	1,051,780	1,315,294	169,878	161,029	248,701
Grasshopper sparrow	2,548	2,322	5,233	77,661	66,523	205,364	96,190	75,427	252,947
Western meadowlark	15,911	15,469	23,921	312,162	305,314	452,740	116,475	113,738	184,254

…table continued

…table continued

(c) Liberal estimates

	Stratum								
	Prairie dog colony			Grassland			Dryland agriculture		
Species	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL
Mountain plover	4,196	3,987	9,521	9,072	6,583	69,703	7,836	7,824	9,306
Burrowing owl	5,649	5,243	12,846	1,753	1,624	4,931	0	0	0
Horned lark	115,743	112,723	139,125	3,007,351	2,946,047	3,463,408	1,065,530	1,034,615	1,284,326
Cassin's sparrow	8,430	8,315	11,975	220,674	218,644	288,187	9,780	6,477	63,523
Lark sparrow	8,355	7,612	15,467	124,503	110,631	245,748	2,437	2,351	4,873
Lark bunting	45,633	44,357	57,179	1,360,075	1,329,684	1,662,825	205,912	195,186	301,456
Grasshopper sparrow	3,430	3,125	7,043	98,181	84,100	259,626	116,594	91,427	306,603
Western meadowlark	21,414	20,819	32,195	394,643	385,985	572,363	141,182	137,864	223,339

Table 3.13. Extrapolated abundance estimates ($\hat{N}$) for eight grassland bird species under three scenarios – conservative, moderate, and liberal – for my study area in eastern Colorado in 2005. Conservative estimates have been adjusted for area not sampled due to inability to contact landowner (no contact), access denied, or strata criteria not met. Moderate estimates have only been adjusted for area not sampled due to access denied or strata criteria not met (under the assumption that "no contact" plots do not differ from surveyed plots). Liberal estimates have not been adjusted. Extrapolated study-area abundance estimates and 95% confidence intervals were summed from extrapolated stratum-specific abundance estimates (Table 3.11). Abundance estimates were extrapolated from density estimates calculated from derived abundance estimates generated under the highest ranking model for detection probability for each species.

	Scenario								
	Conservative			Moderate			Liberal		
Species	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL
Mountain plover	8,577	7,511	35,130	16,758	14,625	69,887	21,103	18,395	88,530
Burrowing owl	3,554	3,298	8,445	5,584	5,180	13,445	7,402	6,867	17,777
Horned lark	1,615,556	1,578,820	1,885,093	3,343,874	3,267,633	3,902,494	4,188,624	4,093,385	4,886,859
Cassin's sparrow	92,725	90,641	140,719	188,885	184,468	289,260	238,884	233,435	363,685
Lark sparrow	52,989	47,250	104,092	106,700	95,104	209,898	135,295	120,593	266,087
Lark bunting	623,171	606,806	781,335	1,279,602	1,245,765	1,606,480	1,611,620	1,569,227	2,021,460
Grasshopper sparrow	83,407	68,356	218,877	176,400	144,273	463,544	218,205	178,653	573,271
Western meadowlark	215,690	210,811	320,406	444,549	434,520	660,915	557,240	544,668	827,897

Table 3.14. Variance components analysis of nine habitat covariates of grassland bird mark-recapture plots and associated estimates of mountain plover (*Charadrius montanus*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs1}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 1.06 (95% CI = 0.68, 1.90). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: -0.60 ag: -0.77	grass: 0.66 ag: 0.44	1.01	0.63	1.85	4.72
act	0.64	0.40	1.01	0.64	1.83	4.72
pdP	0.76	0.42	0.99	0.62	1.78	6.60
pdL1	1.22	0.55	0.94	0.59	1.70	11.32
pdL2	2.24	1.17	0.97	0.62	1.76	8.49
pdL3	2.29	1.74	1.03	0.66	1.87	2.83
grsL1	-0.32	0.75	1.09	0.69	1.97	*
grsL2	0.65	0.94	1.08	0.68	1.95	*
grsL3	1.14	0.90	1.04	0.66	1.88	1.89

* The variance explained by the amount of grassland in landscapes 1 and 2 (grsL1 and grsL2, respectively) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.15. Comparison of abundance estimates ($\hat{N}$) of mountain plover (*Charadrius montanus*) and burrowing owl (*Athene cunicularia hypugaea*) obtained using direct (double-observer) and indirect (latent occupancy) estimation methods on 272 plots in eastern Colorado in 2005. The direct method used counts recorded by double observers on a single plot visit. The indirect method estimated latent abundance using occupancy data collected during 3-4 plot visits. Abundance estimates and 95% confidence intervals were generated under the highest ranking model for each species in program MARK (direct method) and under the Royle/Nichols heterogeneity model in program PRESENCE (indirect method).

	Direct method			Indirect method		
Species	$\hat{N}$	LCL	UCL	$\hat{N}$	LCL	UCL
Mountain plover	63.08	59.17	162.64	153.39	122.47	184.31
Burrowing owl	64.98	60.31	148.36	108.34	89.60	127.08

Table 3.16. Model selection results for seven models of detection probability (p) and abundance (N) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{.}\ N_{plot.}$	64.75	0.00	0.34	1.00	1	62.72
$p_{wind}\ N_{plot}$	65.84	1.08	0.20	0.58	2	61.73
$p_{day}\ N_{plot}$	66.58	1.83	0.14	0.40	2	62.48
$p_{temp}\ N_{plot}$	66.79	2.03	0.12	0.36	2	62.68
$p_{day+wind}\ N_{plot}$	67.62	2.87	0.08	0.24	3	61.41
$p_{temp+wind}\ N_{plot}$	67.91	3.16	0.07	0.21	3	61.71
$p_{day+temp}\ N_{plot}$	68.67	3.91	0.05	0.14	3	62.46

Table 3.17. Covariate estimates ($\hat{\beta}_i$) under seven models of detection probability (p) and abundance (N) for burrowing owl (*Athene cunicularia hypugaea*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{.}\ N_{plot}$	64.75	0.00	0.34	1	p_{int}	=	0.96	0.43	0.11	1.81
$p_{wind}\ N_{plot}$	65.84	1.08	0.20	2	p_{int}	=	-0.12	1.30	-2.66	2.43
					p_{wind}	=	0.50	0.54	-0.57	1.56
$p_{day}\ N_{plot}$	66.58	1.83	0.14	2	p_{int}	=	2.53	3.45	-4.22	9.29
					p_{day}	=	-0.06	0.14	-0.34	0.21
$p_{temp}\ N_{plot}$	66.79	2.03	0.12	2	p_{int}	=	0.65	1.78	-2.84	4.13
					p_{temp}	=	0.02	0.09	-0.15	0.18
$p_{day+wind}\ N_{plot}$	67.62	2.87	0.08	3	p_{int}	=	5.85	7.75	-9.35	21.04
					p_{day}	=	-0.30	0.38	-1.05	0.46
					p_{wind}	=	0.91	0.86	-0.77	2.59
$p_{temp+wind}\ N_{plot}$	67.91	3.16	0.07	3	p_{int}	=	-0.40	2.27	-4.85	4.04
					p_{temp}	=	0.01	0.09	-0.16	0.19
					p_{wind}	=	0.50	0.55	-0.57	1.57
$p_{day+temp}\ N_{plot}$	68.67	3.91	0.05	3	p_{int}	=	3.20	6.42	-9.38	15.79
					p_{day}	=	-0.08	0.19	-0.46	0.30
					p_{temp}	=	-0.01	0.11	-0.24	0.21

Table 3.18. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of burrowing owl (*Athene cunicularia hypugaea*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{.}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 0.82 (95% CI = 0.39, 1.73). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
act	0.35	0.59	0.84	0.40	1.79	*
pdP	-0.08	0.71	0.86	0.41	1.81	*
pdL1	-0.46	0.72	0.84	0.40	1.77	*
pdL2	-1.04	1.18	0.83	0.40	1.75	*
pdL3	-1.54	1.68	0.82	0.39	1.75	0.00
grsL1	0.34	0.70	0.85	0.41	1.79	*
grsL2	0.31	0.72	0.85	0.41	1.80	*
grsL3	0.15	0.74	0.86	0.41	1.81	*

* The variance explained is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.19. Model selection results for 11 models of detection probability (p) and abundance (N) for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{obs+temp+wind}\, N_{plot}$	3474.79	0.00	0.47	1.00	7	3460.78
$p_{obs+temp}\, N_{plot}$	3476.12	1.33	0.24	0.51	6	3464.11
$p_{obs+day+temp+wind}\, N_{plot}$	3476.73	1.93	0.18	0.38	8	3460.71
$p_{obs+wind}\, N_{plot}$	3479.22	4.43	0.05	0.11	6	3467.21
$p_{obs}\, N_{plot}$	3479.77	4.98	0.04	0.08	5	3469.76
$p_{obs+day}\, N_{plot}$	3480.48	5.69	0.03	0.06	6	3468.47
$p_{s}\, N_{plot}$	3518.39	43.60	0.00	0.00	3	3512.38
$p_{temp}\, N_{plot}$	3521.63	46.83	0.00	0.00	2	3517.62
$p_{day}\, N_{plot}$	3523.24	48.45	0.00	0.00	2	3519.24
$p_{.}\, N_{plot}$	3524.03	49.24	0.00	0.00	1	3522.03
$p_{wind}\, N_{plot}$	3524.18	49.39	0.00	0.00	2	3520.18

Table 3.20. Covariate estimates ($\hat{\beta}_i$) under 11 models of detection probability (p) and abundance (N) for horned lark (*Eremophila alpestris*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+temp+wind}$ N_{plot}	3474.79	0.00	0.47	7	p_{int}	=	2.17	0.22	1.73	2.60
					p_{obs1}	=	-0.42	0.15	-0.72	-0.13
					p_{obs2}	=	-0.05	0.17	-0.39	0.28
					p_{obs3}	=	-0.62	0.16	-0.92	-0.31
					p_{obs4}	=	0.74	0.21	0.34	1.15
					p_{temp}	=	-0.03	0.01	-0.05	-0.01
					p_{wind}	=	0.07	0.04	0.00	0.14
$p_{obs+temp}$ N_{plot}	3476.12	1.33	0.24	6	p_{int}	=	2.25	0.22	1.82	2.68
					p_{obs1}	=	-0.36	0.15	-0.65	-0.08
					p_{obs2}	=	-0.01	0.17	-0.34	0.32
					p_{obs3}	=	-0.59	0.16	-0.89	-0.28
					p_{obs4}	=	0.78	0.20	0.38	1.18
					p_{temp}	=	-0.03	0.01	-0.05	0.00
$p_{obs+day+temp+wind}$ N_{plot}	3476.73	1.93	0.18	8	p_{int}	=	2.04	0.52	1.02	3.07
					p_{obs1}	=	-0.42	0.15	-0.71	-0.13
					p_{obs2}	=	-0.05	0.17	-0.39	0.28
					p_{obs3}	=	-0.61	0.16	-0.92	-0.30
					p_{obs4}	=	0.75	0.21	0.34	1.15
					p_{day}	=	0.00	0.01	-0.02	0.03
					p_{temp}	=	-0.03	0.01	-0.05	0.00
					p_{wind}	=	0.07	0.04	0.00	0.14

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+wind}\ N_{plot}$	3479.22	4.43	0.05	6	p_{int}	=	1.69	0.12	1.46	1.92
					p_{obs1}	=	-0.36	0.15	-0.65	-0.07
					p_{obs2}	=	-0.04	0.17	-0.38	0.29
					p_{obs3}	=	-0.65	0.16	-0.96	-0.35
					p_{obs4}	=	0.71	0.20	0.31	1.11
					p_{wind}	=	0.06	0.04	-0.01	0.13
$p_{obs}\ N_{plot}$	3479.77	4.98	0.04	5	p_{int}	=	1.79	0.10	1.59	1.99
					p_{obs1}	=	-0.31	0.14	-0.59	-0.03
					p_{obs2}	=	0.00	0.17	-0.33	0.33
					p_{obs3}	=	-0.62	0.15	-0.92	-0.32
					p_{obs4}	=	0.75	0.20	0.35	1.15
$p_{obs+day}\ N_{plot}$	3480.48	5.69	0.03	6	p_{int}	=	1.43	0.33	0.77	2.08
					p_{obs1}	=	-0.31	0.14	-0.59	-0.03
					p_{obs2}	=	-0.01	0.17	-0.34	0.32
					p_{obs3}	=	-0.59	0.16	-0.90	-0.28
					p_{obs4}	=	0.77	0.20	0.37	1.17
					p_{day}	=	0.01	0.01	-0.01	0.03
$p_s\ N_{plot}$	3518.39	43.60	0.00	3	p_{int}	=	1.51	0.10	1.32	1.69
					p_{grs}	=	0.35	0.13	0.11	0.60
					p_{ag}	=	0.05	0.13	-0.21	0.31
$p_{temp}\ N_{plot}$	3521.63	46.83	0.00	2	p_{int}	=	2.04	0.19	1.67	2.41
					p_{temp}	=	-0.02	0.01	-0.04	0.00
$p_{day}\ N_{plot}$	3523.24	48.45	0.00	2	p_{int}	=	1.17	0.30	0.58	1.75
					p_{day}	=	0.02	0.01	0.00	0.04
$p_{.}\ N_{plot}$	3524.03	49.24	0.00	1	p_{int}	=	1.66	0.05	1.56	1.76
$p_{wind}\ N_{plot}$	3524.18	49.39	0.00	2	p_{int}	=	1.56	0.09	1.38	1.74
					p_{wind}	=	0.05	0.03	-0.02	0.11

Table 3.21. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of horned lark (*Eremophila alpestris*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 128.15 (95% CI = 108.73, 153.29). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: 3.98 ag: -0.11	grass: 1.69 ag: 1.72	125.34	106.29	150.04	2.19
pdP	-1.87	1.75	128.08	108.64	153.26	0.05
pdL1	-1.38	2.46	128.48	108.98	153.74	*
pdL2	-1.31	4.47	128.50	109.08	153.88	*
pdL3	-3.64	5.97	128.46	108.96	153.71	*
grsL1	2.82	1.81	127.45	108.11	152.51	0.55
grsL2	1.86	2.22	128.29	108.82	153.52	*
grsL3	1.78	2.38	128.36	108.88	153.60	*

* The variance explained by the amount of prairie dog colony in landscapes 1, 2, and 3 (pdL1, pdL2, and pdL3 respectively) and the amount of grassland in landscapes 2 and 3 (grsL2 and grsL3, respectively) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.22. Model selection results for nine models of detection probability (p) and abundance (N) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_s\ N_{plot}$	161.34	0.00	0.22	1.00	3	155.28
$p_{.}\ N_{plot}$	161.73	0.40	0.18	0.82	1	159.72
$p_{s+wind}\ N_{plot}$	162.53	1.20	0.12	0.55	4	154.45
$p_{wind}\ N_{plot}$	162.83	1.50	0.11	0.47	2	158.81
$p_{s+temp}\ N_{plot}$	163.34	2.01	0.08	0.37	4	155.26
$p_{s+day}\ N_{plot}$	163.36	2.03	0.08	0.36	4	155.28
$p_{temp}\ N_{plot}$	163.46	2.12	0.08	0.35	2	159.43
$p_{day}\ N_{plot}$	163.75	2.41	0.07	0.30	2	159.72
$p_{s+temp+wind}\ N_{plot}$	164.25	2.91	0.05	0.23	5	154.12

Table 3.23. Covariate estimates ($\hat{\beta}_i$) under nine models of detection probability (p) and abundance (N) for Cassin's sparrow (*Aimophila cassinii*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_s\ N_{plot}$	161.34	0.00	0.22	3	p_{int}	=	2.00	0.38	1.26	2.75
					p_{grs}	=	0.22	0.51	-0.77	1.22
					p_{ag}	=	-2.41	1.86	-6.06	1.25
$p_{.}\ N_{plot}$	161.73	0.40	0.18	1	p_{int}	=	2.01	0.24	1.54	2.48
$p_{s+wind}\ N_{plot}$	162.53	1.20	0.12	4	p_{int}	=	2.27	0.48	1.32	3.21
					p_{grs}	=	0.29	0.52	-0.72	1.30
					p_{ag}	=	-2.31	1.86	-5.94	1.33
					p_{wind}	=	-0.17	0.18	-0.53	0.19
$p_{wind}\ N_{plot}$	162.83	1.50	0.11	2	p_{int}	=	2.32	0.41	1.52	3.12
					p_{wind}	=	-0.17	0.18	-0.51	0.18
$p_{s+temp}\ N_{plot}$	163.34	2.01	0.08	4	p_{int}	=	1.85	1.03	-0.17	3.87
					p_{grs}	=	0.21	0.51	-0.79	1.21
					p_{ag}	=	-2.38	1.86	-6.02	1.27
					p_{temp}	=	0.01	0.05	-0.09	0.11
$p_{s+day}\ N_{plot}$	163.36	2.03	0.08	4	p_{int}	=	2.14	1.73	-1.25	5.54
					p_{grs}	=	0.22	0.51	-0.77	1.22
					p_{ag}	=	-2.41	1.87	-6.06	1.25
					p_{day}	=	-0.01	0.07	-0.15	0.14
$p_{temp}\ N_{plot}$	163.46	2.12	0.08	2	p_{int}	=	1.50	0.97	-0.39	3.40
					p_{temp}	=	0.03	0.05	-0.07	0.12
$p_{day}\ N_{plot}$	163.75	2.41	0.07	2	p_{int}	=	2.05	1.66	-1.21	5.30
					p_{day}	=	0.00	0.07	-0.14	0.14

…table continued

…table continued

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{s+temp+wind}\ N_{plot}$	164.25	2.91	0.05	5	p_{int}	=	1.74	1.04	-0.29	3.77
					p_{grs}	=	0.27	0.52	-0.75	1.29
					p_{ag}	=	-2.16	1.82	-5.72	1.40
					p_{temp}	=	0.03	0.06	-0.08	0.14
					p_{wind}	=	-0.21	0.20	-0.61	0.18

Table 3.24. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of Cassin's sparrow (*Aimophila cassinii*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_s\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 6.64 (95% CI = 4.86, 9.62). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: 0.83 ag: -1.61	grass: 0.64 ag: 2.27	6.59	4.79	9.63	0.75
pdP	-0.94	0.76	6.58	4.81	9.57	0.90
pdL1	-0.90	1.04	6.65	4.86	9.68	*
pdL2	-1.04	1.85	6.65	4.90	9.75	*
pdL3	-1.01	2.45	6.65	4.91	9.77	*
grsL1	0.88	0.89	6.64	4.85	9.65	0.00
grsL2	1.67	1.28	6.57	4.79	9.55	1.05
grsL3	1.99	1.44	6.55	4.78	9.52	1.36

* The variance explained by the amount of prairie dog colony in landscapes 1, 2, and 3 (pdL1, pdL2, and pdL3 respectively) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.25. Model selection results for eight models of detection probability (p) and abundance (N) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{wind}\ N_{plot}$	153.37	0.00	0.30	1.00	2	149.33
$p_{s+wind}\ N_{plot}$	153.45	0.08	0.29	0.96	4	145.32
$p_{temp+wind}\ N_{plot}$	154.79	1.42	0.15	0.49	3	148.71
$p_{day+wind}\ N_{plot}$	154.95	1.58	0.14	0.45	3	148.88
$p_{s}\ N_{plot}$	157.08	3.71	0.05	0.16	3	151.00
$p_{.}\ N_{plot}$	157.14	3.77	0.05	0.15	1	155.12
$p_{day}\ N_{plot}$	158.78	5.41	0.02	0.07	2	154.74
$p_{temp}\ N_{plot}$	159.02	5.65	0.02	0.06	2	154.98

Table 3.26. Covariate estimates ($\hat{\beta}_i$) under eight models of detection probability (p) and abundance (N) for lark sparrow (*Chondestes grammacus*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
p_{wind} N_{plot}	153.37	0.00	0.30	2	p_{int}	=	2.14	0.53	1.09	3.18
					p_{wind}	=	-0.63	0.30	-1.22	-0.04
p_{s+wind} N_{plot}	153.45	0.08	0.29	4	p_{int}	=	2.75	0.67	1.43	4.06
					p_{grs}	=	-1.11	0.64	-2.37	0.14
					p_{ag}	=	-2.25	2.95	-8.04	3.54
					p_{wind}	=	-0.67	0.33	-1.32	-0.03
$p_{temp+wind}$ N_{plot}	154.79	1.42	0.15	3	p_{int}	=	3.30	1.64	0.09	6.51
					p_{temp}	=	-0.05	0.07	-0.18	0.08
					p_{wind}	=	-0.69	0.33	-1.33	-0.04
$p_{day+wind}$ N_{plot}	154.95	1.58	0.14	3	p_{int}	=	3.89	2.94	-1.87	9.65
					p_{day}	=	-0.08	0.13	-0.33	0.17
					p_{wind}	=	-0.66	0.32	-1.29	-0.03
p_s N_{plot}	157.08	3.71	0.05	3	p_{int}	=	1.63	0.37	0.90	2.36
					p_{grs}	=	-1.08	0.57	-2.21	0.04
					p_{ag}	=	-1.63	2.48	-6.48	3.23
$p_{.}$ N_{plot}	157.14	3.77	0.05	1	p_{int}	=	1.10	0.27	0.57	1.62
p_{day} N_{plot}	158.78	5.41	0.02	2	p_{int}	=	2.37	2.17	-1.89	6.63
					p_{day}	=	-0.06	0.10	-0.25	0.14
p_{temp} N_{plot}	159.02	5.65	0.02	2	p_{int}	=	1.56	1.26	-0.90	4.03
					p_{temp}	=	-0.02	0.06	-0.13	0.09

Table 3.27. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of lark sparrow (*Chondestes grammacus*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 19.09 (95% CI = 12.24, 33.60). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: -0.77 ag: -4.34	grass: 1.58 ag: 3.31	19.23	12.18	34.58	*
pdP	2.35	1.83	18.70	11.92	33.26	2.04
pdL1	4.93	2.50	17.49	11.15	31.13	8.38
pdL2	6.57	4.01	18.12	11.54	32.26	5.08
pdL3	8.04	4.99	18.17	11.57	32.36	4.82
grsL1	-0.44	2.09	19.36	12.55	35.01	*
grsL2	0.87	2.53	19.36	12.52	34.93	*
grsL3	1.40	2.82	19.36	12.47	34.79	*

* The variance explained by plot stratum (s) and the amount of grassland in landscapes 1, 2, and 3 (grsL1, grsL2, and grsL3 respectively) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.28. Model selection results for 13 models of detection probability (p) and abundance (N) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{obs+temp+wind}\ N_{plot}$	1239.37	0.00	0.46	1.00	7	1225.33
$p_{obs+day+temp+wind}\ N_{plot}$	1241.09	1.72	0.19	0.42	8	1225.04
$p_{obs+temp}\ N_{plot}$	1241.46	2.09	0.16	0.35	6	1229.43
$p_{obs+wind}\ N_{plot}$	1242.58	3.21	0.09	0.20	6	1230.55
$p_{obs}\ N_{plot}$	1243.18	3.81	0.07	0.15	5	1233.16
$p_{obs+day}\ N_{plot}$	1244.99	5.62	0.03	0.06	6	1232.96
$p_{s+temp+wind}\ N_{plot}$	1254.18	14.82	0.00	0.00	5	1244.16
$p_{s+temp}\ N_{plot}$	1255.93	16.57	0.00	0.00	4	1247.92
$p_{temp}\ N_{plot}$	1256.02	16.65	0.00	0.00	2	1252.01
$p_{.}\ N_{plot}$	1257.93	18.57	0.00	0.00	1	1255.93
$p_{s}\ N_{plot}$	1258.15	18.79	0.00	0.00	3	1252.14
$p_{wind}\ N_{plot}$	1258.58	19.21	0.00	0.00	2	1254.57
$p_{day}\ N_{plot}$	1259.93	20.56	0.00	0.00	2	1255.92

Table 3.29. Covariate estimates ($\hat{\beta}_i$) under 13 models of detection probability (p) and abundance (N) for lark bunting (*Calamonspiza melanocorys*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+temp+wind}\ N_{plot}$	1239.37	0.00	0.46	7	p_{int}	=	2.18	0.37	1.45	2.91
					p_{obs1}	=	-0.10	0.33	-0.75	0.54
					p_{obs2}	=	0.32	0.28	-0.22	0.87
					p_{obs3}	=	-1.07	0.36	-1.77	-0.37
					p_{obs4}	=	0.73	0.27	0.19	1.27
					p_{temp}	=	-0.05	0.02	-0.09	-0.01
					p_{wind}	=	0.14	0.07	0.00	0.28
$p_{obs+day+temp+wind}\ N_{plot}$	1241.09	1.72	0.19	8	p_{int}	=	2.55	0.78	1.03	4.07
					p_{obs1}	=	-0.07	0.33	-0.72	0.59
					p_{obs2}	=	0.36	0.28	-0.20	0.91
					p_{obs3}	=	-1.05	0.36	-1.75	-0.35
					p_{obs4}	=	0.72	0.27	0.18	1.26
					p_{day}	=	-0.01	0.02	-0.05	0.03
					p_{temp}	=	-0.05	0.02	-0.09	-0.01
					p_{wind}	=	0.14	0.07	0.01	0.28
$p_{obs+temp}\ N_{plot}$	1241.46	2.09	0.16	6	p_{int}	=	2.27	0.37	1.55	2.99
					p_{obs1}	=	0.01	0.32	-0.62	0.64
					p_{obs2}	=	0.35	0.28	-0.20	0.89
					p_{obs3}	=	-0.95	0.34	-1.63	-0.28
					p_{obs4}	=	0.75	0.27	0.22	1.29
					p_{temp}	=	-0.04	0.02	-0.08	0.00

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+wind}\ N_{plot}$	1242.58	3.21	0.09	6	p_{int}	=	1.42	0.16	1.10	1.74
					p_{obs1}	=	0.07	0.32	-0.55	0.69
					p_{obs2}	=	0.26	0.27	-0.28	0.80
					p_{obs3}	=	-1.15	0.35	-1.84	-0.45
					p_{obs4}	=	0.66	0.27	0.13	1.19
					p_{wind}	=	0.11	0.07	-0.02	0.24
$p_{obs}\ N_{plot}$	1243.18	3.81	0.07	5	p_{int}	=	1.60	0.12	1.36	1.84
					p_{obs1}	=	0.13	0.31	-0.49	0.74
					p_{obs2}	=	0.29	0.27	-0.25	0.82
					p_{obs3}	=	-1.04	0.34	-1.70	-0.37
					p_{obs4}	=	0.69	0.27	0.16	1.22
$p_{obs+day}\ N_{plot}$	1244.99	5.62	0.03	6	p_{int}	=	1.38	0.51	0.39	2.38
					p_{obs1}	=	0.09	0.33	-0.55	0.73
					p_{obs2}	=	0.27	0.28	-0.28	0.81
					p_{obs3}	=	-1.05	0.34	-1.72	-0.38
					p_{obs4}	=	0.70	0.27	0.17	1.23
					p_{day}	=	0.01	0.02	-0.03	0.05
$p_{s+temp+wind}\ N_{plot}$	1254.18	14.82	0.00	5	p_{int}	=	2.31	0.39	1.55	3.08
					p_{grs}	=	0.09	0.20	-0.31	0.49
					p_{ag}	=	-0.49	0.29	-1.05	0.07
					p_{temp}	=	-0.05	0.02	-0.09	-0.01
					p_{wind}	=	0.13	0.07	0.00	0.27
$p_{s+temp}\ N_{plot}$	1255.93	16.57	0.00	4	p_{int}	=	2.30	0.39	1.54	3.06
					p_{grs}	=	0.19	0.20	-0.20	0.58
					p_{ag}	=	-0.31	0.27	-0.83	0.22
					p_{temp}	=	-0.04	0.02	-0.07	0.00

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{temp}\ N_{plot}$	1256.02	16.65	0.00	2	p_{int}	=	2.31	0.34	1.64	2.98
					p_{temp}	=	-0.04	0.02	-0.07	0.00
$p_{.}\ N_{plot}$	1257.93	18.57	0.00	1	p_{int}	=	1.66	0.09	1.49	1.83
$p_s\ N_{plot}$	1258.15	18.79	0.00	3	p_{int}	=	1.58	0.15	1.28	1.88
					p_{grs}	=	0.23	0.20	-0.15	0.62
					p_{ag}	=	-0.22	0.26	-0.73	0.29
$p_{wind}\ N_{plot}$	1258.58	19.21	0.00	2	p_{int}	=	1.52	0.15	1.23	1.81
					p_{wind}	=	0.07	0.06	-0.05	0.19
$p_{day}\ N_{plot}$	1259.93	20.56	0.00	2	p_{int}	=	1.61	0.47	0.69	2.53
					p_{day}	=	0.00	0.02	-0.03	0.04

Table 3.30. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of lark bunting (*Calamonspiza melanocorys*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 110.71 (95% CI = 90.39, 138.74). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: 0.98 ag: -3.65	grass: 1.87 ag: 2.16	108.47	88.46	136.12	2.02
pdP	1.32	2.15	111.12	90.68	139.35	*
pdL1	3.39	3.27	110.67	90.30	138.78	0.04
pdL2	15.40	6.46	107.73	87.91	135.10	2.69
pdL3	26.77	9.10	105.91	86.43	132.82	4.34
grsL1	3.72	2.13	109.38	89.25	137.17	1.20
grsL2	4.94	2.64	109.11	89.03	136.82	1.45
grsL3	5.99	2.83	108.48	88.52	136.04	2.01

* The variance explained by the amount of prairie dog colony in the plot (pdP) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.31. Model selection results for 15 models of detection probability (*p*) and abundance (*N*) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models are ranked by AICc. ΔAICc is the difference in AICc units from the highest ranking model. AICc weights (w_i), model likelihood (*L*), number of parameters (*K*), and deviance are also shown. AICc weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	*L*	*K*	Deviance
$p_{obs+temp+wind}\ N_{plot}$	212.78	0.00	0.14	1.00	7	198.49
$p_{obs+temp}\ N_{plot}$	212.97	0.19	0.13	0.91	6	200.76
$p_{temp}\ N_{plot}$	213.46	0.67	0.10	0.71	2	209.43
$p_{day+temp}\ N_{plot}$	213.76	0.97	0.09	0.61	3	207.70
$p_{temp+wind}\ N_{plot}$	213.80	1.01	0.09	0.60	3	207.74
$p_{obs+day+temp}\ N_{plot}$	213.84	1.05	0.08	0.59	7	199.55
$p_{day}\ N_{plot}$	213.96	1.17	0.08	0.56	2	209.93
$p_{obs+wind}\ N_{plot}$	214.47	1.69	0.06	0.43	6	202.25
$p_{obs+day+temp+wind}\ N_{plot}$	214.51	1.73	0.06	0.42	8	198.14
$p_{obs+day}\ N_{plot}$	214.78	2.00	0.05	0.37	6	202.56
$p_{wind}\ N_{plot}$	215.31	2.53	0.04	0.28	2	211.28
$p_{.}\ N_{plot}$	216.14	3.35	0.03	0.19	1	214.13
$p_{s+temp}\ N_{plot}$	216.57	3.79	0.02	0.15	4	208.47
$p_{obs}\ N_{plot}$	217.43	4.65	0.01	0.10	5	207.28
$p_{s}\ N_{plot}$	218.73	5.95	0.01	0.05	3	212.67

Table 3.32. Covariate estimates ($\hat{\beta}_i$) under 15 models of detection probability (p) and abundance (N) for grasshopper sparrow (*Ammodramus savannarum*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+temp+wind}$ N_{plot}	212.78	0.00	0.14	7	p_{int}	=	3.81	1.64	0.58	7.03
					p_{obs1}	=	1.60	1.60	-1.52	4.73
					p_{obs2}	=	0.32	1.38	-2.39	3.04
					p_{obs3}	=	-0.60	1.41	-3.36	2.15
					p_{obs4}	=	1.56	1.96	-2.28	5.40
					p_{temp}	=	-0.13	0.07	-0.27	0.02
					p_{wind}	=	-0.38	0.27	-0.91	0.15
$p_{obs+temp}$ N_{plot}	212.97	0.19	0.13	6	p_{int}	=	2.59	1.36	-0.08	5.26
					p_{obs1}	=	2.14	1.69	-1.17	5.46
					p_{obs2}	=	1.22	1.46	-1.63	4.08
					p_{obs3}	=	0.27	1.47	-2.60	3.15
					p_{obs4}	=	2.66	1.98	-1.21	6.53
					p_{temp}	=	-0.15	0.07	-0.28	-0.02
p_{temp} N_{plot}	213.46	0.67	0.10	2	p_{int}	=	2.74	0.93	0.91	4.56
					p_{temp}	=	-0.10	0.05	-0.20	0.00
$p_{day+temp}$ N_{plot}	213.76	0.97	0.09	3	p_{int}	=	0.22	2.15	-4.00	4.44
					p_{day}	=	0.07	0.06	-0.04	0.18
					p_{temp}	=	-0.08	0.06	-0.19	0.03
$p_{temp+wind}$ N_{plot}	213.80	1.01	0.09	3	p_{int}	=	3.15	1.06	1.07	5.23
					p_{temp}	=	-0.10	0.05	-0.20	0.01
					p_{wind}	=	-0.27	0.22	-0.70	0.16

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+day+temp}\ N_{plot}$	213.84	1.05	0.08	7	p_{int}	=	0.34	2.42	-4.41	5.09
					p_{obs1}	=	1.99	1.62	-1.19	5.16
					p_{obs2}	=	1.12	1.38	-1.57	3.82
					p_{obs3}	=	0.10	1.39	-2.63	2.83
					p_{obs4}	=	2.16	1.92	-1.60	5.93
					p_{day}	=	0.06	0.06	-0.05	0.18
					p_{temp}	=	-0.12	0.07	-0.26	0.02
$p_{day}\ N_{plot}$	213.96	1.17	0.08	2	p_{int}	=	-2.02	1.54	-5.04	1.01
					p_{day}	=	0.10	0.05	0.00	0.20
$p_{obs+wind}\ N_{plot}$	214.47	1.69	0.06	6	p_{int}	=	2.71	1.33	0.11	5.32
					p_{obs1}	=	0.14	1.25	-2.32	2.60
					p_{obs2}	=	-0.40	1.22	-2.80	2.00
					p_{obs3}	=	-1.75	1.25	-4.21	0.70
					p_{obs4}	=	0.01	1.70	-3.32	3.33
					p_{wind}	=	-0.47	0.23	-0.92	-0.02
$p_{obs+day+temp+wind}\ N_{plot}$	214.51	1.73	0.06	8	p_{int}	=	2.30	2.96	-3.50	8.11
					p_{obs1}	=	1.59	1.62	-1.58	4.76
					p_{obs2}	=	0.40	1.41	-2.36	3.17
					p_{obs3}	=	-0.59	1.44	-3.40	2.23
					p_{obs4}	=	1.41	1.97	-2.45	5.28
					p_{day}	=	0.04	0.06	-0.09	0.16
					p_{temp}	=	-0.11	0.08	-0.26	0.04
					p_{wind}	=	-0.32	0.28	-0.88	0.23

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+day}\ N_{plot}$	214.78	2.00	0.05	6	p_{int}	=	-2.13	1.91	-5.88	1.61
					p_{obs1}	=	0.76	1.26	-1.71	3.23
					p_{obs2}	=	0.48	1.18	-1.83	2.79
					p_{obs3}	=	-0.84	1.15	-3.10	1.43
					p_{obs4}	=	0.83	1.64	-2.38	4.04
					p_{day}	=	0.11	0.05	0.01	0.21
$p_{wind}\ N_{plot}$	215.31	2.53	0.04	2	p_{int}	=	1.49	0.46	0.59	2.40
					p_{wind}	=	-0.31	0.20	-0.70	0.07
$p_{.}\ N_{plot}$	216.14	3.35	0.03	1	p_{int}	=	0.83	0.24	0.35	1.30
$p_{s+temp}\ N_{plot}$	216.57	3.79	0.02	4	p_{int}	=	2.92	1.17	0.62	5.22
					p_{grs}	=	0.09	0.80	-1.47	1.65
					p_{ag}	=	-0.44	0.71	-1.83	0.94
					p_{temp}	=	-0.10	0.05	-0.20	0.00
$p_{obs}\ N_{plot}$	217.43	4.65	0.01	5	p_{int}	=	1.10	1.05	-0.97	3.16
					p_{obs1}	=	0.38	1.21	-1.99	2.76
					p_{obs2}	=	0.21	1.14	-2.03	2.45
					p_{obs3}	=	-0.97	1.14	-3.20	1.27
					p_{obs4}	=	0.98	1.59	-2.13	4.09
$p_{s}\ N_{plot}$	218.73	5.95	0.01	3	p_{int}	=	0.86	0.57	-0.26	1.99
					p_{grs}	=	0.43	0.74	-1.01	1.88
					p_{ag}	=	-0.26	0.66	-1.56	1.04

Table 3.33. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of grasshopper sparrow (*Ammodramus savannarum*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 7.90 (95% CI = 5.36, 12.69). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: 0.76 ag: 0.23	grass: 1.20 ag: 1.06	8.17	5.48	13.29	*
pdP	-0.84	1.32	8.00	5.41	12.91	*
pdL1	-1.29	2.43	8.02	5.43	12.94	*
pdL2	-4.25	5.86	7.98	5.40	12.86	*
pdL3	-7.87	8.93	7.94	5.37	12.80	*
grsL1	0.01	1.20	8.07	5.45	13.03	*
grsL2	-0.69	1.42	8.03	5.44	12.91	*
grsL3	-1.39	1.58	7.94	5.39	12.73	*

* The variance explained is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.34. Model selection results for 11 models of detection probability (p) and abundance (N) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models are ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. AIC_c weights (w_i), model likelihood (L), number of parameters (K), and deviance are also shown. AIC_c weights sum to one and models with higher likelihood have more weight. Model likelihood is the likelihood of a model relative to the other models. Deviance is the difference in (-2log × likelihood) of the current model and (-2log × likelihood) of the saturated model. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	ΔAIC_c	w_i	L	K	Deviance
$p_{obs}\ N_{plot}$	499.30	0.00	0.20	1.00	5	489.25
$p_{obs+day}\ N_{plot}$	499.42	0.12	0.19	0.94	6	487.36
$p_{obs+day+temp}\ N_{plot}$	499.94	0.64	0.15	0.72	7	485.86
$p_{obs+wind}\ N_{plot}$	500.52	1.22	0.11	0.54	6	488.46
$p_{obs+day+wind}\ N_{plot}$	500.60	1.30	0.11	0.52	7	486.52
$p_{obs+temp}\ N_{plot}$	501.03	1.73	0.09	0.42	6	488.97
$p_{.}\ N_{plot}$	502.12	2.82	0.05	0.24	1	500.12
$p_{day}\ N_{plot}$	502.90	3.60	0.03	0.17	2	498.89
$p_{temp}\ N_{plot}$	503.29	3.99	0.03	0.14	2	499.28
$p_{wind}\ N_{plot}$	503.50	4.20	0.02	0.12	2	499.49
$p_{s}\ N_{plot}$	503.63	4.33	0.02	0.11	3	497.61

Table 3.35. Covariate estimates ($\hat{\beta}_i$) under 11 models of detection probability (p) and abundance (N) for western meadowlark (*Sturnella neglecta*) in eastern Colorado in 2005. Models were ranked by AIC_c. ΔAIC_c is the difference in AIC_c units from the highest ranking model. Model AIC_c weights (w_i) and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. Explanation and coding of model parameters are provided in Table 3.2.

Model	AIC_c	Δ AIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
p_{obs} N_{plot}	499.30	0.00	0.20	5	p_{int}	=	1.92	0.30	1.34	2.50
					p_{obs1}	=	-0.75	0.43	-1.59	0.09
					p_{obs2}	=	-0.13	0.42	-0.96	0.70
					p_{obs3}	=	-0.39	0.40	-1.18	0.40
					p_{obs4}	=	0.92	0.57	-0.19	2.04
$p_{obs+day}$ N_{plot}	499.42	0.12	0.19	6	p_{int}	=	0.93	0.78	-0.60	2.46
					p_{obs1}	=	-0.81	0.44	-1.66	0.04
					p_{obs2}	=	-0.25	0.43	-1.09	0.60
					p_{obs3}	=	-0.43	0.41	-1.23	0.37
					p_{obs4}	=	0.92	0.57	-0.19	2.04
					p_{day}	=	0.04	0.03	-0.02	0.09
$p_{obs+day+temp}$ N_{plot}	499.94	0.64	0.15	7	p_{int}	=	-0.16	1.20	-2.51	2.18
					p_{obs1}	=	-0.78	0.43	-1.63	0.07
					p_{obs2}	=	-0.24	0.44	-1.10	0.61
					p_{obs3}	=	-0.46	0.41	-1.26	0.35
					p_{obs4}	=	0.88	0.57	-0.24	2.00
					p_{day}	=	0.05	0.03	-0.01	0.12
					p_{temp}	=	0.04	0.03	-0.02	0.10

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_{obs+wind}\ N_{plot}$	500.52	1.22	0.11	6	p_{int}	=	1.74	0.35	1.05	2.44
					p_{obs1}	=	-0.76	0.43	-1.60	0.08
					p_{obs2}	=	-0.15	0.42	-0.98	0.69
					p_{obs3}	=	-0.38	0.40	-1.17	0.42
					p_{obs4}	=	0.94	0.57	-0.18	2.06
					p_{wind}	=	0.09	0.10	-0.11	0.29
$p_{obs+day+wind}\ N_{plot}$	500.60	1.30	0.11	7	p_{int}	=	0.74	0.81	-0.84	2.32
					p_{obs1}	=	-0.82	0.44	-1.68	0.03
					p_{obs2}	=	-0.27	0.44	-1.12	0.59
					p_{obs3}	=	-0.42	0.41	-1.22	0.38
					p_{obs4}	=	0.94	0.57	-0.18	2.06
					p_{day}	=	0.04	0.03	-0.02	0.09
					p_{wind}	=	0.09	0.10	-0.11	0.30
$p_{obs+temp}\ N_{plot}$	501.03	1.73	0.09	6	p_{int}	=	1.66	0.57	0.54	2.78
					p_{obs1}	=	-0.73	0.43	-1.57	0.11
					p_{obs2}	=	-0.11	0.43	-0.94	0.73
					p_{obs3}	=	-0.39	0.40	-1.19	0.40
					p_{obs4}	=	0.91	0.57	-0.21	2.02
					p_{temp}	=	0.01	0.03	-0.04	0.07
$p_{.}\ N_{plot}$	502.12	2.82	0.05	1	p_{int}	=	1.75	0.14	1.48	2.01
$p_{day}\ N_{plot}$	502.90	3.60	0.03	2	p_{int}	=	0.95	0.73	-0.48	2.38
					p_{day}	=	0.03	0.03	-0.02	0.08
$p_{temp}\ N_{plot}$	503.29	3.99	0.03	2	p_{int}	=	1.32	0.48	0.37	2.27
					p_{temp}	=	0.02	0.03	-0.03	0.07
$p_{wind}\ N_{plot}$	503.50	4.20	0.02	2	p_{int}	=	1.59	0.23	1.13	2.05
					p_{wind}	=	0.08	0.10	-0.12	0.27

…table continued

…table continued

Model	AIC_c	ΔAIC_c	w_i	K	$\hat{\beta}_i$			SE	LCL	UCL
$p_s\ N_{plot}$	503.63	4.33	0.02	3	p_{int}	=	1.47	0.22	1.04	1.90
					p_{grs}	=	0.45	0.32	-0.18	1.08
					p_{ag}	=	0.45	0.35	-0.24	1.13

Table 3.36. Variance components analysis of eight habitat covariates of grassland bird mark-recapture plots and associated estimates of western meadowlark (*Sturnella neglecta*) abundance in eastern Colorado in 2005. Analysis was conducted on derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs}\ N_{plot}$). Relationships between habitat covariates and abundance estimates are represented by β estimates and associated standard errors (SE). The mean model estimated an overall process variance of 5.13 (95% CI = 4.27, 6.27). Each habitat covariate was run singly, and the remaining process variance ($\hat{\sigma}^2$), associated 95% confidence interval, and percent of overall process variation explained are shown. Explanation and coding of habitat covariates are provided in Table 3.5.

Habitat covariate	$\hat{\beta}$	SE ($\hat{\beta}$)	Remaining process variance			% Variation explained
			$\hat{\sigma}^2$	LCL	UCL	
s	grass: -0.09 ag: -0.71	grass: 0.37 ag: 0.38	5.08	4.23	6.22	0.97
pdP	0.36	0.38	5.14	4.28	6.28	*
pdL1	0.20	0.54	5.15	4.29	6.30	*
pdL2	0.58	0.99	5.15	4.29	6.29	*
pdL3	0.86	1.31	5.15	4.28	6.29	*
grsL1	0.17	0.41	5.15	4.29	6.30	*
grsL2	-0.40	0.49	5.14	4.28	6.29	*
grsL3	-0.72	0.53	5.11	4.26	6.25	0.39

* The variance explained by the amount of prairie dog colony in the plot (pdP) and in landscapes 1, 2, and 3 (pdL1, pdL2, and pdL3, respectively) and the amount of grassland in landscapes 1 and 2 (grsL1 and grsL2, respectively) is negative due to different degrees of freedom in calculating the respective variances of each habitat covariate and can be considered zero.

Table 3.37. Estimated detection probabilities ($\hat{p}$) for eight grassland bird species in eastern Colorado in 2005. Estimates were generated in program MARK under a constant detection model ($p_.$) and do not typically represent top model parameter estimates as indicated by ΔAIC_c and AIC_c weights (w_i). Standard errors (SE) and 95% confidence intervals of parameter estimates are also shown.

Species	($p_.$) ΔAIC_c	($p_.$) w_i	$\hat{p}$	SE	LCL	UCL
Mountain plover	3.34	0.06	0.93	0.04	0.81	0.97
Burrowing owl	0.00	0.34	0.72	0.09	0.53	0.86
Horned lark	49.24	0.00	0.84	0.01	0.83	0.85
Cassin's sparrow	0.40	0.18	0.88	0.02	0.82	0.92
Lark sparrow	3.77	0.05	0.75	0.05	0.64	0.84
Lark bunting	18.57	0.00	0.84	0.01	0.82	0.86
Grasshopper sparrow	3.35	0.03	0.70	0.05	0.59	0.79
Western meadowlark	2.82	0.05	0.85	0.02	0.81	0.88

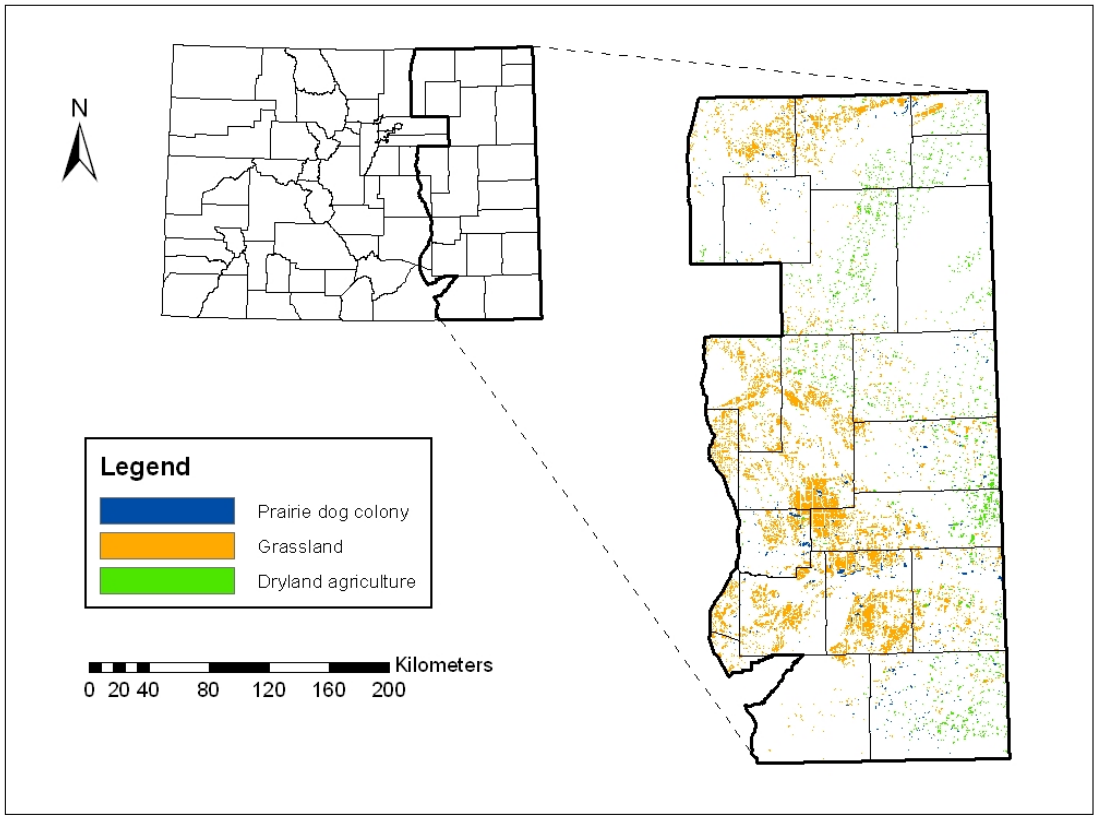


Figure 3.1. Study area and stratified sampling frame of a grassland avifauna study conducted in 2005 on three different habitat types of shortgrass prairie in eastern Colorado, USA.

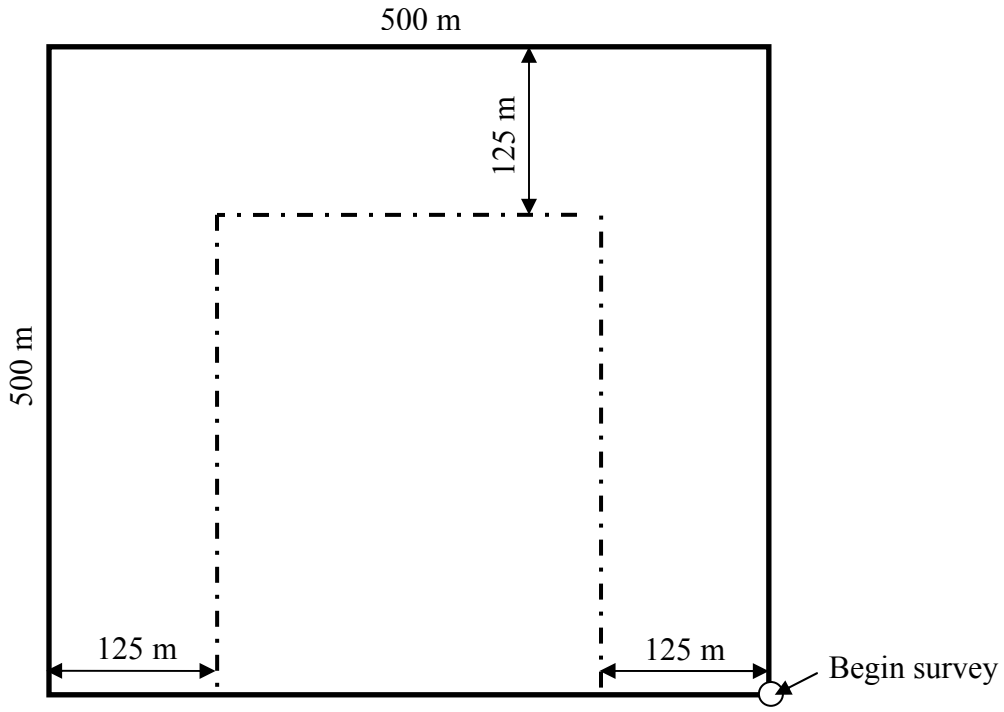


Figure 3.2. Diagram of survey "transect" walked by observers during double-observer surveys conducted on randomly selected 500-m × 500-m plots in eastern Colorado in 2005.

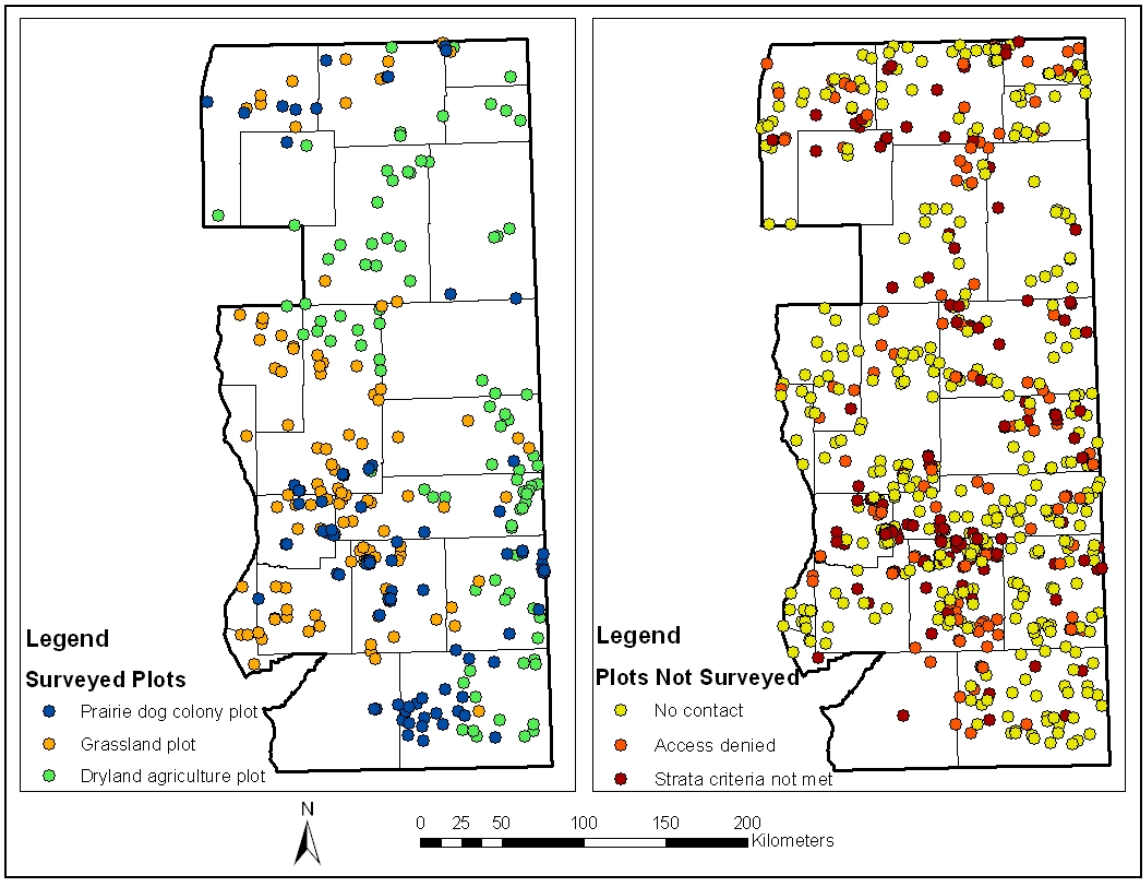


Figure 3.3. Fates of plots selected in a grassland avifauna study conducted in 2005 in shortgrass prairie in eastern Colorado, USA. Locations are shown for surveyed plots in three strata – prairie dog colony, grassland, and dryland agriculture – and plots not surveyed due to inability to contact the landowner (no contact), access denied by the landowner or lessee, or if strata criteria were not met.

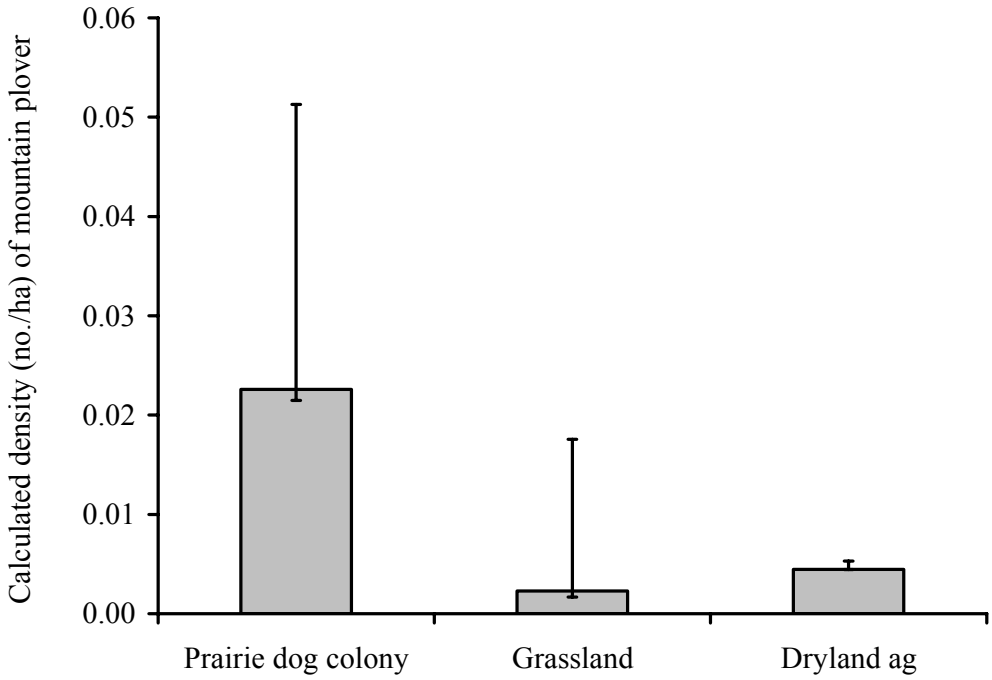


Figure 3.4. Calculated density of mountain plover (*Charadrius montanus*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs1}\,N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

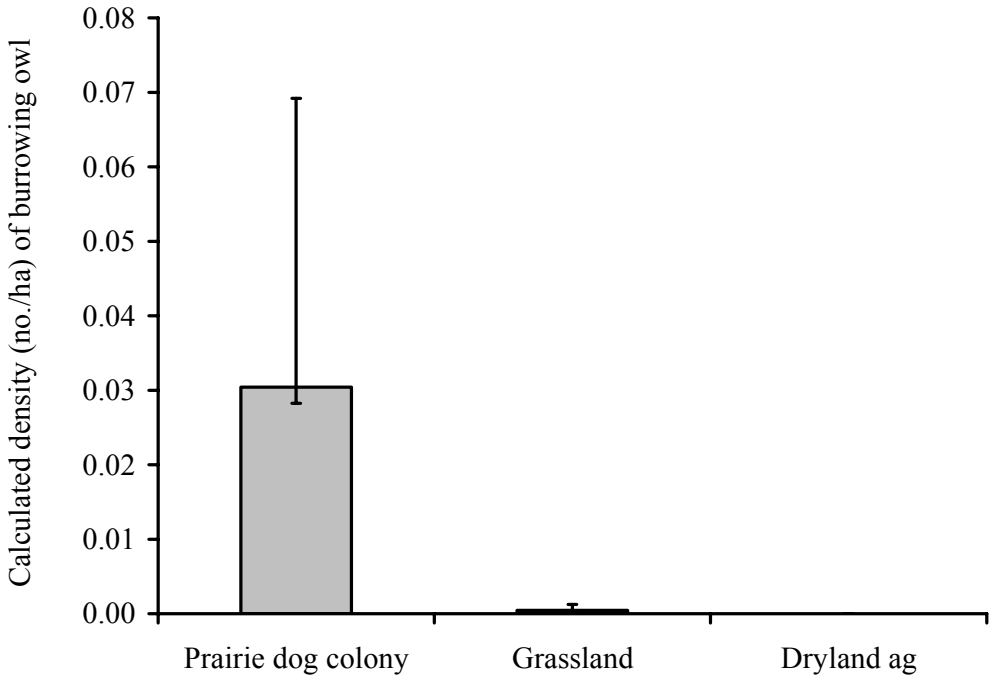


Figure 3.5. Calculated density of burrowing owl (*Athene cunicularia hypugaea*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. No burrowing owls were detected on the 91 dryland agriculture plots surveyed in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{.}\ N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

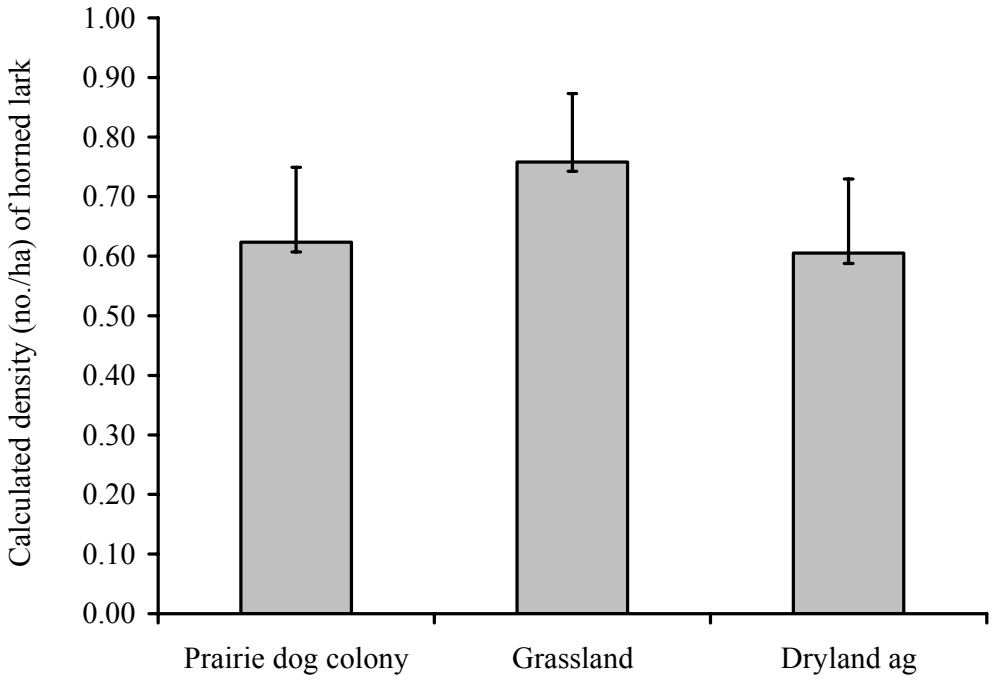


Figure 3.6. Calculated density of horned lark (*Eremophila alpestris*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}\,N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

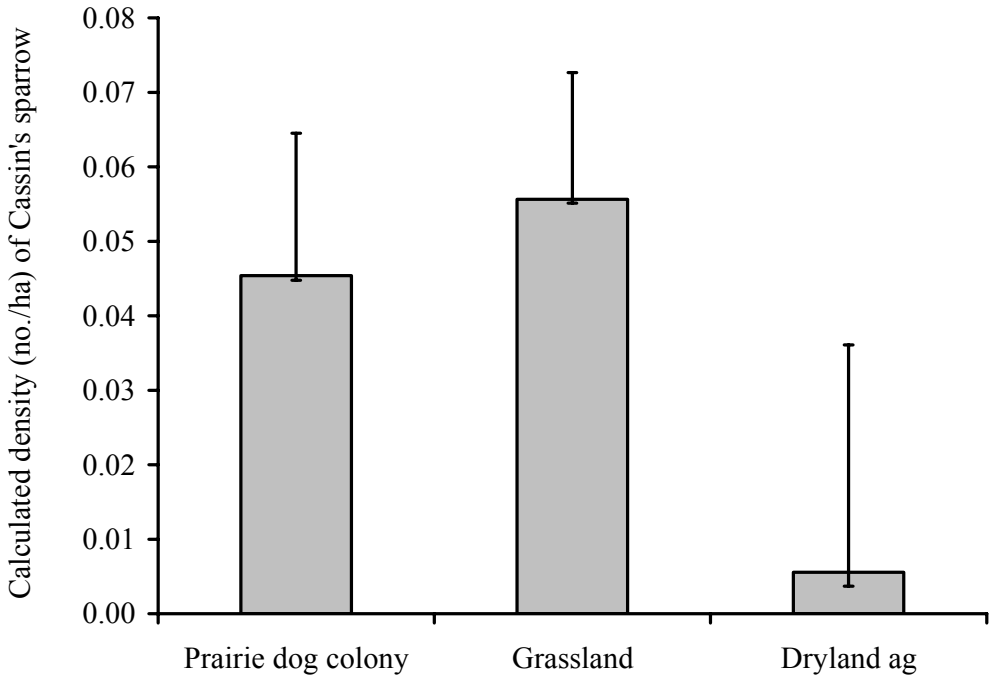


Figure 3.7. Calculated density of Cassin's sparrow (*Aimophila cassinii*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_s N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

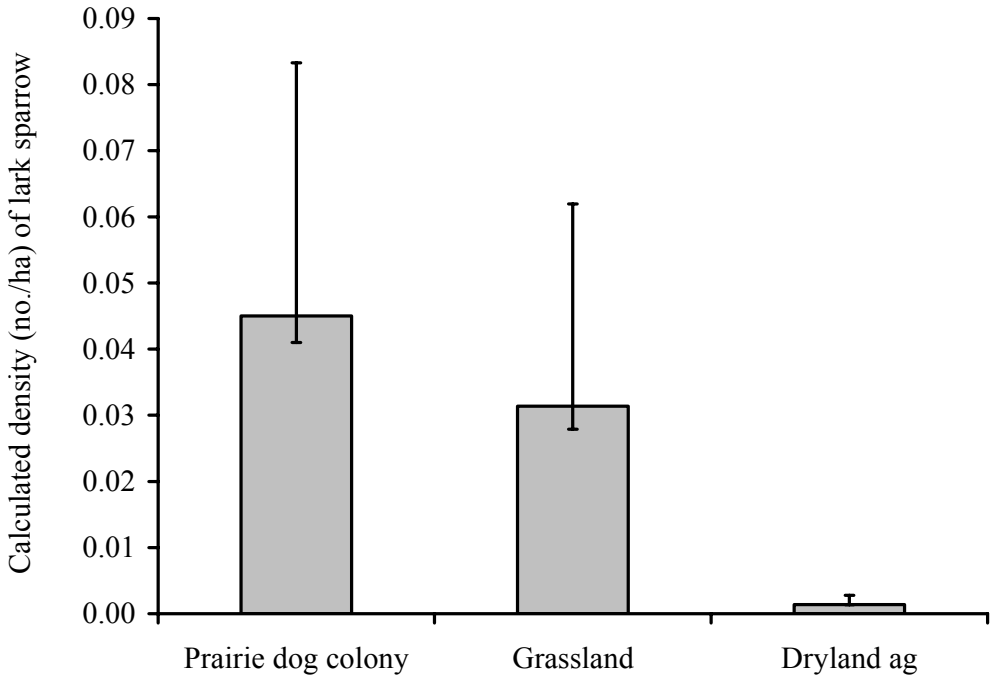


Figure 3.8. Calculated density of lark sparrow (*Chondestes grammacus*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{wind}\,N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

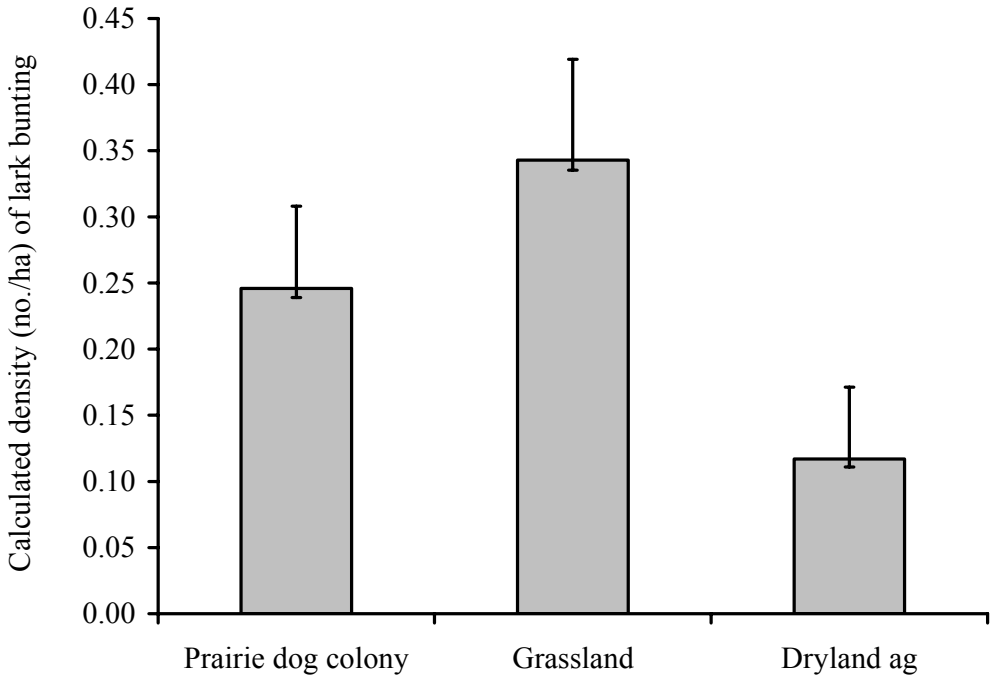


Figure 3.9. Calculated density of lark bunting (*Calamonspiza melanocorys*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

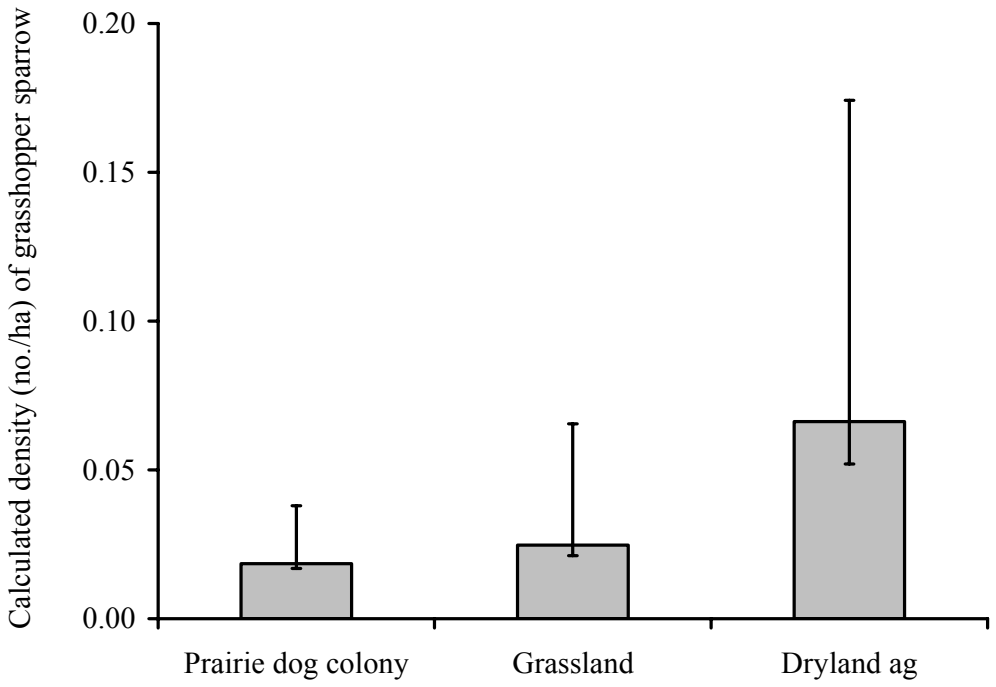


Figure 3.10. Calculated density of grasshopper sparrow (*Ammodramus savannarum*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs+temp+wind}N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

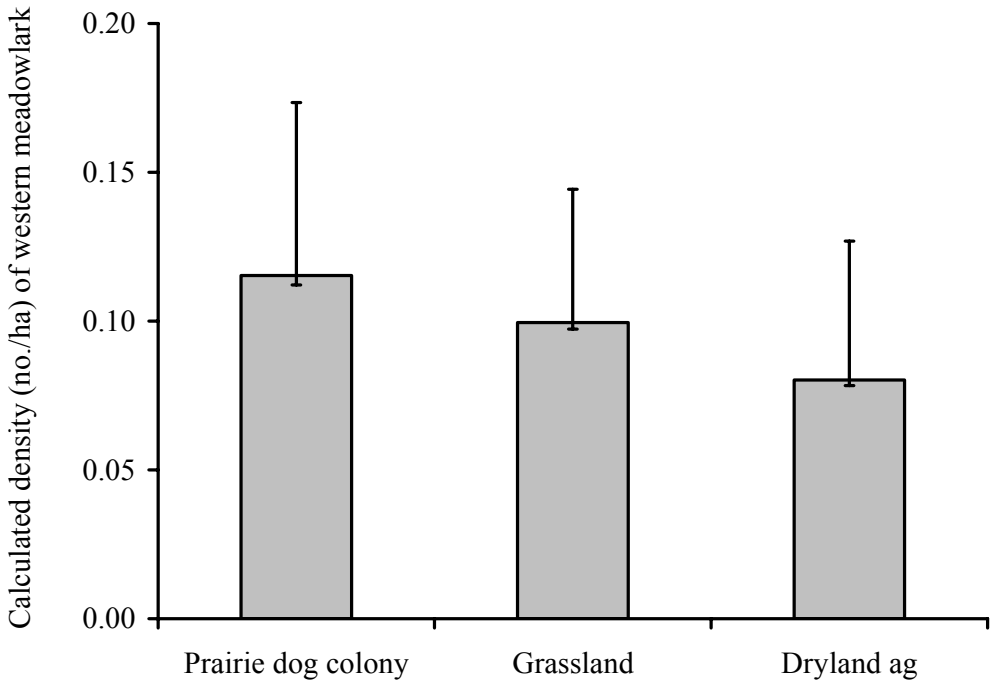


Figure 3.11. Calculated density of western meadowlark (*Sturnella neglecta*) in three strata – prairie dog colony, grassland, and dryland agriculture – in eastern Colorado in 2005. Densities were calculated from derived abundance estimates generated under the highest ranking model for detection probability ($p_{obs}\,N_{plot}$). Error bars represent 95% confidence intervals. Explanation and coding of model parameters are provided in Table 3.2.

CHAPTER 4

IMPLICATIONS FOR GRASSLAND BIRD MONITORING AND CONSERVATION

INTRODUCTION

As avian ecologists and wildlife biologists, our common goal is to manage avian species and communities to ensure their long-term success. All agree, monitoring is necessary – but why, what, and how should monitoring take place (Nichols and Williams 2006)? While the answers to these questions should be specific to each study and its objectives, employing the best monitoring methodologies available over the appropriate scale is always important. To effectively conserve avian species, we must expand the focus of our studies from isolated segments of populations to range-wide assessments. Broad-scale studies are inherently more challenging to conduct, but we must not ignore the need for such studies. In addition, the quality of our research should not suffer simply because we enlarge its scope – otherwise inference will be limited. Monitoring methodologies continue to be developed which allow statistical rigor to be maintained within logistical constraints.

The objective of my study was not to monitor avian occupancy and abundance, but rather to examine applications of "how" and to test biological predictions of interest. I evaluated recently developed, statistically rigorous methods to estimate these population parameters in the shortgrass prairie ecosystem. By answering the question, "are

occupancy and double-observer methods feasible for monitoring grassland birds?", my study can improve the design of future monitoring programs. My study was the first study on grassland birds in Colorado which employed probability-based sampling over a broad extent – the eastern plains. Because over 80% of eastern Colorado is in private ownership, a study of this scope will, by necessity, work on private lands. Private lands provide important habitat for endangered and threatened species, and we must be able to work with landowners if our conservation efforts are to be successful. This study was conducted with the cooperation of over 600 private landowners, and ~92% of surveyed plots were located on privately owned land. These results suggest that approaches incorporating similar methodologies may be successfully applied in other areas. Below I discuss these and other aspects of my study, recommendations for future research, and general implications for grassland bird monitoring and conservation, with emphasis on my focal study species – the mountain plover and the burrowing owl.

WHAT SHOULD WE MONITOR? – OCCUPANCY VERSUS ABUNDANCE

From a management- or conservation-based perspective, we need to develop explicit goals and define alternative management actions we will take to achieve those goals. Reliable information on the state of system and other goal-related variables are required to establish baseline conditions and to evaluate management actions. Thus, rather than asking "what should we monitor?" we must ask ourselves, what are we trying to measure given our study goals and the corresponding parameter will be the answer.

In this study, I evaluated methods to estimate two population parameters that provide different information – species occupancy (Chapter 2) and abundance (Chapter

3). Species occupancy allows us to monitor resource selection, including shifts in habitat use, extinction and colonization of patches, and species co-occurrence. Abundance allows us to monitor changes, or trends, in population size. The information provided by both metrics is important so that biologists can make sound management decisions and evaluations and policy makers can make informed decisions on species conservation issues. One measure is not "better" than the other, but rather provides information to address different questions. The choice of which parameter to measure is specific to the study in hand.

The use of occupancy data has become increasingly popular in monitoring programs, often because researchers believe such data to be less expensive and time-consuming to collect than abundance data. While occupancy estimates may be informative of populations of rare species such as the mountain plover, they may not be particularly useful for common species such as the horned lark which occurred virtually everywhere in my study area. Estimation methods have also been developed which allow estimation of latent abundance from occupancy data (Royle and Nichols 2003). My study was not designed with the purpose of estimating latent abundance. Design and modeling adjustments would be necessary to obtain a more accurate picture of avian populations from measurements of occupancy (discussed below).

HOW SHOULD WE MONITOR? – APPLYING NEW METHODOLOGIES

Methods to monitor grassland birds are of current and vital interest to management, conservation, and regulatory agencies alike. The results of numerous studies indicate that detectability is usually imperfect (i.e., $p < 1$, Nichols 1992, Lancia et

al. 1994). Thus, unadjusted counts cannot reliably be used to indicate or evaluate relative changes in species population status. Incorporation of methodologies which estimate detection probabilities and adjust count statistics accordingly is essential to rigorous monitoring programs.

My study demonstrated that both occupancy and dependent double-observer methodologies are feasible for monitoring grassland bird species over large areas. Field protocols were fairly easy to implement in the shortgrass ecosystem. My results suggest that adequate sample sizes can be obtained to estimate species occupancy and abundance for less common species such as the mountain plover and burrowing owl, using a probability-based sampling scheme.

Occupancy

For single-season studies, occupancy is considered closed (MacKenzie et al. 2006). However, temporary emigration may occur, resulting in overestimation of species occupancy rates (and latent abundance). To minimize this problem, plot size should be appropriate for the study species and consecutive site visits timed close enough together so that movements (in or out of the area) are unlikely to occur. Design adjustments may require a combination of both approaches, especially for species whose resource type, or area, changes during the breeding season. For example, the average brood-rearing home range for mountain plover is approximately 56 ha (Knopf and Rupert 1996). The home range of plovers is often larger during the incubation period. Adjusting my plot size from 25 ha to 56 ha and sampling during the brood-rearing period may improve estimates of mountain plover occupancy. Ideally, plot size and timing of visits would be customized

for each species of interest, a difficult feat to accomplish in community-level studies. If the assumption of closure for a species cannot be met, a more appropriate interpretation of occupancy data may be as resource use (MacKenzie 2006).

Abundance

Results of double-observer surveys were promising, particularly for species such as mountain plovers and burrowing owls which occur in low numbers and whose movements are easy to track during surveys. Double-observer methodology is more cost- and time-efficient than physical mark-recapture techniques and can be accomplished in a single visit. Proper implementation of double-observer methods also promises to avoid bias associated with violation of at least two assumptions important to distance sampling: 1) all individuals on the line or point are detected with probability equal to 1, and 2) individuals do not move in response to the observer before being detected. These assumptions can be difficult to meet in field conditions (Rosenstock et al. 2002), such as with some grassland bird species that move secretively in response to observers before being detected (e.g., mountain plover, grasshopper sparrow). Previous estimation of mountain plover abundance using distance sampling has typically employed motorized vehicles (e.g., trucks, ATV's), which may lessen plover's response to observers (Wunder et al. 2003, Plumb et al. 2005). This protocol is not feasible in many areas (e.g., cultivated fields) or for multiple-species studies. The use of double-observer methodology is another option for estimates of grassland bird abundance.

I was able to effectively implement double-observer methods in open shortgrass prairie habitats to reduce the potential of double counting individuals. While this

methodology appears to work well for low-density species such as the mountain plover and burrowing owl, the application to species which occur at higher densities presents a greater challenge. In addition, limitations may exist to the extension of this methodology to other habitat types, such as forests, where bird movement is more difficult to track. To ameliorate such circumstances, plot sizes could be reduced, survey duration shortened, or other survey design changes made to improve the resulting abundance estimates.

Abundance may also be estimated using a latent-occupancy approach. While double-observer methods require the presence of two people with one visit to a plot, the latent-occupancy approach employs a single observer with repeated visits (≥3, MacKenzie and Royle 2005). Because assumptions of closure are less likely to be violated, the double-observer method provides more precise abundance estimates than does information from occupancy data. Given these considerations, double-observer methods would seem to be a better and cheaper way to estimate abundance, and, if numbers of individuals on plots are high, I would espouse this view. Alternatively, for low-density species such as mountain plover, a latent-occupancy survey could be envisioned where an equal effort is employed (e.g., using two observers at the same visit and treating their observations as independent sampling occasions). How such a design would perform (e.g., precision of estimates) is unknown and the methods of Royle (2004) as well as future developments should be examined. Data collection for both independent double-observer and latent-occupancy approaches could occur concurrently. Methodological developments might focus on combining these two sources of data in a joint likelihood to obtain the best abundance estimates possible. I think such an approach deserves attention and look forward to such developments.

Sampling Frame

My study also demonstrated that probability-based sampling schemes can be used effectively in broad-scale studies and that statistical rigor is not sacrificed to obtain large sample sizes. Using Theobald et al.'s (in press) implementation, I evaluated a spatially balanced sampling (SBS) approach with equal sampling probability within three strata. The SBS design is useful for those instances when good spatial coverage of the study area is desired, including studies investigating spatial variation of a response variable. This design maximizes spatial independence among sample locations and minimizes spatial autocorrelation (Theobald et al. in press). The Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm used to implement the SBS approach is robust to adjustments (increases) in sample size (i.e., additional samples remain spatially balanced). This provides design flexibility where some plots cannot be sampled, as in my study, due to denial of access, incorrect habitat type, or logistical difficulties, assuming that such non-response issues occur randomly in regard to spatial location. The utility of the SBS approach can be increased by the inclusion of unequal sampling probabilities, allowing the sampling design to be tailored to individual study needs while still permitting inference to the entire sampling frame. For example, a study specifically designed to estimate the burrowing owl population in eastern Colorado might want to sample all habitat types but with unequal probabilities. Target habitats (e.g., prairie dog colonies) would be sampled at a higher probability than non-target habitats (e.g., agriculture fields, shrubland), and estimates would be weighted by the inclusion probability.

RECOMMENDATIONS FOR FUTURE STUDIES

I recommend several logistical improvements that may decrease difficulties and increase inference of future studies. Inference of my results is limited by the proportion of plots that I could not include in my sampling frame. For instance, I was not able to survey 294 prairie dog colony plots due to inability to contact the landowner (154 plots), access denied by the landowner or lessee (34 plots), or if strata criteria were not met (106 plots). The problem of limited inference could be lessened in future studies by decreasing the number of plots not surveyed due to these reasons. This could be achieved by 1) allowing for additional time to contact landowners and lessees, and 2) improving Geographic Information System (GIS) data, especially of prairie dog colonies, and limiting that data to only the most recent.

In broad-scale studies, pre-field-season logistics are often more time-consuming than conducting the surveys themselves. Substantial time and effort is required and should be invested up-front in order to maximize sample size, widen biological inference, and make the field season more efficient. Determining the correct landowner and lessee of a plot and subsequently obtaining the correct contact information can be difficult, especially in the case of absentee landowners or in areas where land is changing ownership rapidly. In addition, because, under a probability-based sampling scheme, plots are chosen without regard to property boundaries, individual plots may have multiple landowners – up to four in the case of my study. My field crew and I spent as much time contacting landowners as conducting surveys. The amount of time invested to gain access would be the same regardless of the number of surveys (visits) conducted. While updated, comprehensive county ownership maps and directories would be

extremely useful, large amounts of time prior to field sampling are needed for this type of study. I suggest for studies with similar field protocols working on private land to dedicate 3-4 months in pre-field logistics.

Inference could also be improved by using more accurate GIS data to represent land cover classifications. Based solely on plots I was able to groundtruth, I estimated the accuracy of my land cover classification data (combined from a number of sources) to be approximately 68% at the plot-level (500-m) scale. Broken down by strata, I found 17 plots (~16%) mischaracterized as dryland agriculture, 22 plots (~18%) mischaracterized as grassland, and 92 plots (~51%) mischaracterized as prairie dog colony. Most (~75%) misclassifications were due to incorrect (often outdated) prairie dog colony location data. In addition, Conservation Reserve Program (CRP) data was unavailable for over half of my study area which accounted for ~19% of misclassifications. Based on these estimates, accuracy of land cover classification data in eastern Colorado could be substantially improved by improving prairie dog colony location data.

Prairie dog colonies are more difficult to map than other types of habitat due to their inherently transient nature. Colonies may expand their boundaries within short periods of time, and may blink in and out of existence. There are various ways to obtain colony location data, such as aerial surveys, digitization from aerial photography, and on-the-ground delineation, but each has its limitations. Aerial surveys do not provide information on individual colony area and configuration which is necessary to investigate species-habitat relationships. Digital photography does not allow us to distinguish the presence or absence of prairie dogs. On-the-ground delineation is time consuming. Regardless of the method used to collect location data, I recommend restricting prairie

dog colony data to only those recently collected (e.g., within the previous 2-3 years) in order to improve the integrity of the sampling frame.

CONSERVATION AND MANAGEMENT IMPLICATIONS

Conservation of grassland birds will require that biologists gather reliable information on avian population status and habitat use. This entails not only obtaining unbiased estimates but also conducting studies at the appropriate scale and in the appropriate habitats. Most grassland bird studies, especially those looking at landscape-scale effects, have been conducted in the mixed-grass and tallgrass prairies of the Midwest. Additional long-term and broad-scale studies are needed to further our knowledge of avian-habitat relationships in the shortgrass prairie ecosystem. The results of my study suggest the effect of habitat factors, both at the plot-and landscape-levels, may vary among regions and with the population parameter measured (e.g., occupancy or abundance). In my study, the amount of prairie dog colony in the landscape appeared to greatly affect burrowing owl occupancy (Chapter 2), but had no effect on owl abundance (Chapter 3). Thus, once we know what and how we want to monitor, we still need to consider the inter-relationships of population parameters.

This study investigated the relationships of avian occupancy, abundance, and density with three habitat types found in Colorado's shortgrass prairie ecosystem – prairie dog colonies, native shortgrass, and dryland agriculture. While these three habitats do make up a large portion of the eastern plains, there is also significant acreage covered in sagebrush and other shrublands, irrigated agriculture, and CRP. Although my focal species (mountain plover and burrowing owl) do not typically use these additional habitat

types, all of my other study species probably do. For these grassland birds, we need to look at other habitat types beyond the scope of this study to obtain a full picture of grassland birds in Colorado.

We also must consider this when planning land management and acquisition. A wide variety of habitat types and conditions (e.g., seral stages) are needed to support grassland bird communities. While a species-specific approach is appropriate in some circumstances, considering the needs of the grassland community as a whole is equally important if we are to conserve the shortgrass prairie and its suite of avifauna. I advocate a community-based approach to land management and conservation activities.

While this is easily said, it is more difficult to achieve. First, we need to obtain reliable information for the suite of grassland birds. Then, we must be able to apply this knowledge to gain understanding of the ecology behind the responses we observe and to manage populations and habitat appropriately. Metapopulations of some grassland birds (e.g., Cassin's sparrows, lark buntings) appear to vary drastically in size between years, possibly in response to weather conditions – a factor we are unable to manage. Management may be difficult even for those species with apparently clear habitat associations (e.g., mountain plover). For example, difficulties may occur in managing or targeting land acquisition for specific prairie dog colony attributes (e.g., size, shape, distance between colonies) which may be important to avian species occupancy or abundance but which are likely to change in a relatively short amount of time. Given these constraints, what are we to do?

Historically, grassland birds lived in a structurally diverse ecosystem, one which evolved under varying gradients of temperature and seasonal precipitation as well as

combinations of both grazing and fire disturbances. The shifting spatiotemporal mosaic was, and is, essential to maintain the diversity of species which call the prairie home (Fuhlendorf and Engle 2001). My results suggest that prairie dogs provide valuable habitat within the shortgrass prairie ecosystem for some grassland birds, and that conservation of avian species of concern is inexorably tied to their fate. While I believe that successful conservation actions will incorporate land management incentives to benefit prairie dogs, I acknowledge the difficulty of managing for specific colony attributes. Instead of intensively managing for one particular habitat type or condition, I advocate managing for heterogeneity. This would include not only conserving prairie dog colony habitat, but also re-establishing those ecosystem processes that produce natural variation within native shortgrass. I believe that restoring those processes that create and sustain heterogeneity, rather than attempting to simply re-create a pattern, is the most viable solution to long-term management and conservation challenges. In addition, I would promote the reseeding of disturbed prairie with native species, especially on CRP lands. Restoring the land's natural vegetation and processes would help ensure that suitable habitat is available for a variety of grassland inhabitants despite natural fluctuations in weather and prairie dog populations.

The effect of habitat and the importance of habitat diversity should be considered throughout a species' range. My study was restricted within Colorado's state borders. The range of my eight study species extends beyond these state borders. Future studies should strive to address range-wide populations and can be accomplished with coordination of research and monitoring efforts across geographical and organizational boundaries.

Monitoring, management, and conservation of grassland birds will remain topics of importance. Controversy surrounding the effects prairie dogs have on the shortgrass ecosystem and its other inhabitants will likely continue. Conservation actions must include not only targeted land acquisition but partnerships with private landowners to meet land management goals over the broad scale necessary to achieve successful results. Additional research should be conducted to refine our knowledge of avian-habitat relationships in the shortgrass prairie and to investigate other potentially important habitat factors on avian population parameters. Despite these continued challenges, I hope the results of my study will serve to inform grassland bird conservation issues and provide impetus to the implementation of more rigorous sampling and survey methodologies in broad-scale studies.

LITERATURE CITED

Dreitz, V. J., P. M. Lukacs, and F. L. Knopf. 2006. Monitoring low density avian populations: an example using Mountain Plover. Condor 108:700-706.

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. Bioscience 51:625-632.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland, USA.

MacKenzie, D. I. 2006. Modeling the probability of resource use: The effect of, and dealing with, detecting a species imperfectly. Journal of Wildlife Management 70:367-374.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier Inc., San Diego, California, USA.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42:1105–1114.

Nichols, J. D. 1992. Capture-recapture models. Bioscience 42:94-102.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668-673.

Plumb, R. E., F. L. Knopf, and S. H. Anderson. 2005. Minimum population size of Mountain Plovers breeding in Wyoming. Wilson Bulletin 117:15-22.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: Current practices and an alternative. Auk 119:46-53.

Royle, J. A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60: 108-115.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

Wunder, M. B., F. L. Knopf, and C. A. Pague. 2003. The high-elevation population of Mountain Plovers in Colorado. Condor 105:654-662.

APPENDIX I

GEOGRAPHIC INFORMATION SYSTEM (GIS) PROCEDURES

SUMMARY

My study area consisted of all areas in Colorado located ~48 km east of Interstate 25, excluding lands owned by the Department of Defense. Within this area, I conducted occupancy and abundance surveys of grassland birds in three strata – black-tailed prairie dog colonies, native grassland not occupied by prairie dogs (hereafter simply referred to as grassland), and dryland agriculture. I determined land cover types within the study area using 30-m vegetation classification data into which I incorporated all available Conservation Reserve Program (CRP), road, and prairie dog colony data. For each stratum, a spatially balanced sampling tool (Theobald 2004) was used to assign a random order to each grid cell meeting strata criteria (Theobald et al. in press).

Based on this random order, I surveyed 282 plots throughout eastern Colorado in May and June, 2005. Digital aerial photography was later obtained for the extent of my study area during this period. Using these aerials, I digitized prairie dog colonies within 2250 m of surveyed plot boundaries. I then combined these data with 30-m vegetation classification data to obtain habitat covariates, specifically the amount of prairie dog colony and grassland in landscapes surrounding surveyed plots, at multiple spatial scales. These data were used in models investigating the effect of habitat covariates on grassland bird occupancy and abundance.

My sampling design was conducted using the Geographic Information System (GIS), ArcInfo/ArcGIS 9.0, and the tools therein. Below I provide a detailed account of all GIS procedures used to develop my sampling frame and apply a spatially balanced sampling design, as well as procedures applicable to my data analyses. Pathways for all ArcInfo/ArcGIS procedures (in capital letters), script text, and descriptions of datasets are provided at the end of this appendix.

DETAILED GIS PROCEDURES

A. Data Preparation – Combining Data

1. Create study area

- DISSOLVE counties.shp (output: Colorado.shp)
- create temporary polyline shapefile in ArcCatalog; draw line following I-25 north-south and then move line east 48,300m (30mi) using Editor
- split (cut) Colorado polygon using Editor by sketching this line and erase western "half"
- select by attributes landstatus.shp using ArcMap 9.0 Select by Attributes where 'OWNER'='DOD' and EXPORT selected polygons to new shapefile (output: DOD.shp)
- ERASE DOD areas from remaining eastern Colorado polygon (input features=counties_Dissolve.shp, erase features=DOD.shp, output: StudyArea_2005.shp – renamed 'StudyArea_2005_old.shp' after step 6, Edit study area)

2. Clip existing layers to study area

- CONVERT StudyArea_2005.shp to coverage (output: studyarea_f)
- GRIDCLIP es_nlcd_cop raster (basinwide veg data) to studyarea_f in ArcInfo Grid (Grid: GRIDCLIP es_nlcd_cop bw_clip COVER studyarea_f; output: bw_clip). This did not remove interior DOD area from es_ncld_cop.
- CONVERT DOD.shp to raster (cell size=30, Environment: snap to raster=bw_clip, output: feature_dod1)
- COMBINE feature_dod1 and bw_clip rasters in ArcInfo Grid (Grid: bwclip_dod = bw_clip + feature_dod1; output: bwclip_dod)
- RECLASSIFY bwclip_dod raster (NoData=0, all other values=200,000, output: reclass_bwd1)
- COMBINE reclass_bwd1 and bw_clip rasters in ArcInfo Grid (Grid: bw_2005sa = bw_clip + reclass_bwd1; output: bw_2005sa).
- CLIP 3 road files (hwy.shp, mjr_rds.shp, loc_rds.shp) to StudyArea_2005.shp (output: hwy_Clip_2005.shp, mjr_rds_Clip_2005.shp, loc_rds_Clip_2005.shp)

3. Incorporate CRP into clipped basinwide

- CONVERT crpdist.shp (CRP data for SE Colorado) to raster (cell size=30, Environment: snap to raster=bw_2005sa, output: feature_crpd1)

- COMBINE feature_crpd1 and bw_2005sa rasters in ArcInfo Grid (Grid: bwcrpdist = bw_2005sa + feature_crpd1; output: bwcrpdist)

- RECLASSIFY bwcrpdist raster (NoData=0, all other values=100,000, output: reclass_bwcr1)

- COMBINE reclass_bwcr1 and bw_2005sa rasters in ArcInfo Grid (Grid: bwcrp1 = bw_2005sa + reclass_bwcr1; output: bwcrp1)

- CONVERT cdow_crp.shp (CRP data for Weld Co.) to raster (cell size=30, Environment: snap to raster=bw_2005sa, output: feature_cdow1)

- COMBINE feature_cdow1 and bwcrp1 rasters in ArcInfo Grid (Grid: bwcrpcdow = bwcrp1 + feature_cdow1; output: bwcrpcdow)

- RECLASSIFY bwcrpcdow raster (NoData=0, all other values=100,000, output: reclass_bwcr2)

- COMBINE reclass_bwcr2 and bwcrp1 rasters in ArcInfo Grid (Grid: bw-crp_2005sa = bwcrp1 + reclass_bwcr2; output: bw-crp_2005sa)

4. Incorporate clipped roads into basinwide-CRP layer

- CONVERT hwy_Clip_2005.shp to raster (field=ROUTE, cell size=30, Environment: snap to raster= bw-crp_2005sa, output: feature_hwy)

- COMBINE feature_hwy and bw-crp_2005sa rasters in ArcInfo Grid (Grid: bwcrphwy = bw-crp_2005sa + feature_hwy, output: bwcrphwy)

- RECLASSIFY bwcrphwy raster (NoData=0, all other values=400,000, output: reclass_bch1)

- COMBINE reclass_bch1 and bw-crp_2005sa rasters in ArcInfo Grid (Grid: bwcrprd1 = bw-crp_2005sa + reclass_bch1; output: bwcrprd1)

- CONVERT mjr_rds_Clip_2005.shp to raster (field=SURF_TYPE, cell size=30, Environment: snap to raster= bw-crp_2005sa, output: feature_mjr)

- COMBINE feature_mjr and bw-crp_2005sa rasters in ArcInfo Grid (Grid: bwcrpmjr = bw-crp_2005sa + feature_mjr; output: bwcrpmjr)

- RECLASSIFY bwcrpmjr raster (NoData=0, all other values=800,000, output: reclass_bcm1)

- COMBINE reclass_bcm1 and bwcrprd1 rasters in ArcInfo Grid (Grid: bwcrprd2 = bwcrprd1 + reclass_bcm1; output: bwcrprd2)

- select by attributes loc_rds_Clip_2005.shp where 'SURF_TYPE'=all types <u>except</u> 'NON-MAINTAINED' and 'UNIMPORVED' (sic), and EXPORT selected features to new shapefile (output: selectloc_rds_Clip_2005.shp)

- CONVERT selectloc_rds_Clip_2005.shp to raster (field=SURF_TYPE, cell size=30, Environment: snap to raster= bw-crp_2005sa, output: feature_loc)

- COMBINE feature_loc and bw-crp_2005sa rasters in ArcInfo Grid (Grid: bwcrploc = bw-crp_2005sa + feature_loc; output: bwcrploc)

- RECLASSIFY bwcrploc raster (NoData=0, all other values=1,600,000, output: reclass_bcl1)

- COMBINE reclass_bcl1 and bwcrprd2 rasters in ArcInfo Grid (Grid: bwcrprd3 = bwcrprd2 + reclass_bcl1; output: bwcrprd3)

5. Incorporate PD location data into basinwide-CRP-roads layer

a. Comanche NG colony location data

- CONVERT Comanche2003_all_colonies.shp to raster (field=COLONY_NAM, cell size=30, Environment: snap to raster= bwcrprd3, output: feature_cng1)

- RECLASSIFY (No Data = No Data, all other values=10,000, output: reclass_fcng1)

- COMBINE reclass_fcng1 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3cngr = bwcrprd3 + reclass_fcng1; output: bcr3cngr)

- RECLASSIFY bcr3cngr raster (10,021=3,200,000 (346 cells); 13,107=3,200,000 (20,511 cells); 13,304=3,200,000 (1,473 cells); all other values=0; output: reclass_bcr31 (total cells=22,330))

- COMBINE reclass_bcr31 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3pd1 = bwcrprd3 + reclass_bcr31; output: bcr3pd1)

b. Pawnee NG colony location data

i) 2004

- import png_pdog2004.e00 to coverage
- CONVERT png_pdog2004 polygon coverage to raster (field=ID, cell size=30, Environment: snap to raster= bwcrprd3, output: feature_png1)
- RECLASSIFY feature_png1 raster (No Data = No Data, all other values=10,000, output: reclass_fpng1)
- COMBINE reclass_fpng1 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3pg1r = bwcrprd3 + reclass_fpng1; output: bcr3pg1r)
- RECLASSIFY bcr3pg1r raster (10,021=6,400,000 (36 cells); 13,107=6,400,000 (7,985 cells); 13,304=6,400,000 (34 cells); all other values=0; output: reclass_bcr32 (total cells=8,055))
- COMBINE reclass_bcr32 and bcr3pd1 rasters in ArcInfo Grid (Grid: bcr3pd2 = bcr3pd1 + reclass_bcr32; output: bcr3pd2)

ii) 2003 (for towns 'plagued-out' in 2004)

- copy png_pdog2003.shp and rename pdog_png_2003_all_edit2004.shp, then delete duplicate 2004 towns using ArcMap 9.0 Editor
- COMVERT pdog_png_2003_all_edit2004.shp to raster (field=ID, cell size=30, Environment: snap to raster= bwcrprd3, output: feature_png2)
- RECLASSIFY feature_png2 raster (No Data = No Data, all other values (0) = 10,000, output: reclass_fpng2)
- COMBINE reclass_fpng2 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3pg2r = bwcrprd3 + reclass_fpng2; output: bcr3pg2r)
- RECLASSIFY bcr3pg2r raster (10,021=12,800,000 (12 cells); 13,107=12,800,000 (1,009 cells); 13,304=12,800,000 (23 cells); all other values=0; output: reclass_bcr33 (total cells=1,044))
- COMBINE reclass_bcr33 and bcr3pd2 rasters in ArcInfo Grid (Grid: bcr3pd3 = bcr3pd2 + reclass_bcr33; output: bcr3pd3)

c. CDOW aerial survey data

i) Active online colonies

- create CDOWaerial_all.xls and CDOWaerial_all.txt files which contain begin and end points for detected colonies for those 22 counties in study area (taken from All.xls)

- format text file using program R 2.0.0 script (output: CDOWaerial_all_outfile.txt)

- GENERATE polyline coverage from CDOWaerial_all_outfile.txt (output: PDaerial)

- DEFINE PROJECTION of PDaerial coverage (coordinate system=WGS 1984 UTM Zone 13N)

- PROJECT PDaerial coverage (output coordinate system=NAD 1927 UTM Zone 13N, geographic transformation=NAD 27 to WGS 84 _ 13, output: pda_Project.shp)

- CONVERT pda_Project.shp to raster (field=ID, cell size=30, Environment: snap to raster= bwcrprd3, output: feature_pda1)

- RECLASSIFY feature_pda1 raster (No Data = No Data, all other values=10,000, output: reclass_fpda1)

- COMBINE reclass_fpda1 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3pa1r = bwcrprd3 + reclass_fpda1; output: bcr3pa1r)

- RECLASSIFY bcr3pa1r raster (10,021=25,600,000 (1,254 cells); 13,107=25,600,000(19,203 cells); 13,304=25,600,000 (1,281 cells); all other values=0; output: reclass_bcr34 (total cells=21,738))

- COMBINE reclass_bcr34 and bcr3pd3 rasters in ArcInfo Grid (Grid: bcr3pd4 = bcr3pd3 + reclass_bcr34; output: bcr3pd4)

ii) Active offline colonies

- create CDOWaerial_offline.dbf containing point locations of detected colonies for those 22 counties in study area using Excel (taken from All.xls)

- CREATE FEATURE CLASS (point shapefile) from CDOWaerial_offline.dbf (output: XYCDOWaerial_offline.shp)

- DEFINE PROJECTION of XYCDOWaerial_offline.shp (coordinate system=WGS 1984 UTM Zone 13N)

- PROJECT XYCDOWaerial_offline.shp (output coordinate system=NAD 1927 UTM Zone 13N, geographic transformation=NAD 27 to WGS 84 _ 13, output: pda_offline_Project.shp)

- because conversion from point to raster would not execute, BUFFER points of pda_offline_Project.shp by 20 m (output: pda_offline_Project_Buffer.shp)**,** then EXPORT data (output: Export_pda_offline_pb.shp)

- CONVERT Export_pda_offline_pb.shp to raster (field=ID, cell size=30, Environment: snap to raster=bwcrprd3, output: feature_pda2)

- RECLASSIFY feature_pda2 raster (No Data = No Data, all other values (0) = 10,000; output: reclass_fpda2)

- COMBINE reclass_fpda2 and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3pa2r = bwcrprd3 + reclass_fpda2; output: bcr3pa2r)

- RECLASSIFY bcr3pa2r raster (10,021=51,200,000 (41 cells); 13,107=51,200,000 (312 cells); 13,304=51,200,000 (18 cells); all other values=0; output: reclass_bcr35 (total cells=371))

- COMBINE reclass_bcr35 and bcr3pd4 rasters in ArcInfo Grid (Grid: bcr3pd5 = bcr3pd4 + reclass_bcr35; output: bcr3pd5)

d. EDAW colony location data

- in ndis btpd.shp select by attributes where SOURCE = (all except PNG and CNG) and EXPORT selected features to shapefile (ouput: ndis_btpd_minusNG.shp)

- CLIP ndis_btpd_minusNG.shp to StudyArea_2005.shp (output: ndis_btpd_minusNG_2005.shp)

- copy ndis_btpd_minusNG_2005.shp and delete towns in northern Weld County which were determined extinct in Summer 2004 (output: ndis_btpd_minusNG_edit2004.shp)

- CONVERT ndis_btpd_minusNG_edit2004.shp to raster (field=source, cell size=30, Environment: snap to raster=bwcrprd3, output: feature_ndis1)

- RECLASSIFY feature_ndis1 raster (No Data = No Data, all other values=10,000, output: reclass_fndis)

- COMBINE reclass_fndis and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3ndsr = bwcrprd3 + reclass_fndis; output: bcr3ndsr)

- RECLASSIFY bcr3ndsr raster (10,021=102,400,000 (46,440 cells); 13,107=102,400,000 (329,130 cells); 13,304=102,400,000 (12,836 cells); all other values=0; output: reclass_bcr36 (total cells=388,406))

- COMBINE reclass_bcr36 and bcr3pd5 rasters in ArcInfo Grid (Grid: bcr3pd6 = bcr3pd5 + reclass_bcr36; output: bcr3pd6)

e. 2004 pilot study colony location data

For each of the 10 towns mapped by 2004 pilot study that are in 2005 study area, I attempted the following:

- format dbf file using Excel
- convert dbf file to a point shapefile using ArcView 3.2 (add table to Project, add event theme to View where X=W and Y=N, in View, Theme/Convert to shapefile)
- delete extraneous (non-PD town) points using ArcView 3.2/Theme/Edit
- create polygon shapefile from point shapefile using XTools extension ('Make one polygon from points' option) in ArcView 3.2
- union all 10 polygon shapefiles using ArcToolbox 9.0 Analysis Tools/Overlay/Union (output: pd04_poly_Union)
- transform projection, <u>but</u> did not work despite trying multiple transformation formats on polygons & points – they would disappear from view in ArcCatalog/ArcMap, so…

Because this would not work, I instead used polygons (pd_2004_techs.shp) created in ArcMap in 2004 which were based on rough estimates of colony location, size and shape by field techs. To do this…

- CONVERT pd_2004_techs.shp to raster (field=source, cell size=30, Environment: snap to raster=bwcrprd3, output: feature_pd04)

- RECLASSIFY feature_pd04 raster (No Data = No Data, all other values(1)=10,000, output: reclass_ftech)

- COMBINE reclass_ftech and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3tchr = bwcrprd3 + reclass_ftech; output: bcr3tchr)

- RECLASSIFY bcr3tchr raster (10,021=204,800,000 (496 cells); 13,107=204,800,000 (2,569 cells); 13,304=204,800,000 (34 cells); all other values=0; output: reclass_bcr37 (total cells=3,099))

- COMBINE reclass_bcr37 and bcr3pd6 rasters in ArcInfo Grid (Grid: bcr3pd7 = bcr3pd6 + reclass_bcr37; output: bcr3pd7)

f. CNHP colony location data

- CLIP btpd_cnhpdata_02_2005.shp to StudyArea_2005.shp (output: btpd_cnhp_clip_2005.shp)

- CONVERT btpd_cnhp_clip_2005.shp to raster (field=EO_NUM, cell size=30, Environment: snap to raster=bwcrprd3, output: feature_cnhp)

- RECLASSIFY feature_cnhp raster (No Data = No Data, all other values=10,000, output: reclass_fcnhp)

- COMBINE reclass_fcnhp and bwcrprd3 rasters in ArcInfo Grid (Grid: bcr3cnhr = bwcrprd3 + reclass_fcnhp; output: bcr3cnhr)

- RECLASSIFY bcr3cnhr raster (10,021=409,600,000 (2,322 cells); 13,107=409,600,000 (46,933 cells); 13,304=409,600,000 (2,617 cells); all other values=0; output: reclass_bcr38 (total cells=51, 872))

- COMBINE reclass_bcr38 and bcr3pd7 rasters in ArcInfo Grid (Grid: bcr3pd8 = bcr3pd7 + reclass_bcr38; output: bcr3pd8)

Final raster (bcr3pd8) which includes basinwide, CRP, roads (3), and prairie dog (8) data has the following values:

Land cover type	Value
Urban/Built Up	1
Agriculture Land	2
Barren	6
Water	9
Residential	11
Commercial	12
Dryland Ag	21
Irrigated Ag	22
Rock	61
Lower Montane Riparian Woodland	81
Foothill Riparian Woodland and Shrubland	82
Open water	1011
Comm/Ind/Transportation	1023
Bare rock/Sand/Clay	1031
Transitional	1033
Forest - Deciduous	1041
Forest - Evergreen	1042
Shrubland	1051
Grasslands	1071
Agr - Pasture/hay	1081

…table continued

…table continued

Land cover type	Value
Agr - Row crops	1082
Agr - small grains	1083
Agr - fallow	1084
Wetland - woody	1091
Wetlands - herbaceous	1092
Lower Montane-Foothills Shrubland	3102
Mid-grass Prairie	3106
Shortgrass Prairie	3107
Sand Dune and Swale Complex	3108
Sagebrush Shrubland	3201
Salt Desert Shrubland	3209
Grass/Misc. Cactus Mix	3304
Pinyon-Juniper Woodland	4101
Juniper Savanna	4102
Gambel's Oak/Serviceberry Shrubland	4201
Ponderosa Pine Woodland	5201
Douglas Fir-Ponderosa Pine Forest	5203
Subalpine/Montane Riparian Shrubland	8103
CRP	100,000 < y < 200,000
DOD	200,000 <y < 400,000
Highway	400,000 < y < 800,000
Major road	800,000 < y < 1,600,000
Local road	1,600,000 < y < 3,200,000
PD Comanche	3,200,000 < y < 6,400,000
PD Pawnee 2004	6,400,000 < y < 12,800,000
PD Pawnee 2003	12,800,000 < y < 25,600,000
PD aerial online	25,600,000 < y < 51,200,000
PD aerial offline	51,200,000 < y < 102,400,000
PD EDAW edited	102,400,000 < y <204,800,000
PD 04 pilot study/techs	204,800,000 < y <409,600,000
PD CNHP	409,600,000 < y < 819,200,000

6. Edit Study Area

- in counties.shp, select by attributes where FID=14 (Adams County) or 20 (Arapahoe County), and EXPORT selected data (output: Adams_Arapahoe.shp)

- ERASE Adams_Arapahoe.shp from StudyArea_2005.shp (output: StudyArea_05_final.shp)

- CONVERT StudyArea_05_final.shp to coverage (output: sa05_final)

- GRIDCLIP bcr3pd8 raster to new study area (sa05_final) in ArcInfo Grid (Grid: GRIDCLIP bcr3pd8 bcr3pd8_f COVER sa05_final; output: bcr3pd8_f)

B. Sampling Frame & Spatially Balanced Sampling

1. GRIDCLIP bcr3pd8_f raster to reduce grid size for use with sampling tool – reduces output file size (Arc: GRIDCLIP bcr3pd8_f landcvr_05 540000 4090000 770000 4550000; output: landcvr_05). In landcvr_05 raster, there are 18,374,650 cells classified as dry ag (value 21), 43,015,233 cells classified as grassland (values 3107, 3304), and 485,681 cells classified as prairie dog (values > 3,200,000).

2. Prairie dog colony sampling frame and SBS
Prairie dog plots were defined as a 500-m × 500-m area centered on any 30-m grid cell containing the 'prairie dog' land cover type (values >3,200,000) and overlaying grassland (values 3107 and 3304) or dryland agriculture (value 21) vegetative cover types. **(No neighborhood requirement.)**

- create new PD-only raster (pd_05) using ArcMap 9.0 Raster Calculator, (pd_05 = CON ([landcvr_05] >= 3200000 , 1 , 0)

- RECLASSIFY pd_05 raster (0=NoData, 1=1, output: reclass_pd_05)

- GRIDCLIP reclass_pd_05 raster in ArcInfo Arc (Arc: GRIDCLIP reclass_pd_05 pd2005 540000 4090000 770000 4550000; output: pd2005)

- run spatially balanced sample tool (Theobald 2004) on pd2005 raster (output folder w/sbs_1 raster renamed SBS_PD_05)

- CONVERT sbs_1 raster to polygon shapefile (output: sbs_pd_05.shp (485,681 polygons))

- in sbs_pd_05.shp attribute table, add columns (SBS_ORDER, CENTROID_X, CENTROID Y, NW_X, NW_Y, NE_X, NE_Y, SE_X, SE_Y, SW_X, SW_Y) and calculate centroids (using ESRI VBA scripts) and plot vertices; sort by GRIDCODE, find record #600 (GRIDCODE=335,630)

- in sbs_pd_05.shp, select by attributes where GRIDCODE<= 335,630, and EXPORT data (output: sbs_pd600_05.shp)

- in sbs_pd600_05.dbf (using Excel), sort data by GRIDCODE and assign SBS_ORDER (1-600), **resort by ID** and save again as dbf; then sort by SBS_ORDER and save as sbs_pd600_05_polyinfile.txt

- in TextPad, delete extraneous info (only need coordinates of four vertices) and save

- format R script (script_05.R) with correct in and out file names and save

- in program R, change directory to workspace with R script file and sbs_pd600_05_polyinfile.txt and run script (command line: source("script_05.R"); output: sbs_pd600_05_polyoutfile.txt)

- in TextPad, delete extraneous info (numbers along left side) and add final line ("END") and save

- GENERATE preliminary polygon coverage from sbs_pd600_05_polyoutfile.txt (output: sbspd600_05) (NOTE: an additional tool (BUILD or CLEAN) is needed to build polygon topology)

3. Dryland agriculture sampling frame and SBS

Dryland agriculture plots were defined as a 500-m × 500-m (25 ha) area centered on any 30-m grid cell having **100% of the specified neighborhood in dryland ag** (value 21). Neighborhood was defined as a 17-cell × 17-cell square (equal to a 510-m × 510-m area).

- create new dry-ag-only raster (dryag_05) using ArcMap 9.0 Raster Calculator (dryag_05 = CON ([landcvr_05] == 21 , 1 , 0))

- calculate focal mean of cells in dryag_05 raster using ArcMap 9.0 Raster Calculator (ag05_fmean = FOCALMEAN ([dryag_05] , RECTANGLE , 17 , 17 , NODATA))

- reclassify ag05_fmean raster using ArcMap 9.0 Raster Calculator (ag05fm_1 = CON ([ag05_fmean] == 1 , 1 , 0))

- RECLASSIFY ag05fm_1 raster (0=No Data, 1=1, output: r_ag05fm1 (1,502,822 cells))

- GRIDCLIP r_ag05fm1 raster in ArcInfo Arc (Arc: GRIDCLIP r_ag05fm1 ag2005 540000 4090000 770000 4550000; output: ag2005)

- run spatially balanced sampling tool on ag2005 raster (output folder w/sbs_1 raster renamed SBS_AG_05)

- CONVERT sbs_1 raster to shapefile (output: sbs_ag_05.shp (1,502,822 polygons))

- in sbs_ag_05.shp attribute table, add columns, calculate centroids and plot vertices, sort by GRIDCODE, find record #600 (GRIDCODE=100,965)

- select by attributes (GRIDCODE <= 100,965) and EXPORT data (output: sbs_ag600_05.shp)

- in sbs_ag600_05.dbf (using Excel) sort by GRIDCODE and assign SBS_ORDER (1-600), resort by ID, save as dbf file

- resort by SBS_ORDER and save as text file (sbs_ag600_05_polyinfile.txt)

- in TextPad, delete extra info from sbs_ag600_05_polyinfile.txt

- format R script and run in program R (output: sbs_ag600_05_polyoutfile.txt)

- in TextPad, delete extra info from sbs_ag600_05_polyoutfile.txt and add "END" to final line, save

- GENERATE preliminary polygon coverage from sbs_ag600_05_polyoutfile.txt (output: sbsag600_05)

4. Grassland sampling frame and SBS

Grassland plots were defined as a 500-m × 500-m (25 ha) area centered on any 30-m grid cell having **100% of the specified neighborhood in grassland** (values 3107 and 3304). Neighborhood was defined as a 17-cell × 17-cell square (equal to a 510-m × 510-m area).

- RECLASSIFY landcvr_05 raster (3107=1, 3304=1, all other values=0, output: grass_05)

- calculate focal mean of cells in grass_05 raster using ArcMap 9.0 Raster Calculator (grs05_fmean = FOCALMEAN ([grass_05] , RECTANGLE , 17 , 17 , NODATA))

- reclassify grs05_fmean raster using ArcMap 9.0 Raster Calculator (grs05fm_1 = CON ([grs05_fmean] == 1 , 1 , 0))

- RECLASSIFY grs05fm_1 raster (0=No Data, 1=1, output: r_grs05fm1 (7,041,550 cells))

- GRIDCLIP r_grs05fm1 raster in ArcInfo Arc (Arc: GRIDCLIP r_grs05fm1 grass2005 540000 4090000 770000 4550000; output: grass2005)

- run spatially balanced sample tool on grass2005 raster (output folder w/sbs_1 raster renamed SBS_GRASS_05)

- CONVERT sbs_1 raster to shapefile (output: sbs_grass_05.shp (7,041,550 polygons))

- in sbs_grass_05.shp attribute table, add columns, calculate centroids and plot vertices, sort by GRIDCODE, find record #600 (GRIDCODE=21,313)

- select by attributes (GRIDCODE <= 21,313) and EXPORT data (output: sbs_grass600_05.shp)

- in Excel, in sbs_grass600_05.dbf, sorted by GRIDCODE and assign SBS_ORDER (1-600), resorted by ID, saved as dbf file

- resort by SBS_ORDER and save as text file (sbs_grass600_05_polyinfile.txt)

- in TextPad, delete extra info from sbs_grass600_05_polyinfile.txt

- format R script and run in program R (output: sbs_grass600_05_polyoutfile.txt)

- in TextPad, delete extra info from sbs_grass600_05_polyoutfile.txt and add "END" to final line, save

- GENERATE preliminary polygon coverage from sbs_grass600_05_polyoutfile.txt (output: sbsgrs600_05)

C. Obtaining Covariate Data

1. Digitize prairie dog colonies

a. Download digital aerial photography

b. Determine surveyed plots in GIS

- from Access database, create file of plots surveyed in 2005 (output: surveyed2005.dbf)

- from surveyed2005.dbf, copy plot vertices and save in TextPad as surveyed2005_plot_polyinfile.txt

- format R script and run in program R (output: surveyed2005_plot_polyoutfile.txt)

- in TextPad, delete extra info from surveyed2005_plot_polyoutfile.txt and add "END" to final line, save

- GENERATE preliminary polygon coverage from surveyed2005_plot_polyoutfile.txt (output: splots05)

- CONVERT splots05 to shapefile (output: plotbounds_s05.shp)

- CREATE FEATURE CLASS (point shapefile) from surveyed2005.dbf (output: XYsurveyed2005.shp)

- to provide visual reference and assist with digitizing PD colonies, PROJECT plotbounds_s05.shp and XYsurveyed2005.shp (output coordinate system=NAD 1983 UTM Zone 13N, geographic transformation=NAD_1927_To_NAD_1983_NADCON, output: plotbounds_s05_n83.shp, XYsurveyed2005_n83.shp)

b. Create 2250 m square "buffer" around each surveyed plot

- from surveyed2005.dbf, copy 2250 buffer vertices and save in TextPad as surveyed2005_b2250_polyinfile.txt

- format R script and run in program R (output: surveyed2005_b2250_polyoutfile.txt)

- in TextPad, delete extra info from surveyed2005_b2250_polyoutfile.txt and add "END" to final line, save

- GENERATE preliminary polygon coverage from surveyed2005_b2250_polyoutfile.txt (output: 2250buffer)

- CLEAN preliminary 2250buffer polygon coverage (dangle length=0.127, fuzzy tolerance=4.3162, output: 2250buffer_c)

- in 2250buffer_c coverage, add column named 'Dissolve' and set all equal to '1'

- DISSOLVE 2250buffer_c coverage (dissolve item=Dissolve, output: 2250buffer_cd)

- CONVERT 2250buffer_cd to shapefile (output: 2250buffer.shp)

- DEFINE PROJECTION of 2250buffer.shp (coordinate system=NAD 1927 UTM Zone 13N)

- PROJECT 2250buffer.shp (output coordinate system=NAD 1983 UTM Zone 13N, geographic transformation=NAD_1927_To_NAD_1983_NADCON, output: 2250buffer_n83.shp)

- copy 2250buffer_n83.shp and rename PDhabitat_to_2250frplot_n83.shp

c. Digitize PD colonies within each 2250 m square buffer

- for each plot, print out GIS map of plot/buffer and aerial

- in GIS, systematically scan area at 1:5000 scale searching for PD

- when PD found, follow limit of burrows and map on paper copy

- rules for pd delineation:
    - burrow size and appearance: halo-like appearance but not too indistinct – often bright white; distinctness of burrows differs depending on veg cover and exposure/quality of aerial photography, so I use groundtruthed data (plot & 500 m buffer) as a reference for delineating/determining active/recently active PD vs. old pd and ant mounds
    - burrow distribution: individual burrows somewhat clustered and irregular; tight groupings with regular spacing and small light spots NOT delineated as PD
    - boundary delineation: typically determined by outermost burrows, except when distinct veg difference exists between colony and surrounding area; when defining boundary in area of sparse burrows, 'split the difference'
    - burrow-like appearance in ACTIVE ag (i.e., obvious rows) NOT delineated as PD

- complete 'paper delineations' for a county, then digitize in GIS at 1:5000 scale by editing PDhabitat_to_2250frplot_n83.shp (CUT POLYGON, and assign habitat attribute in table)

- after digitization complete, in PDhabitat_to_2250frplot_n83.shp select pd habitat by attribute and EXPORT (output: PDhabitat_to2250frplot_export_n83.shp)

- PROJECT PDhabitat_to2250frplot_export_n83.shp (output coordinate system=NAD 1927 UTM Zone 13N, geographic transformation=NAD_1927_To_NAD_1983_NADCON, output: PDhabitat_to2250frplot_export_n27.shp)

- CONVERT PDhabitat_to2250frplot_export_n27.shp to raster (field = Habitat, cell size = 30, Environment: snap to raster = landcvr_05, output: feature_pd05 (299,439 cells))

2. Calculate amount and % of PD habitat at 3 scales (a plot plus its 500-m, 1500-m, or 2250-m rounded buffer) – from polygon data

- JOIN plotbounds_s05.shp with XYsurveyed2005.shp (output: JOIN_plotbounds_XYsurveyed_05.shp)

- BUFFER JOIN_plotbounds_XYsurveyed_05.shp at three distances – 500, 1500, 2250 m (output: BUF500_ JOIN_plotbounds_XYsurveyed_05.shp, BUF1500_ JOIN_plotbounds_XYsurveyed_05.shp, BUF2250_ JOIN_plotbounds_XYsurveyed_05.shp)

- INTERSECT PDhabitat_to2250frplot_export_n27.shp with joined plot layer (JOIN_plotbounds_XYsurveyed_05.shp) and 3 buffer layers from previous step (output: INT_plot_PD_s05.shp, INT_BUF500_PD_s05.shp, INT_ BUF1500_PD_s05.shp, INT_ BUF2250_PD_s05.shp)

- in INT_plot_PD_s05.shp, add columns and calculate area of PD and % PD (PDarea/PLOTarea)

- DISSOLVE on plot number for intersected buffer layers – resulting output has 1 record per plot, may have multiple polygons per record (output: DIS_INT_BUF500_PD_s05.shp, DIS_INT_ BUF1500_PD_s05.shp, DIS_INT_ BUF2250_PD_s05.shp)

- for each of these layers, add columns and calculate PD area and %

- JOIN files INT_plot_PD_s05.shp, DIS_INT_BUF500_PD_s05.shp, DIS_INT_ BUF1500_PD_s05.shp, and DIS_INT_ BUF2250_PD_s05.shp to JOIN_plotbounds_XYsurveyed_05.shp, and EXPORT joined table (output: Export_JOIN_PDfeature_s05.dbf)

3. Calculate amount and % of all habitat types (incl. grassland) at 3 scales (a plot plus its 500-m, 1500-m, or 2250-m rounded buffer) – from raster data

a. Clip basinwide around surveyed plots

- from surveyed2005.dbf, copy 2500 buffer vertices and save in TextPad as surveyed2005_b2500forcombine_polyinfile.txt

- format R script and run in program R (output: surveyed2005_b2500forcombine _polyoutfile.txt)

- in TextPad, delete extra info from surveyed2005_b2500forcombine _polyoutfile.txt and add “END” to final line, save

- GENERATE preliminary polygon coverage from surveyed2005_b2500forcombine _polyoutfile.txt (output: 2500buffer)

- CLEAN preliminary 2500buffer polygon coverage (dangle length = 0.127, fuzzy tolerance = 4.3162, output: 2500buffer_c)

- DISSOLVE 2500buffer_c coverage (output: 2500buffer_cd)

- CONVERT 2500buffer_cd to raster in ArcInfo Grid (Grid: 2500buf = POLYGRID(2500buffer_cd, # , # , # , 30); output: 2500buf)

- COMBINE 2500buf and es_nlcd_cop rasters in ArcInfo Grid (Grid: 2500buf_bw = es_nlcd_cop + 2500buf; output: 2500buf_bw)

- RECLASSIFY 2500buf_bw raster (NoData = NoData, all other values = 0, output: reclass_bufbw)

- COMBINE reclass_bufbw and es_nlcd_cop rasters in ArcInfo Grid (Grid: bw_2500buf = es_ncld_cop + reclass_bufbw; output:bw_2500buf)

b. Incorporate digitized PD into clipped basinwide

- COMBINE feature_pd05 and bw_2500buf rasters in ArcInfo Grid (Grid: bw_pd_buf = bw_2500buf + feature_pd05; output: bw_pd_buf)

- RECLASSIFY bw_pd_buf raster (NoData = 0, all other values = 10,000, output: rcls_bwpdbuf)

- COMBINE rcls_bwpdbuf and bw_2500buf rasters in ArcInfo Grid (Grid: habitat_s05 = bw_2500buf + rcls_bwpdbuf; output: habitat_s05)

- RECLASSIFY habitat_s05 raster (≥10,000 = 10,000, 3304 = 3107, all other values remain the same, output: habitat_s05r)

- CONVERT habitat_s05r raster to shapefile (output: habitat_s05r.shp)

c. Clip PD-basinwide layer to round buffers and calculate areas

- INTERSECT habitat_s05r.shp with joined plot (JOIN_plotbounds_XYsurveyed_05.shp) and buffer layers (BUF500_JOIN_plotbounds_XYsurveyed_05.shp, BUF1500_JOIN_plotbounds_XYsurveyed_05.shp, BUF2250_JOIN_plotbounds_XYsurveyed_05.shp) (output: INT_plot_hab_s05_raw.shp, INT_BUF500_hab_s05.shp, INT_BUF1500_hab_s05.shp, INT_BUF2250_hab_s05.shp)

- Check for discrepancies in INT_plot_hab_s05_raw.shp (make sure ag and grassland plots are 100% of respective stratum) and correct (output: INT_plot_hab_s05_edit.shp)

- DISSOLVE plot files (output: DIS_INT_plot_hab_s05_raw.shp, DIS_INT_plot_hab_s05_edit.shp)

- EXPORT edited plots from DIS_INT_plot_hab_s05_edit.shp (output: Export_DIS_INT_plot_hab_s05_raw.shp, Export_DIS_INT_plot_hab_s05_edit.shp; see also Export_Plot_hab_s05_edited.dbf)

- DISSOLVE buffer files (output: DIS_INT_BUF500_hab_s05.shp, DIS_INT_BUF1500_hab_s05.shp, DIS_INT_BUF2250_hab_s05.shp)

- INTERSECT joined buffer layers (BUF500_ JOIN_plotbounds_XYsurveyed_05.shp, BUF1500_ JOIN_plotbounds_XYsurveyed_05.shp, BUF2250_ JOIN_plotbounds_XYsurveyed_05.shp) with exported edited plot files (Export_DIS_INT_plot_hab_s05_raw.shp, Export_DIS_INT_plot_hab_s05_edit.shp) (output: INT_BUF500_ExportPlotHabRaw_s05.shp, INT_BUF500_ExportPlotHabEdits_s05.shp, INT_BUF1500_ExportPlotHabRaw_s05.shp, INT_BUF1500_ExportPlotHabEdits_s05.shp, INT_BUF2250_ExportPlotHabRaw_s05.shp, INT_BUF2250_ExportPlotHabEdits_s05.shp)

- DISSOLVE intersected buffer files from previous step (output: DIS_INT_BUF500_ExportPlotHabRaw_s05.shp, DIS_INT_BUF500_ExportPlotHabEdits_s05.shp, DIS_INT_BUF1500_ExportPlotHabRaw_s05.shp, DIS_INT_BUF1500_ExportPlotHabEdits_s05.shp, DIS_INT_BUF2250_ExportPlotHabRaw_s05.shp, DIS_INT_BUF2250_ExportPlotHabEdits_s05.shp)

- in dissolved buffer files from previous step, add columns and calculate AREA and PLOT_HAB fields

- for each buffer, JOIN dissolved buffer file from previous step with DIS_INT_BUFxxx_hab_s05.shp, and EXPORT joined table as dbf (output: Export_JOIN_BUF500_hab_s05_AreaAdjustment.dbf, Export_JOIN_BUF1500_hab_s05_AreaAdjustment.dbf, Export_JOIN_BUF2250_hab_s05_AreaAdjustment.dbf)

D. Determine Habitat Acreage in Study Area (for Extrapolation)

1. Obtain estimates of prairie dog colonies (using county acreage from White et al. 2005)

- for counties partially surveyed, determine % of county surveyed using GIS and calculate PD acreage in study area:

  Weld: 48.2595% surveyed × 21,302 ha PD in county= 10,280 ha PD in study area
  Elbert: 69.4746% surveyed × 1,719 ha = 1,194 ha PD in study area
  El Paso: 17.2690% surveyed × 6,739 ha = 1,164 ha PD in study area
  Pueblo: 10.4754% surveyed × 18,406 ha = 1,929 ha PD in study area
  Las Animas: 44.4717% surveyed × 13,132 ha = 5,840 ha PD in study area

- add to total area for remaining 15 counties (165,246 ha) = 185,653 ha PD in study area

2. Obtain estimates for grassland and dry agriculture

- CLIP bw_2005sa raster to edited study area (see Step A.6) (output: bw_2005sar) and calculate acreage:

  Grassland (values 3107, 3304) = 45,798,444 cells = 4,121,859.96 ha
  Dry ag (value 21) = 19,624,415 cells = 1,766,197.35 ha

- estimate percent of PD which overlaps other habitat types using digitized data (under assumption that PD-veg relationship in digitized area is representative of study area):

  83.57% of digitized PD overlaps grassland (basinwide data) = 155,150 ha
  3.12% of digitized PD overlaps dry ag (basinwide data) = 5,792 ha
  (13.31% of digitized PD overlaps other habitat types (basinwide data))

- adjust grassland and dry ag acreage for PD overlap; final acreages:

  Grassland = 4,121,859.96 – 155,150 = 3,966,710 ha
  Dry ag = 1,766,197.35 – 5,792 = 1,760,405 ha
  PD = 185,653 ha

ARCINFO/ARCGIS PROCEDURES

- BUFFER – ArcToolbox 9.0 Analysis Tools/Proximity/Buffer
- BUILD – ArcToolbox 9.0 Coverage Tools/Data Management/Topology/Build
- CLEAN – ArcToolbox 9.0 Coverage Tools/Data Management/Topology/Clean
- CLIP – ArcToolbox 9.0 Analysis Tools/Extract/Clip
- COMBINE – ArcINFO Grid: [outputraster] = [inputraster1] + [inputraster2]
- CONVERT – ArcToolbox 9.0 Conversion Tools/To Coverage/Feature to Coverage
- CONVERT – ArcToolbox 9.0 Conversion Tools/To Raster/Feature to Raster
- CREATE FEATURE CLASS – ArcCatalog 9.0/Create Feature Class/From XY Table
- CUT POLYGON – ArcGIS 9.0 Editor/Cut polygon feature
- DEFINE PROJECTION – ArcToolbox 9.0 Data Management Tools/Projections and Transformations/Define Projection
- DISSOLVE – ArcToolbox 9.0 Data Management Tools/Generalization/Dissolve
- ERASE – ArcToolbox 9.0 Analysis Tools/Overlay/Erase
- EXPORT – ArcMap 9.0 Export Data/Selected Features OR All Features
- GENERATE – ArcToolbox 9.0 Coverage Tools/Conversion/To Coverage/Generate
- GRIDCLIP – ArcINFO Grid: GRIDCLIP [inputraster] [outputraster] COVER [inputcoverage]
- IMPORT – ArcToolbox 9.0
- INTERSECT – ArcToolbox 9.0 Analysis Tools/Overlay/Intersect (order matters!)
- JOIN – ArcToolbox 9.0 Data Management Tools/Joins/Add Join
- MOVE FEATURE – ArcGIS 9.0 Editor/Move feature
- PROJECT – ArcToolbox 9.0 Data Management Tools/Projections and Transformations/Feature/Project
- RECLASSIFY – ArcToolbox 9.0 Spatial Analyst/Reclass/Reclassify
- UNION – ArcToolbox 9.0 Analysis Tools/Overlay/Union

SCRIPTS

1. Calculate area of polygon

Pre-Logic VBA Script Code =

```
Dim dblArea as double
Dim pArea as IArea
Set pArea = [shape]
dblArea = pArea.area
```

Variable = dblArea

2. Calculate centroid of polygon

Pre-Logic VBA Script Code =

```
Dim dblY As Double
Dim pArea As IArea
Set pArea = [Shape]
dblY = pArea.Centroid.Y
```

Variable = dblY

3. Program R 2.0.0 script (written by Jeff Tracy, CSU)

```
dat <- read.table("surveyed2005_b2500forcombine_polyinfile.txt", header=F)

nr <- nrow(dat)
nc <- ncol(dat)
total_vals <- nr*nc;
print(paste("num rows =", nr, "; num columns =", nc), quote=F)
print(dat[1,])

sink("surveyed2005_b2500forcombine_polyoutfile.txt")
for(i in 1:nr) {
	print(i, quote=F)
	for(j in 1:(nc/2)) {
		x.ind <- 2*(j-1)+1;
		y.ind <- 2*(j-1)+2;
		print(paste(dat[i,x.ind],",",dat[i,y.ind]), quote=F)
	}
	print("END", quote=F)
}
sink()
```

DATASETS

"Basinwide" data (es_nlcd_cop raster): 30-m data; from Dave Theobald (CSU; October 2004); NAD 1927 UTM Zone13N (within study area). Ecological systems of Colorado were classified by the CDOW and BLM using Landsat TM imagery from spring and fall dates of the years 1993-1995. The CDOW/BLM's Basinwide dataset was then reclassified to combine the 100 or so classes into ecological classes roughly based on Rondeau's Southern Rocky Ecological Systems publication. The basinwide mosaic was corrected to fill in gaps created at the seams of the watersheds in the original basinwide data. The NLCD data for nearby surrounding states were also added to these data.

CDOT statewide geographic data set (including county and road data): downloaded from <http://www.dot.state.co.us/App_DTD_DataAccess/GeoData/index.cfm?fuseaction=GeoDataMain>; NAD 1927 UTM Zone 13N (within study area).

Conservation Reserve Program data:

> **crpdist.shp:** from Seth McClean (CDOW Colorado Springs; October 2004); NAD 1927 UTM Zone 13N; hand digitized with LandSat imagery and FSA-drawn boundary; dated 2000. Polygon data representing CRP field locations for portions of eastern Colorado.
>
> **cdow_crp.shp:** from Stu McFarland (NRCS Greeley office; April 2004); NAD 1927 UTM Zone 13N. Polygon data representing CRP field locations for Weld County, Colorado.

Prairie dog colony data:

> **All.xls (raw CDOW aerial data):** from Jon Kindler (CDOW Fort Collins; October 2004); WGS 84 UTM Zone 13N. Begin/end transect point data from 2002 aerial survey of prairie dog colonies in eastern Colorado (White et al. 2005).
>
> **btpd_cnhpdata_02_2005.shp:** from Michael Menefee (CNHP Fort Collins; February 2005); NAD 1927 UTM Zone 13N. Polygon data representing prairie dog colony locations in eastern Colorado.
>
> **Comanche2003_all_colonies.shp:** from Geri Mason (USFS CNG; November 2004); NAD 1927 UTM Zone 13N. Polygon data representing prairie dog colony locations on the Comanche National Grassland. Colonies were mapped on the national grasslands between late May and early August 2003. A hand-held Trimble GeoExplorer3 GPS unit was used to obtain positional readings every second.

ndis btpd.shp: from Natural Diversity Information Source, CDOW; downloaded from <http://ndis.nrel.colostate.edu/ftp/ftp_response.asp>; November 2004; NAD 1927 UTM Zone 13N. Polygon data representing prairie dog colony locations in eastern Colorado compiled from multiple sources including EDAW, Inc. (2000), the Colorado Bird Observatory (2000), the City of Ft. Collins (2000), and the U.S. Fish and Wildlife Service (1999).

png_pdog2003.shp: from Mary Hattis (USFS PNG; April 2004); NAD 1927 UTM Zone 13N. Polygon data representing prairie dog colony locations on the Pawnee National Grassland (excludes colonies on the Central Plains Experimental Range).

png_pdog2004.e00: from Mary Hattis (USFS PNG; November 2004); NAD 1927 UTM Zone 13N. Polygon data representing prairie dog colony locations on the Pawnee National Grassland (excludes colonies on the Central Plains Experimental Range).

Digital aerial photography: downloaded from <ftp://rockyftp.cr.usgs.gov/ngtoc/colo_naip/>; March 2005; NAD 1983 UTM Zone 13N. These are 2005 Colorado NAIP compressed county mosaics. The compression ratio is 15:1. The imagery is natural color, one meter GSD to NAIP specs.

LITERATURE CITED

Theobald, D. T. 2004. GIS - RRQRR: Spatially balanced sampling tool. ArcGIS v.9.0 extension. Language: Python. Operating System: Windows XP. Software Application ESRI ArcGIS v.9.0. Colorado State University, Fort Collins, Colorado, USA.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265-272.

COMPREHENSIVE LITERATURE CITED

Agnew, W., D. W. Uresk, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. Journal of Range Management 39:135-139.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Barko, V. A., J. H. Shaw, and D. M. Leslie. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwestern Naturalist 44:484-489.

Beason, R. C. 1995. Horned Lark (*Eremophila alpestris*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 195. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies - mammals. Pages 149-166 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Borchers, D. L., S. T. Buckland, and W. Zucchini. 2002. Estimating Animal Abundance - Closed Populations. Springer, New York, New York, USA.

Brennan, L. A., and W. P. Kuvlesky. 2005. North American grassland birds: An unfolding conservation crisis? Journal of Wildlife Management 69:1-13.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: Initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152.

Brown, N. L. 2001. The howdy owls of Arizona: A review of the status of *Athene cunicularia*. Journal of Raptor Research 35:344-350.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling - Estimating Abundance of Biological Populations. Oxford University Press, Oxford, UK.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference - A Practical Information-Theoretic Approach. Springer, New York, New York, USA.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1-202.

Butts, K. O. 1973. Life history and habitat requirements of burrowing owls in western Oklahoma. Thesis, Oklahoma State University, Stillwater, Oklahoma, USA.

Colorado Division of Wildlife. 2003. Colorado Vegetation Classification Project. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Colorado Division of Wildlife. 2003. Conservation Plan for Grassland Species in Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Conway, C. J., and J. C. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501-511.

Corn, P. S., and C. R. Peterson. 1996. Prairie legacies - amphibians and reptiles. Pages 125-134 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Cunningham, M. A., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Applications 16:1062-1075.

Davis, S. K. 2004. Area sensitivity in grassland passerines: Effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. Auk 121:1130-1145.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, M. P. Nenneman, and B. R. Euliss. 2003. Effects of management practices on grassland birds: Mountain Plover. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, P. A. Rabie, and B. R. Euliss. 2003. Effects of management practices on grassland birds: Burrowing Owl. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between burrowing owl and black-tailed prairie dog declines: A 7 year analysis. Journal of Wildlife Management 64:1067-1075.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. Canadian Journal of Zoology-Revue Canadienne de Zoologie 73:1375-1379.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2003. Annual survival and population estimates of mountain plovers in southern Phillips County, Montana. Ecological Applications 13:1013-1026.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2005. Mountain plover population responses to black-tailed prairie dogs in Montana. Journal of Wildlife Management 69:1546-1553.

Dreitz, V. J. 2005. Resolving conflicts of Mountain Plovers (*Charadrius montanus*) breeding on agricultural lands in Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado, USA.

Dreitz, V. J., P. M. Lukacs, and F. L. Knopf. 2006. Monitoring low density avian populations: an example using Mountain Plover. Condor 108:700-706.

Dreitz, V. J., M. B. Wunder, and F. L. Knopf. 2005. Movements and home ranges of Mountain Plovers raising broods in three Colorado landscapes. Wilson Bulletin 117:128-132.

Dunning, J. B., Jr., R. K. Bowers, Jr., S. J. Suter, and C. E. Bock. 1999. Cassin's Sparrow (*Aimophila cassinii*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 471. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

EDAW Inc. 2000. Black-tailed prairie dog study of eastern Colorado. Prepared for the Colorado Department of Natural Resources, Denver, Colorado, USA.

Fletcher, R. J., and R. R. Koford. 2002. Habitat and landscape associations of breeding birds in native and restored grasslands. Journal of Wildlife Management 66:1011-1022.

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. Bioscience 51:625-632.

Gervais, J. A., and R. G. Anthony. 2003. Chronic organochlorine contaminants, environmental variability, and the demographics of a burrowing owl population. Ecological Applications 13:1250-1262.

Gervais, J. A., D. K. Rosenberg, and R. G. Anthony. 2003. Space use and pesticide exposure risk of male burrowing owls in an agricultural landscape. Journal of Wildlife Management 67:155-164.

Goodwin, H. T. 1995. Pliocene-Pleistocene biogeographic history of prairie dogs, Genus *Cynomys* (*Sciuridae*). Journal of Mammalogy 76:100-122.

Grant, R. A. 1965. The Burrowing Owl in Minnesota. Loon 37:2-17.

Graul, W. D. 1973. Breeding adaptations of the mountain plover (*Charadrius montanus*). Dissertation, University of Minnesota, St. Paul, Minnesota, USA.

Graul, W. D. 1975. Breeding biology of the Mountain Plover. Wilson Bulletin 87:6-31.

Graul, W. D., and L. E. Webster. 1976. Breeding status of Mountain Plover. Condor 78:265-267.

Haire, S. L., C. E. Bock, B. S. Cade, and B. C. Bennett. 2000. The role of landscape and habitat characteristics in limiting abundance of grassland nesting songbirds in an urban open space. Landscape and Urban Planning 48:65-82.

Hamer, T. L., C. H. Flather, and B. R. Noon. 2006. Factors associated with grassland bird species richness: the relative roles of grassland area, landscape structure, and prey. Landscape Ecology 21:569-583.

Hanni, D. 2002. A comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Hanni, D. 2003. Section-based monitoring of breeding birds in eastern Colorado. Rocky Mountain Bird Observatory and Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington, D.C., USA.

Haug, E. A., and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of burrowing owls in Saskatchewan. Journal of Wildlife Management 54:27-35.

Hines, J. E. 2006. Program PRESENCE v 2.0. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA. Online at <http://www.mbr-pwrc.usgs.gov/software/presence.html>.

Holroyd, G. L., R. Rodriguez-Estrella, and S. R. Sheffield. 2001. Conservation of the Burrowing Owl in western North America: Issues, challenges, and recommendations. Journal of Raptor Research 35:399-407.

Huggins, R. M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133-140.

Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. Biometrics 47:725-732.

Hughes, A. J. 1993. Breeding density and habitat preference of the burrowing owl in northeastern Colorado. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Hutto, R. L., and J. S. Young. 2002. Regional landbird monitoring: Perspectives from the northern Rocky Mountains. Wildlife Society Bulletin 30:738-750.

Hutto, R. L., and J. S. Young. 2003. On the design of monitoring programs and the use of population indices: A reply to Ellingson and Lukacs. Wildlife Society Bulletin 31:903-910.

Johnson, D. H., and L. D. Igl. 2001. Area requirements of grassland birds: A regional perspective. Auk 118:24-34.

Jones, S. R. 1998. Burrowing Owl. Pages 220-221 *in* H. E. Kingery, editor. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership, Denver, Colorado, USA.

Kantrud, H. A., and R. L. Kologiski. 1983. Avian associations of the northern Great Plains grasslands. Journal of Biogeography 10:331-350.

Kingery, H. E., editor. 1998. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership, Denver, Colorado, USA.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

Knopf, F. L. 1996. Mountain Plover (*Charadrius montanus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 211. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Knopf, F. L. 1996. Prairie legacies - birds. Pages 135-148 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Knopf, F. L., and B. J. Miller. 1994. *Charadrius montanus* - montane, grassland, or bare-ground plover? Auk 111:504-506.

Knopf, F. L., and J. R. Rupert. 1995. Habits and habitats of Mountain Plovers in California. Condor 97:743-751.

Knopf, F. L., and J. R. Rupert. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

Knopf, F. L., and J. R. Rupert. 1999. The use of crop fields by breeding Mountain Plovers. Studies in Avian Biology 19:81-86.

Knowles, C. 1998. Availability of black-tailed prairie dog habitat for black-footed ferret recovery. Unpublished final report to U.S. Fish and Wildlife Service.

Knowles, C. J., C. J. Stoner, and S. P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

Korfanta, N. M., L. W. Ayers, S. H. Anderson, and D. B. McDonald. 2001. Preliminary assessment of Burrowing Owl population status in Wyoming. Journal of Raptor Research 35:337-343.

Kotliar, N. B., B. W. Baker, A. D. Whicker, and G. Plumb. 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental Management 24:177-192.

Kretzer, J. E., and J. F. Cully. 2001. Effects of black-tailed prairie dogs on reptiles and amphibians in Kansas shortgrass prairie. Southwestern Naturalist 46:171-177.

Kuenning, R. R., and H. E. Kingery. 1998. Mountain Plover. Pages 170-171 *in* H. E. Kingery, editor. Colorado Breeding Bird Atlas. Colorado Bird Atlas Partnership and Colorado Division of Wildlife, Denver, Colorado, USA.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookout, editor. Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, Maryland, USA.

Lanyon, W. E. 1994. Western Meadowlark (*Sturnella neglecta*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 104. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Lomolino, M. V., R. Channell, D. R. Perault, and G. A. Smith. 2001. Downsizing nature: Anthropogenic dwarfing of species and ecosystems. Pages 223-243 *in* J. L. Lockwood and M. L. McKinney, editors. Biotic Homogenization. Kluwer, New York, New York, USA.

Lomolino, M. V., and G. A. Smith. 2003. Prairie dog towns as islands: Applications of island biogeography and landscape ecology for conserving nonvolant terrestrial vertebrates. Global Ecology and Biogeography 12:275-286.

Lomolino, M. V., and G. A. Smith. 2004. Terrestrial vertebrate communities at black-tailed prairie dog (*Cynomys ludovicianus*) towns. Biological Conservation 115:89-100.

Lomolino, M. V., G. A. Smith, and V. Vidal. 2004. Long-term persistence of prairie dog towns: Insights for designing networks of prairie reserves. Biological Conservation 115:111-120.

Lueders, A. S. 2002. Influences of vegetative structure on avian populations under grazing regimes in North Dakota mixed-grass prairie. Thesis, Colorado State University, Fort Collins, Colorado, USA.

MacKenzie, D. I. 2006. Modeling the probability of resource use: The effect of, and dealing with, detecting a species imperfectly. Journal of Wildlife Management 70:367-374.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier Inc., San Diego, California, USA.

MacKenzie, D. I., J. D. Nichols, N. Sutton, K. Kawanishi, and L. L. Bailey. 2005. Improving inferences in population studies of rare species that are detected imperfectly. Ecology 86:1101-1113.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42:1105–1114.

Martin, J. W., and J. R. Parrish. 2000. Lark Sparrow (*Chondestes grammacus*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 488. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

McIntyre, N. E. 2004. Historical and current status of breeding and wintering Western Burrowing Owls (*Athene cunicularia hypugaea*) in Texas. Journal of Raptor Research 38:91-95.

Miller, B., G. Ceballos, and R. Reading. 1994. The prairie dog and biotic diversity. Conservation Biology 8:677-681.

Miller, B., R. Reading, J. Hoogland, T. Clark, G. Ceballos, R. List, S. Forrest, L. Hanebury, P. Manzano, J. Pacheco, and D. Uresk. 2000. The role of prairie dogs as a keystone species: Response to Stapp. Conservation Biology 14:318-321.

Miller, B. J., and F. L. Knopf. 1993. Growth and survival of Mountain Plovers. Journal of Field Ornithology 64:500-506.

Miller, S. D., and J. F. Cully. 2001. Conservation of black-tailed prairie dogs (*Cynomys ludovicianus*). Journal of Mammalogy 82:889-893.

Murphy, R. K., K. W. Hasselblad, C. D. Grondahl, J. G. Sidle, R. E. Martin, and D. W. Freed. 2001. Status of the Burrowing Owl in North Dakota. Journal of Raptor Research 35:322-330.

National Drought Mitigation Center. 2004. The Drought Monitor. University of Nebraska-Lincoln, Lincoln, Nebraska, USA. Online at <http://drought.unl.edu>.

Nichols, J. D. 1992. Capture-recapture models. Bioscience 42:94-102.

Nichols, J. D. 1999. Monitoring is not enough: On the need for a model-based approach to migratory bird management. *In* R. Bonney, D. N. Pashley, R. J. Cooper, and L. Niles, editors. Strategies for Bird Conservation: The Partners in Flight Planning Process. Cornell Lab of Ornithology, Cape May, New Jersey, USA. Online at <http://birds.cornell.edu/pifcapemay>

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393-408.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668-673.

Olson, S. L., and D. Edge. 1985. Nest site selection by mountain plovers in northcentral Montana. Journal of Range Management 38:280-282.

Orth, P. B., and P. L. Kennedy. 2001. Do land-use patterns influence nest-site selection by burrowing owls (*Athene cunicularia hypugaea*) in northeastern Colorado? Canadian Journal of Zoology-Revue Canadienne de Zoologie 79:1038-1045.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical-inference from capture data on closed animal populations. Wildlife Monographs 62:1-135.

Plumb, R. E., F. L. Knopf, and S. H. Anderson. 2005. Minimum population size of Mountain Plovers breeding in Wyoming. Wilson Bulletin 117:15-22.

Plumpton, D. L., and R. S. Lutz. 1993. Nesting habitat use by Burrowing Owls in Colorado. Journal of Raptor Research 27:175-179.

Poff, N. L. 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. Journal of the North American Benthological Society 16:391-409.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105-119.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology of Burrowing Owls occupying black-tailed prairie dog towns in southeastern Montana. Journal of Raptor Research 35:296-303.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: Current practices and an alternative. Auk 119:46-53.

Rotenberry, J. T., and S. T. Knick. 1999. Multiscale habitat associations of the Sage Sparrow: Implications for conservation biology. Studies in Avian Biology 19:95-103.

Royle, J. A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60: 108-115.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Samson, F. B., and F. L. Knopf, editors. 1996. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin 32:6-15.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, Results and Analysis 1966-2005. Version 6.2.2006. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. Online at <http://www.mbr-pwrc.usgs.gov/bbs/>.

Sauer, J. R., J. E. Fallon, and R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for bird conservation regions. Journal of Wildlife Management 67:372-389.

Seber, G. A. F. 1982. The Estimation of Animal Abundance and Related Parameters. Second edition. Blackburn Press, Caldwell, New Jersey, USA.

Shackford, J. S. 1996. Studies and observations of Mountain Plover in the Great Plains. Page 27 *in* D. P. Coffin, editor. Summary report - shortgrass prairie/Mountain Plover workshop. Denver Audubon Society, Aurora, Colorado, USA.

Shackford, J. S., and D. M. Leslie. 1994. Mountain Plover breeding activity on cultivated fields. Federal aid project E-26-1. Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma, USA.

Shackford, J. S., D. M. Leslie, and W. D. Harden. 1999. Range-wide use of cultivated fields by Mountain Plovers during the breeding season. Journal of Field Ornithology 70:114-120.

Shane, T. G. 2000. Lark Bunting (*Calamospiza melanocorys*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 542. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Sheffield, S. R., and M. Howery. 2001. Current status, distribution, and conservation of the Burrowing Owl in Oklahoma. Journal of Raptor Research 35:351-356

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, D. N. Svingen. 2001. Occurrence of Burrowing Owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research. 35:316-321.

Sidle, J. G., D. H. Johnson, and B. R. Euliss. 2001. Estimated areal extent of colonies of black-tailed prairie dogs in the northern Great Plains. Journal of Mammalogy 82:928-936.

Sissons, R. A., K. L. Scalise, T. I. Wellicome. 2001. Nocturnal foraging and habitat use by male Burrowing Owls in a heavily-cultivated region of southern Saskatchewan. Journal of Raptor Research 35:304-309.

Smith, G. A., and M. V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138:592-602.

Stapp, P. 1998. A reevaluation of the role of prairie dogs in Great Plains grasslands. Conservation Biology 12:1253-1259.

Stephens, S. E., D. N. Koons, J. J. Rotella, and D. W. Willey. 2003. Effects of habitat fragmentation on avian nesting success: A review of the evidence at multiple spatial scales. Biological Conservation 115:101-110.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Theobald, D. T. 2004. GIS - GRTS: Spatially balanced sampling tool. ArcGIS v.9.0 extension. Language: Python. Operating System: Windows XP. Software Application ESRI ArcGIS v.9.0. Colorado State University, Fort Collins, Colorado, USA.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. In press. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Environmental Management.

Thompson, C. D. 1984. Selected aspects of burrowing owl ecology in central Wyoming. Thesis, University of Wyoming, Laramie, Wyoming, USA.

Thompson, S. K. 2002. Sampling. John Wiley and Sons, New York, New York, USA.

Thompson, W. L. 2002. Towards reliable bird surveys: Accounting for individuals present but not detected. Auk 119:18-25.

Toombs, T. P. 1997. Burrowing owl nest-site selection in relation to soil texture and prairie dog colony attributes. Thesis, Colorado State University, Fort Collins, Colorado, USA.

U.S. Fish and Wildlife Service. 1999. Proposed threatened status for the Mountain Plover. Pages 7587-7601 *in* Federal Register Volume 64, Number 30. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants: 12-month finding for a petition to list the black-tailed prairie dog as threatened. Pages 5476-5488 *in* Federal Register Volume 65, Number 24. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2003. Endangered and threatened wildlife and plants: Withdrawal of the proposed rule to list the Mountain Plover as threatened. Pages 53083-53101 *in* Federal Register Volume 68, Number 174. Washington D.C., USA.

U.S. Fish and Wildlife Service. 2004. Endangered and threatened wildlife and plants: Finding for the resubmitted petition to list the black-tailed prairie dog as threatened. Pages 51217-51226 *in* Federal Register Volume 69, Number 159. Washington D.C., USA.

Valiulis, J. 2003. The use of continuous and categorical measures of landscape structure in predicting biotic response: An example using grassland birds. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Venner, M. 2002. Habitat approach to streamlining Section 7 - Colorado Department of Transportation's Shortgrass Prairie Initiative. Pages 109-117 *in* Sustainability and Environmental Concerns in Transportation 2002. Transportation Research Board National Research Council, Washington D.C., USA.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

Vermeire, L. T., R. K. Heitschmidt, P. S. Johnson, and B. F. Sowell. 2004. The prairie dog story: Do we have it right? BioScience 54:689-695.

Vickery, P. D. 1996. Grasshopper Sparrow (*Ammodramus savannarum*). *In* A. Poole and F. Gill, editors. The Birds of North America, No. 239. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and the American Ornithologists' Union, Washington D.C., USA.

Weaver, T., E. M. Payson, and D. L. Gustafson. 1996. Prairie ecology - the shortgrass prairie. Pages 67-75 *in* F. B. Samson and F. L. Knopf, editors. Prairie Conservation: Preserving North America's Most Endangered Ecosystem. Island Press, Washington, D.C., USA.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46, Supplement, 120-138.

White, G. C., K. P. Burnham, and D. R. Anderson. 2002. Advanced features of program MARK. Pages 368-377 *in* R. Fields, editor. Integrating People and Wildlife for a Sustainable Future, Proceedings of the Second International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA.

White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265-272.

Wiens, J. A. 1973. Pattern and process in grassland bird communities. Ecological Monographs 43:237-270.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and Management of Vertebrate Populations. Academic Press, San Diego, California, USA.

Winter, M., D. H. Johnson, J. A. Shaffer, T. M. Donovan, and W. D. Svedarsky. 2006. Patch size and landscape effects on density and nesting success of grassland birds. Journal of Wildlife Management 70:158-172.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2002. Vegetation of prairie dog colonies and non-colonized shortgrass prairie. Journal of Range Management 55:502-508.

Winter, S. L., J. F. Cully, and J. S. Pontius. 2003. Breeding season avifauna of prairie dog colonies and non-colonized areas in shortgrass prairie. Transactions of the Kansas Academy of Science 106:129-138.

Wunder, M. B., and F. L. Knopf. 2003. The Imperial Valley of California is critical to wintering Mountain Plovers. Journal of Field Ornithology 74:74-80.

Wunder, M. B., F. L. Knopf, and C. A. Pague. 2003. The high-elevation population of Mountain Plovers in Colorado. Condor 105:654-662.