Monitoring Breeding Birds in The City of Fort Collins Foothills Natural Areas

BIRD CONSERVANCY OF THE ROCKIES

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***Vision**: Native bird populations are sustained in healthy ecosystems*

***Core Values**: (Our goals for achieving our mission)*

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2. ***Education** is critical to the success of bird conservation.*
3. ***Stewardship** of birds and their habitats is a responsibility we all share.*

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***Researching** bird ecology and response to anthropogenic and natural processes. Our research informs management and conservation strategies using the best available science.*

***Educating** people of all ages to instill an awareness and appreciation for birds and a conservation ethic.*

***Fostering** good stewardship on private and public lands through voluntary, cooperative partnerships that create win-win solutions for wildlife and people.*

***Partnering** with local, state and federal agencies, private citizens, schools, universities, and other organizations for bird conservation.*

***Sharing** the latest information on bird populations, land management and conservation practices to create informed publics.*

***Delivering** bird conservation at biologically relevant scales by working across political and jurisdictional boundaries in the Americas.*

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Executive Summary

The Foothill Natural Areas are of high conservation value due to the high biodiversity, social, and economic services it provides to our community. The City of Fort Collins manages several natural areas along the northern Front Range. Monitoring wildlife populations for biodiversity can be an effective tool for guiding management decisions. The objective of this monitoring program is to determine population density and distributions of breeding birds that inhabit these natural areas to assist with management planning.

In 2020 Bird Conservancy of the Rockies staff surveyed 462 points in Foothills Shrubland habitat using a point-transect survey method developed by Bird Conservancy. Using data collected, we generated density estimates using a hierarchical distance sampling model. The benefit of this hierarchical distance sampling framework is the ability to provide spatially explicit density estimates as functions of covariates. The hierarchical distance sampling model also allowed us to address two important issues when monitoring wildlife populations, 1) spatial sampling and 2) detection probability.

We used a focal species approach and identified five focal species representative of the foothills grassland & shrubland habitats; Vesper Sparrow, Grasshopper Sparrow, Spotted Towhee, Blue-gray Gnatcatcher and Yellow-breasted Chat. These species integrate ecological processes that contribute to the maintenance of foothill shrubland ecosystem function. Management actions aimed at conserving these focal species will also protect a larger number of species occurring in the management areas. We show how species density relationships to landscape metrics and vegetation structure along with predictive distribution models can be used as an effective tool to assist with management planning. Grass cover, grass height, and shrubland cohesion influenced focal species density along both ends of the landscape and vegetation continuum. We found strong support for non-linear relationships between bird density; shrub cover and shrub height. These relationships show bird density increases up to an optimal level of shrub cover and shrub height and then decreases past a certain threshold.

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Introduction

Foothill shrublands are found in the foothills, canyon slopes and lower mountains of the Rocky Mountains and on hogbacks/outcrops in the west (NatureServe 2021). Extending from southern New Mexico through Colorado and north into Wyoming, and west into the Intermountain region (NatureServe 2021). In Colorado, foothill shrublands occur at lower montane elevations skirting mountains forming a transitional belt between grasslands and mixed coniferous forests. These shrublands form large patch communities at elevations between 4900 and 9500 feet. These patch communities can be characterized by a variety of species where oak is absent, although they may intergrade in places with oak and form mixed mountain shrublands. These communities form patchy mosaics across the landscape that change substantially over short distances and can be interspersed with trees.

Anthropogenic disturbances to foothill shrublands are increasing due to human population growth. Extensive modification of shrubland communities due to conversion of lands to urban development are a threat to sustaining recreational opportunities and wildlife populations. Monitoring and species habitat relationships will be important to inform wildlife management plans.

Management for most species requires reliable abundance estimates (Bowden et al. 2003). Abundance estimates allow us to measure changes in population size and to assess the impact of habitat loss or harvesting (Buckland et al. 2008). Relating species density or abundance to landscape and habitat structure is also fundamental to ecological science. Royle et al. (2004) developed hierarchical models that account for spatial variation in abundance and detection probability at sampling units. These models can be used to create spatially explicit maps (Sillette et al. 2012). This is appealing for conservation managers in that they can characterize the structure of local populations in space (Royle et al. 2004).

We used a focal species approach and identified five focal species; Grasshopper Sparrow, Vesper Sparrow, Blue-gray Gnatcatcher, Spotted Towhee and Yellow-breasted Chat. These species integrate ecological processes that contribute to the maintenance of foothill shrubland ecosystem function. Understanding the habitat use and distribution of these focal species can help guide management actions and also protect a larger number of species occurring in the same areas. We show how species density relationships to landscape metrics and vegetation structure along with predictive distribution models can be used as an effective tool to assist with management planning.
In addition we modeled shrubland/grassland connectivity to visualize patch nodes weighted by area and perimeter links between shrubland/grassland patches. Mitigating biodiversity loss due to land use change and habitat fragmentation in addition to natural adaptation and maintaining

species populations under climate change involves conserving connectivity, the ability of species to move across landscapes (Heller & Zavaleta 2009).

Study Area

The City of Fort Collins survey locations were in the City Natural Areas along the foothills West of Fort Collins (Fig 1).

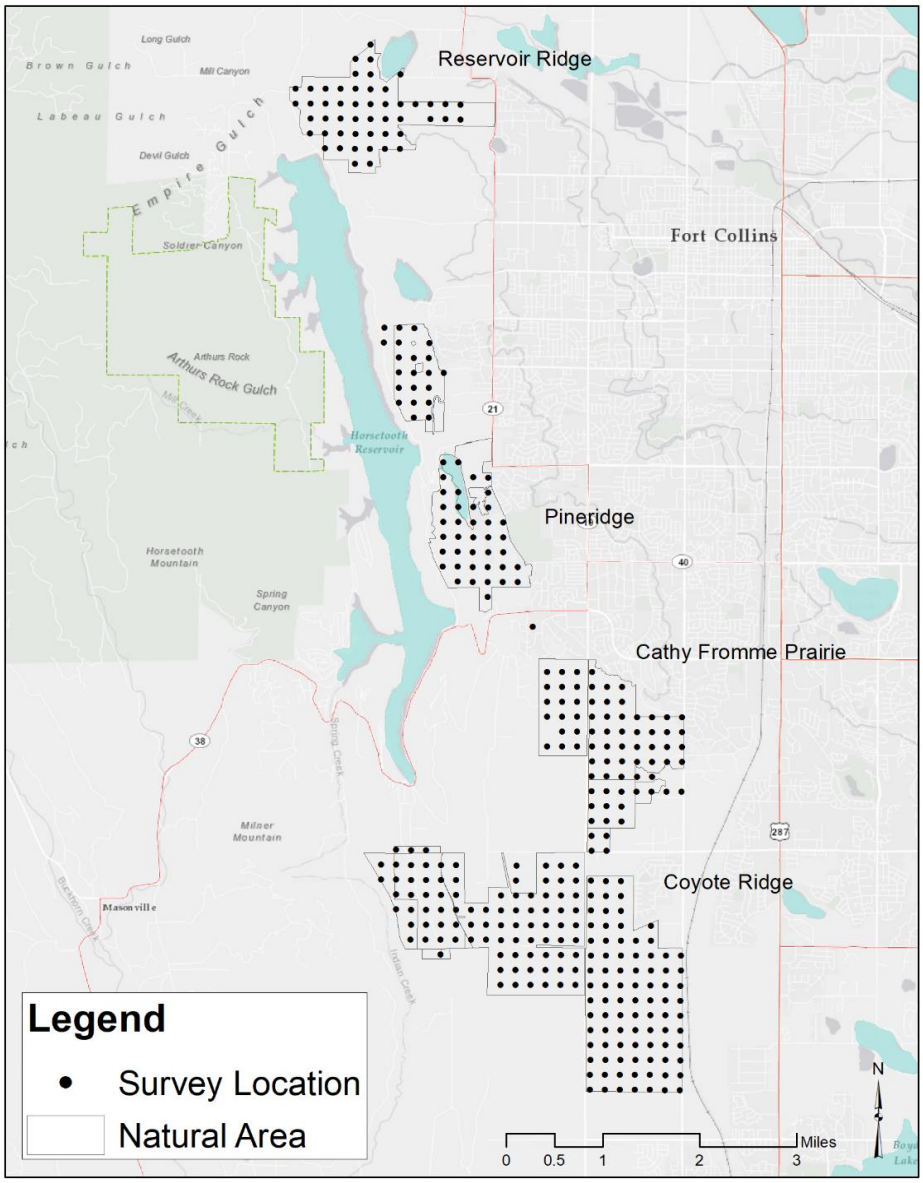

Figure 1. City of Fort Collins Natural Areas breeding bird survey study area.

Methods

Sampling Design and Methods

A systematic 250-m grid of point count stations was created by the City of Fort Collins Natural Areas Department to survey the properties. In 2020 there were 462 point count stations that were surveyed once between May 11th and June 11th (Fig 1). Point count surveys started one half-hour before sunrise and ended by 11 a.m., often earlier.

Point count locations were navigated to on foot using a handheld GPS unit. We recorded atmospheric data (temperature, cloud cover, precipitation, and wind speed) and time of day at the start and end of each daily survey effort. All GPS data were logged in Universal Transverse Mercator (UTM) North American Datum 1983.

At each station, we conducted a 6-minute point count survey consisting of six consecutive 1-minute intervals. This protocol, which is described more fully by Hanni et al. (2016), uses Distance sampling (Buckland et al. 2001) and removal sampling (Farnsworth et al. 2002). For each bird detected, observers recorded species, sex, how it was detected (call, song, visual, wing beat, other), distance from observer at time of detection, and the 1-minute interval in which it was detected. We measured distances using a Bushnell Yardage Pro laser rangefinder.

Point counts were not conducted during periods of heavy snow, rain, or wind greater than 10 mph. Between point count surveys, we recorded the presence of high-priority and other rare or unusual bird species, but we did not use these observations in our analyses. We also noted the presence of any other wildlife or interesting site observations.

Abundance/Density Estimation

We used a hierarchical distance sampling model described in Sillett et al. (2012). This hierarchical model includes sub-models that allow for the abundance process and the detection process to vary as functions of covariates i.e., grass height. In the abundance component of the model, the number of birds at each point (N_i) was modeled using a Poisson random variable. The expectation for the number of birds at a point count is $E[N_i] = \lambda$. The detection process in the model is based on classical distance sampling methods developed by Buckland et al. (2001). We used a half normal scale parameter and only considered constant models on detection. We estimated parameters of the generalized multinomial mixture model by maximizing the integrated likelihood function in program R software (R Development Core Team 2019) using the ‘unmarked’ package (Fiske, Chandler & Royle 2010).

We used an information theoretic approach to select the top models (Burnham and Anderson 2002). If over dispersion was detected we used QAIC (Burnham & Anderson 2002). We ranked models by the Akaike Information Criterion (AIC) (Akaike 1973) and considered a set of candidate models to be the best if AIC values were within $\Delta AIC < 2$. We developed distribution models by using the top model to predict abundance/densities throughout the foothill Natural Areas. We derived species richness by overlaying the species distribution models.

Model Covariates

Covariates collected in the field used in the models were percent cover of grass, grass height (cm), percent shrub cover and shrub height (cm). In program R we used the landscape metrics package (*Hesselbarth et al. 2019)* with LANDFIRE existing vegetation type layer (USGS 2014), to derive shrubland cohesion within the sampling unit (250 x 250 meters square, (15.44 acres)). We fit a quadratic effect on shrub cover and shrub height. We developed twenty nine models to observe bird density response to landscape and vegetation structure covariates. The detection model was held constant for all models.

Landscape Connectivity

We explored shrubland/grassland connectivity using the LANDFIRE existing vegetation type layer (USGS 2014) with the grainscape package in R (Chubaty and Doctolero 2020). The grainscape package models functional connectivity, the patch network characterizes connectivity relationships among habitat patches. These networks are mapped, where habitat patches are nodes, and potential paths for dispersal among patches are links. Interpretation consists of measuring the connectivity between two locations on the surface using one of several metrics, among which least-cost path and resistance distance are used. The input to grainscape is a resistance surface raster map, non-shrubland and grassland vegetation (LANDFIRE), and a second raster indicating the focal patches that serve as nodes in a network. We use native shrubland and grassland vegetation as our focal patches when building the network.

Results

Density Estimates

The biologist observed a total of 102 species in the Foothills/ Shrubland natural areas (Appendix A). Seventeen of these species are species of conservation concern or regional importance as designated by Partners In Flight (PIF 2017).

We estimated density and developed distribution models for five species; Vesper Sparrow, Grasshopper Sparrow, Spotted Towhee, Blue-gray Gnatcatcher and Yellow-breasted Chat. Density estimates are presented in Table 1.

Table 1. Mean density estimates (2009-2020) on Foothill Shrubland Natural Area properties (D = # of birds/ 15.4 acres), SE = Standard Error, and 95% lower (LCL) and upper (UCL) confidence limits.

Species	D	SE	LCL	UCL
Vesper Sparrow	3.15	0.23	2.74	3.62
Grasshopper Sparrow	1.54	0.15	1.27	1.87
Spotted Towhee	0.79	0.07	0.67	0.93
Blue-gray Gnatcatcher	0.24	0.05	0.16	0.36
Yellow-breasted Chat	0.30	0.04	0.23	0.39

Grassland area on the east side of Cathy Fromme Natural Area (E. Youngberg)

Vesper Sparrow's top model included shrubland cohesion, grass cover, grass height, shrub cover and shrub height (Table 2). Density increased with grass height and decreased with shrubland cohesion (Fig. 2) and grass cover (Table 2). Strong quadratic effects were seen with shrub cover and shrub height (Fig. 2, Graphs 3 & 4). Optimal shrub cover is 20.9% and optimal shrub height is 99.8 cm (Fig. 2). Vesper Sparrow occurred in higher densities in Coyote Ridge natural areas (Figure 7).

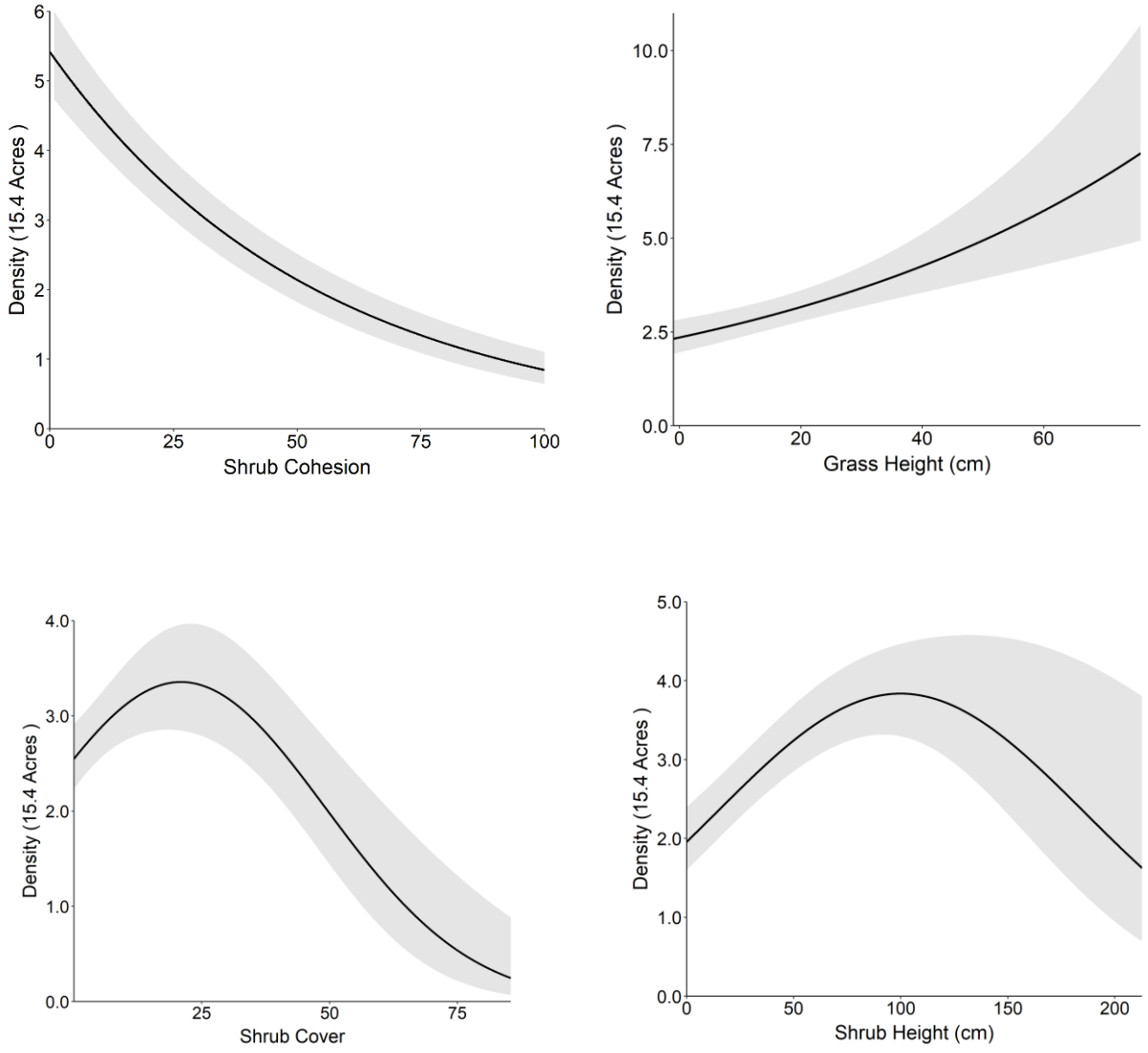

Figure 2 (Graphs 1-4): Vegetation effects on density estimates for Vesper Sparrow

Grasshopper Sparrow's top model included shrubland cohesion, grass cover, shrub cover and shrub height (Table 2). Density increased with grass cover and decreased with shrubland cohesion. Strong positive effects were seen with grass cover, and strong quadratic effects were seen with shrub cover and shrub height (Fig 3. Graphs 2 & 4). Optimal shrub cover is 25.4% and shrub height is 90 cm (Fig 3). Grasshopper Sparrow occurred in higher densities in Reservoir Ridge and Coyote Ridge natural areas (Figure 8).

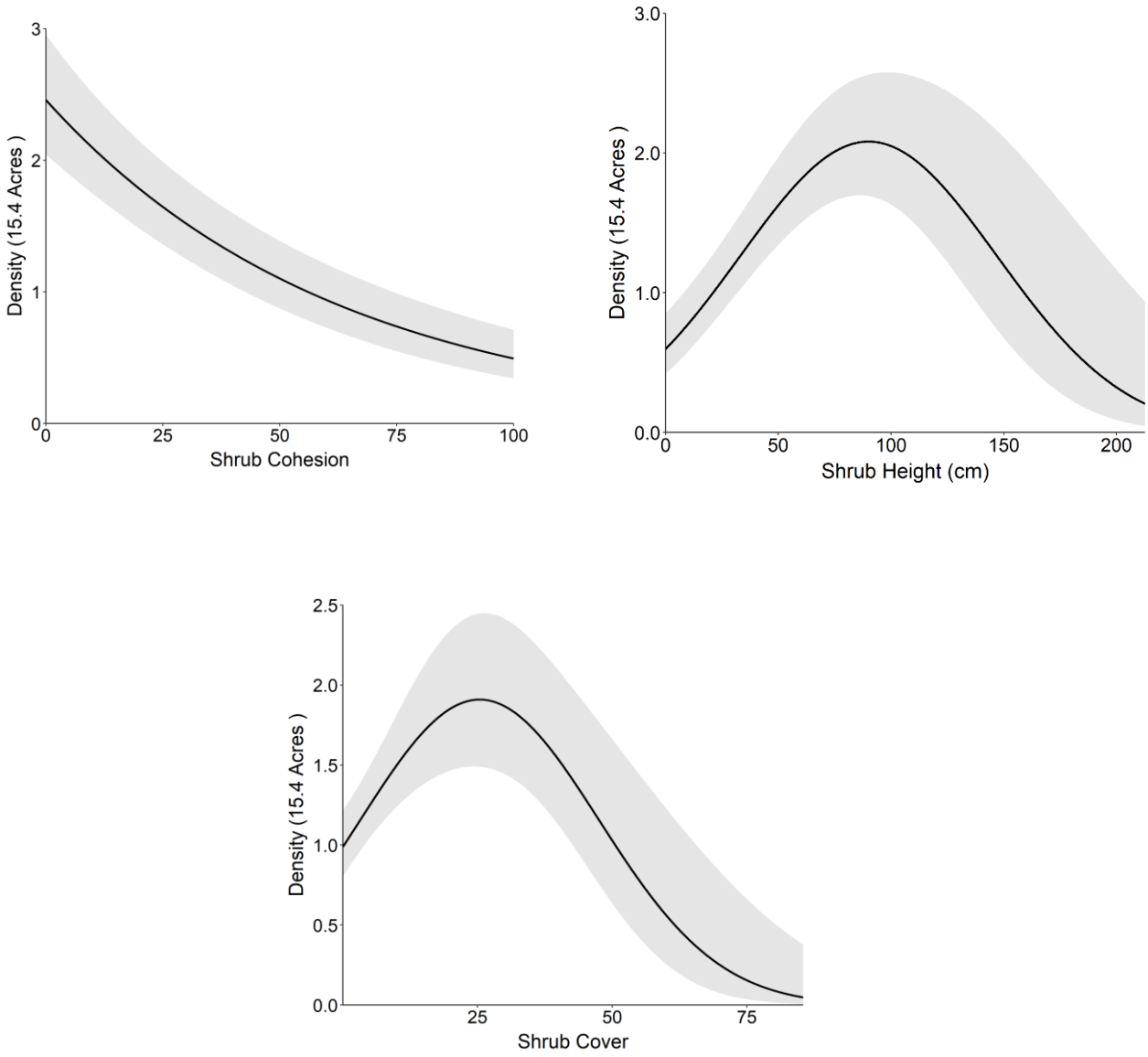

Figure 3 (Graphs 1-3): Vegetation effects on density estimates for Grasshopper Sparrow

Spotted Towhee's top model included shrubland cohesion, shrub cover and shrub height (Table 2). Density increased with shrubland cohesion. Strong effects were seen with shrubland cohesion, and strong quadratic effects were seen with shrub height and shrub cover (Fig 4. Graphs 2 & 3). Optimal shrub cover is 61.3% and optimal shrub height is 107.3 cm (Fig. 4). Spotted Towhee occurred in higher densities along the western edge of the natural areas (Figure 9).

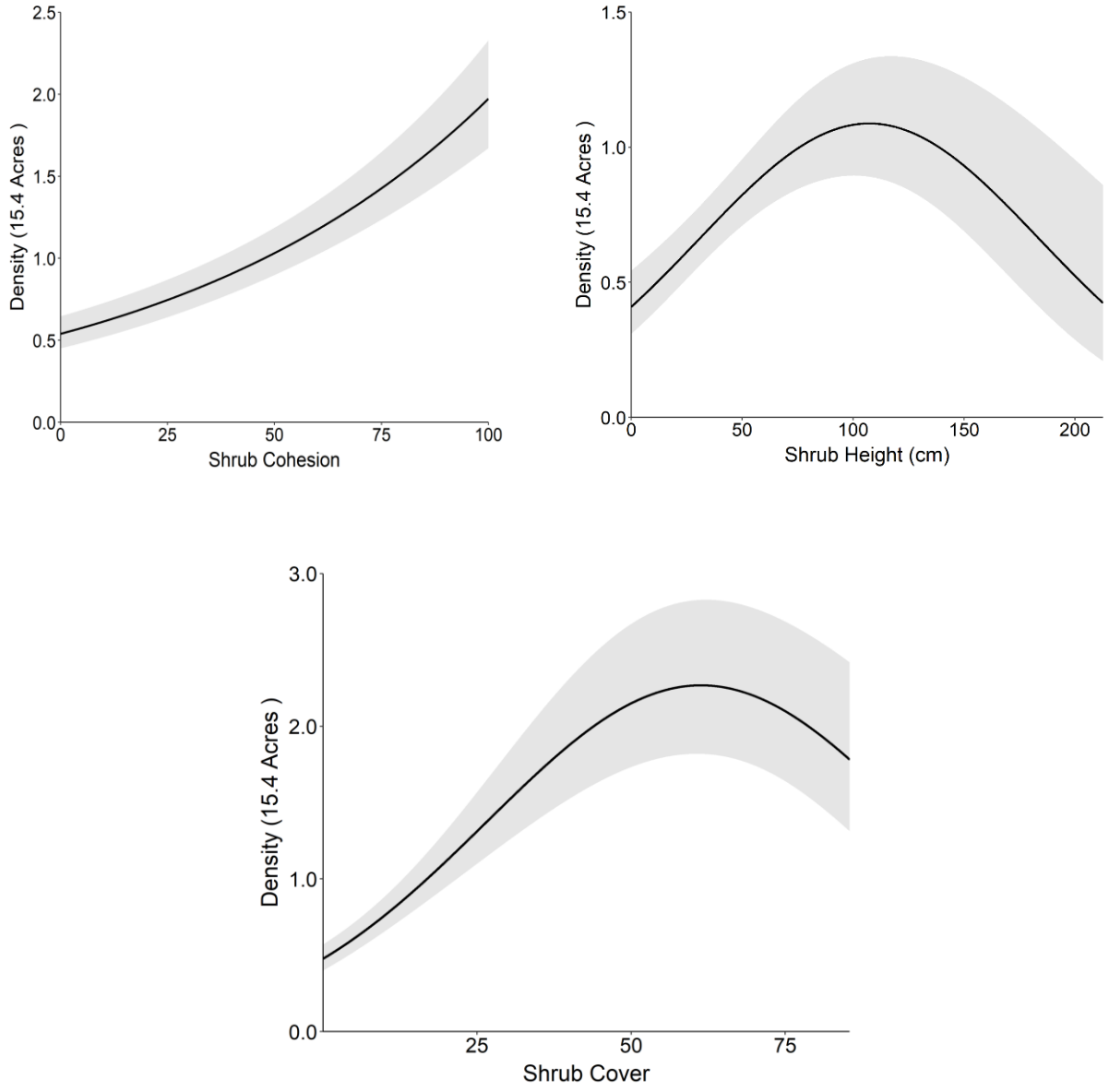

Figure 4 (Graphs 1-3): Vegetation effects on density estimates for Spotted Towhee

Blue-gray Gnatcatcher's top model included shrubland cohesion, grass cover, shrub cover and shrub height (Table 2). Density decreased with grass cover and increased with shrubland cohesion (Fig. 2). Strong quadratic effects were seen with shrub cover and shrub height (Fig. 5, Graphs 3 & 4). Optimal shrub cover is 70% and optimal shrub height is 115 cm (Fig. 5). Blue-gray Gnatcatcher occurred in higher densities in Maxwell and Coyote Ridge natural areas (Figure 5).

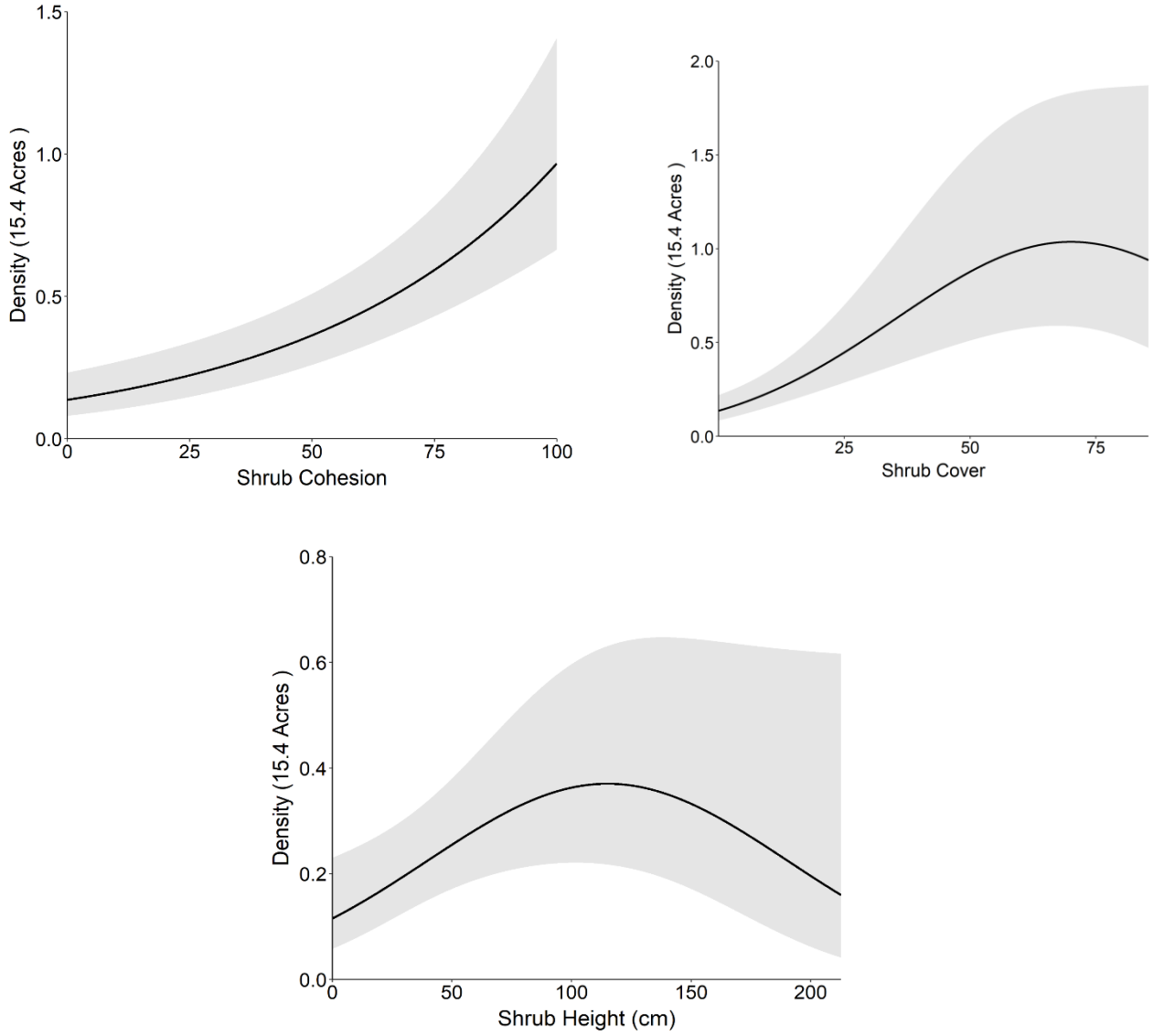

Figure 5 (Graphs 1-3): Vegetation effects on density estimates for Blue-gray Gnatcatcher

Yellow-breasted Chat's top model included shrubland cohesion, grass height, shrub cover and shrub height (Table 2). Density increased with shrubland cohesion and grass height (Fig. 6). Strong quadratic effects were seen with shrub cover and shrub height (Fig. 6, Graphs 3 & 4). Optimal shrub cover is 47.8% and optimal shrub height is 141.9 cm (Fig. 6). Yellow-breasted Chat occurred in higher densities on the western periphery of the natural areas (Figure 6).

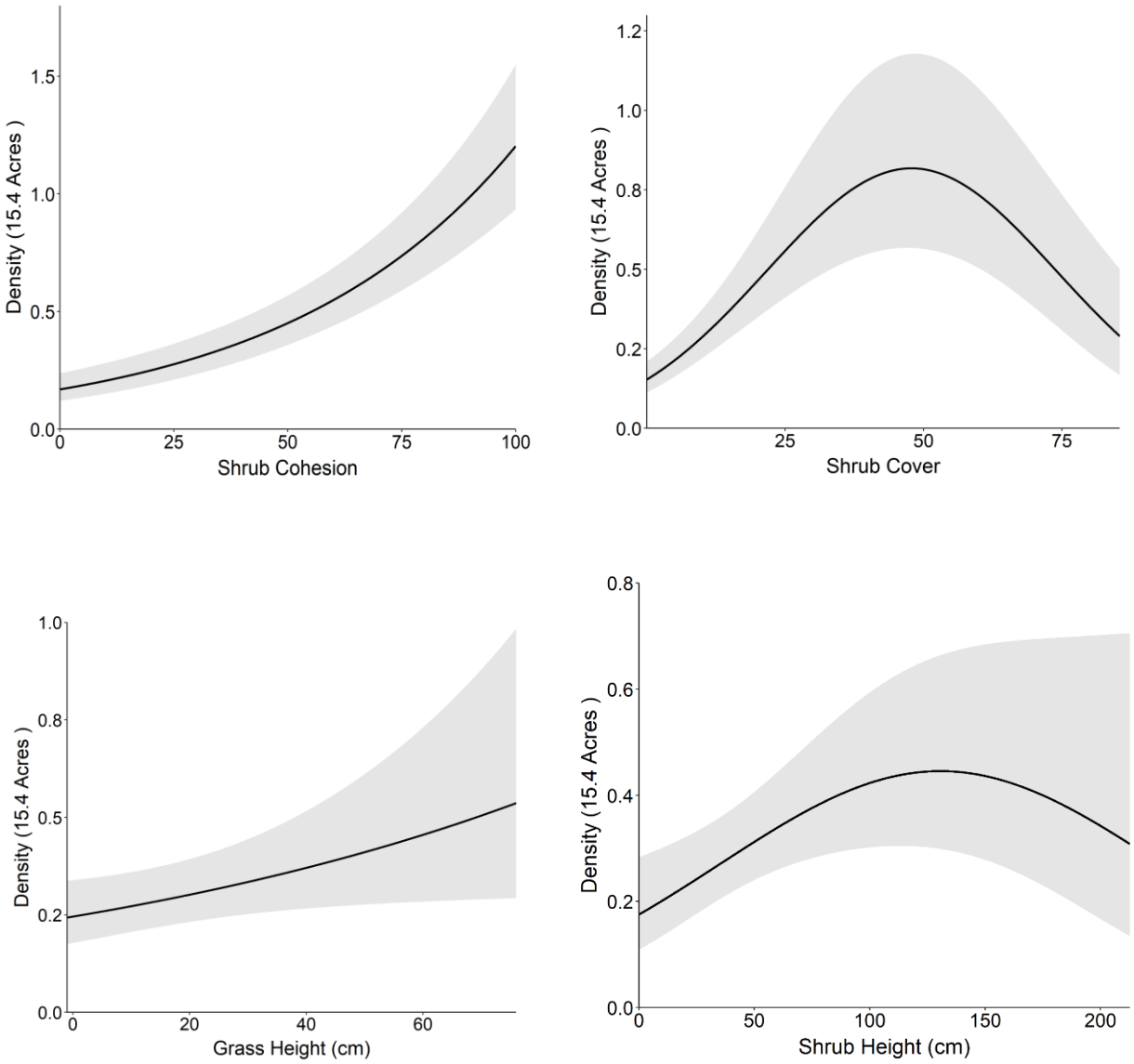

Figure 6 (Graphs 1-4): Vegetation effects on density estimates for Yellow-breasted Chat

Table 2: Best model parameter estimates, standard errors (SE) and lower and upper 95% confidence limits (LCL and UCL, respectively) for the density (λ) of focal species. Cohe = Cohesion and Cov = Cover.

Species	Covariates	Estimate	SE	UCL	LCL
Vesper Sparrow	(Intercept)	1.15	0.07	1.02	1.28
	Shrub Cohe	-0.80	0.06	-0.91	-0.69
	Grass Cov	-0.17	0.04	-0.23	-0.10
	Grass Height	0.15	0.03	0.08	0.21
	Shrub Cov	0.24	0.09	0.07	0.40
	Shrub Cov^2	-0.22	0.06	-0.33	-0.11
	Shrub Height	0.26	0.04	0.18	0.34
	Shrub Height^2	-0.09	0.02	-0.13	-0.04
Grasshopper Sparrow	(Intercept)	0.43	0.10	0.24	0.62
	Shrub Cohe	-0.69	0.08	-0.84	-0.54
	Grass Cov	0.24	0.06	0.12	0.35
	Shrub Cov	0.56	0.12	0.31	0.80
	Shrub Cov^2	-0.36	0.09	-0.53	-0.18
	Shrub Height	0.49	0.08	0.34	0.63
	Shrub Height^2	-0.20	0.04	-0.28	-0.11
Spotted Towhee	(Intercept)	-0.24	0.08	-0.39	-0.09
	Shrub Cohe	0.56	0.05	0.47	0.65
	Shrub Cov	0.78	0.08	0.63	0.93
	Shrub Cov^2	-0.14	0.02	-0.19	-0.10
	Shrub Height	0.37	0.07	0.24	0.51
	Shrub Height^2	-0.11	0.02	-0.15	-0.06
Blue-Gray Gnatcatcher	(Intercept)	-1.42	0.20	-1.82	-1.02
	Shrub Cohe	0.84	0.14	0.57	1.11
	Grass Cov	-0.25	0.10	-0.46	-0.05
	Shrub Cov	0.92	0.19	0.55	1.28
	Shrub Cov^2	-0.14	0.05	-0.24	-0.05
	Shrub Height	0.44	0.16	0.12	0.75
	Shrub Height^2	-0.11	0.05	-0.21	-0.01
Yellow-Breasted Chat	(Intercept)	-1.20	0.13	-1.47	-0.94
	Shrub Cohe	0.84	0.08	0.68	1.01
	Grass Height	0.10	0.05	0.01	0.20
	Shrub Cov	1.01	0.13	0.76	1.26
	Shrub Cov^2	-0.25	0.04	-0.33	-0.18
	Shrub Height	0.33	0.12	0.10	0.56
	Shrub Height^2	-0.07	0.03	-0.13	-0.01

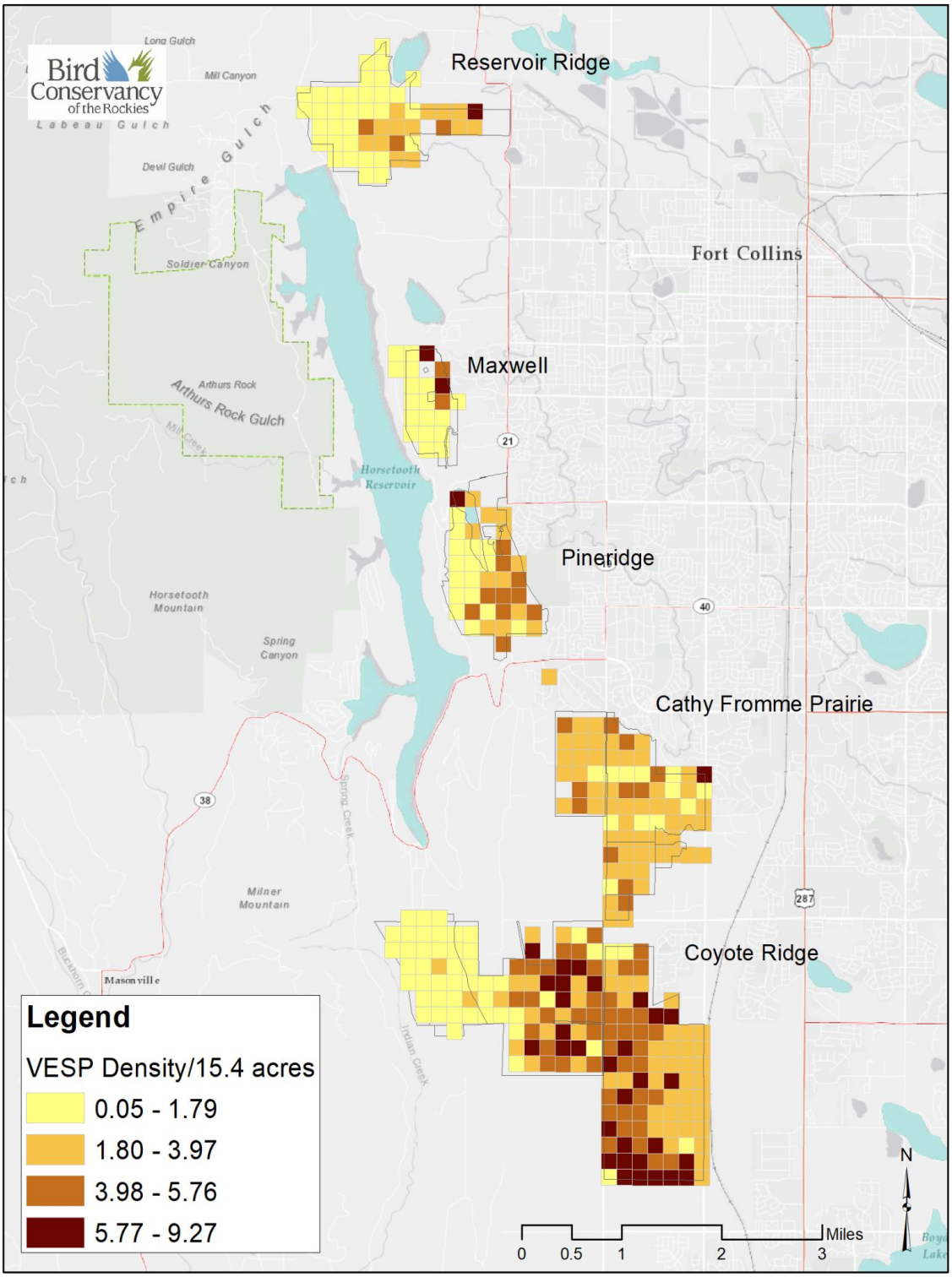

Figure 7: Density and distribution of Vesper Sparrow in the Foothills/ Shrubland Natural Areas

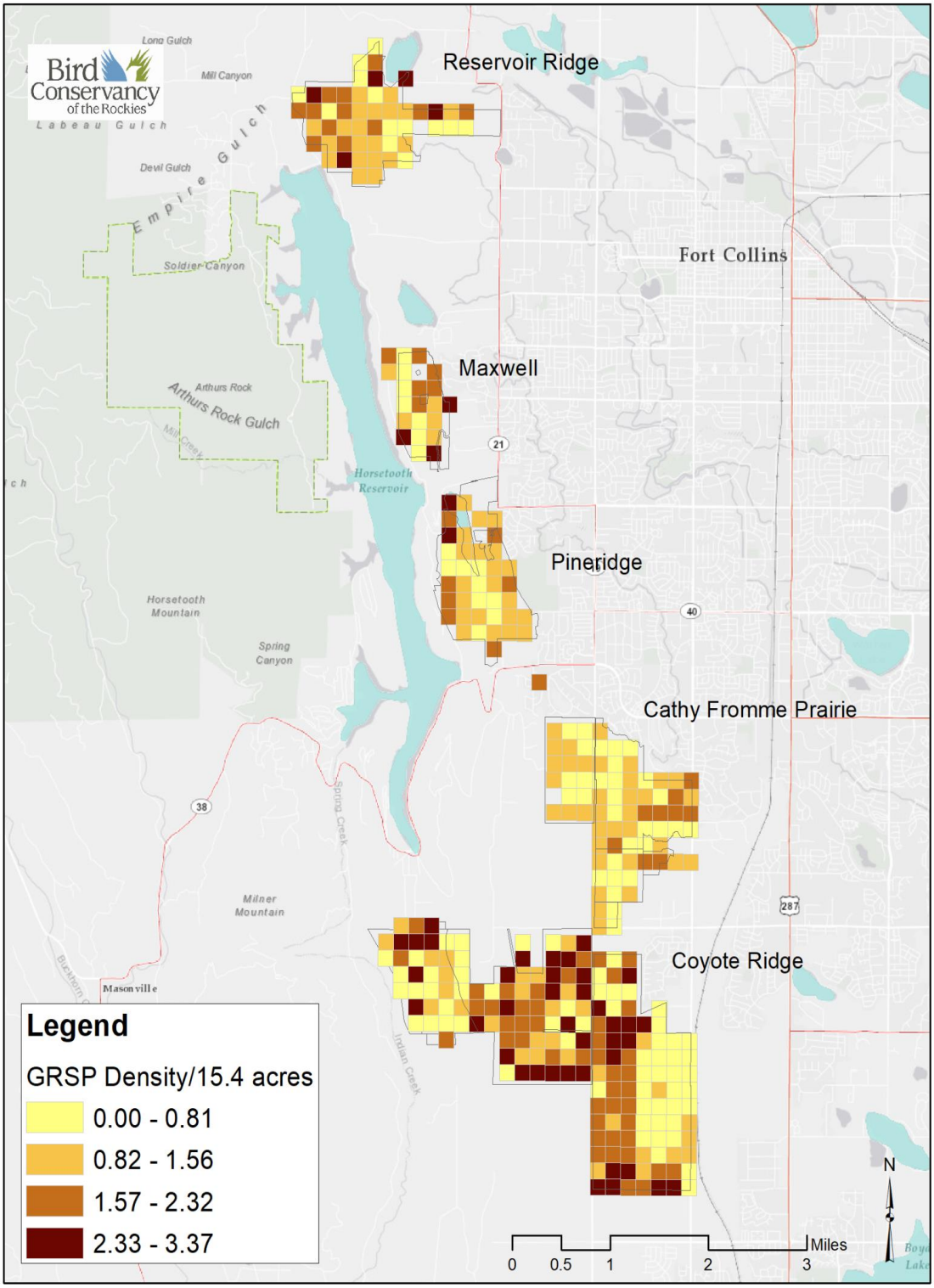

Figure 8: Density and distribution of Grasshopper Sparrow in the Foothills/ Shrubland Natural Areas

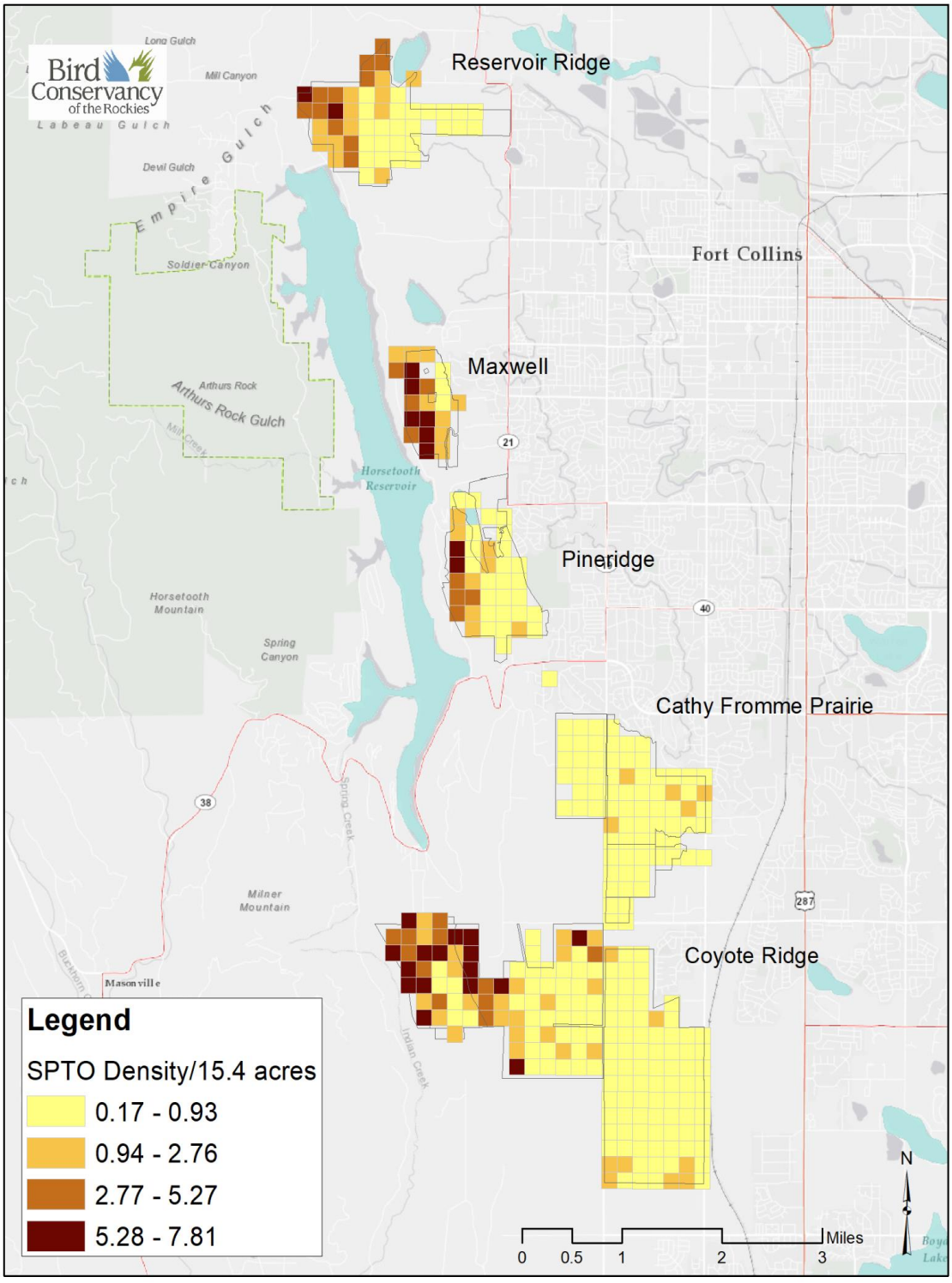

Figure 9: Density and distribution of Spotted Towhee in the Foothills/ Shrubland Natural Areas

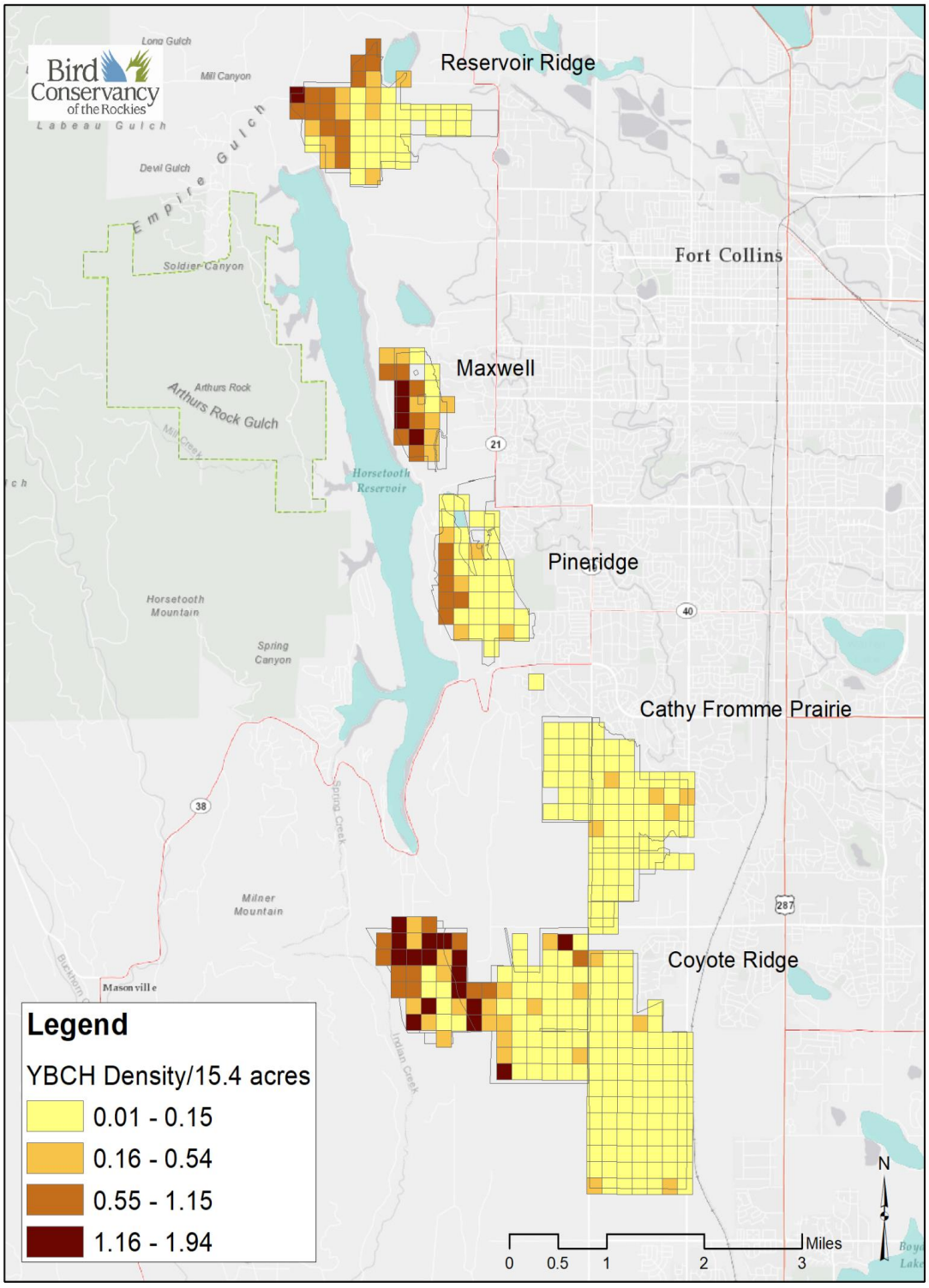

Figure 10: Density and distribution of Yellow-breasted Chat in the Foothills/ Shrubland Natural Areas

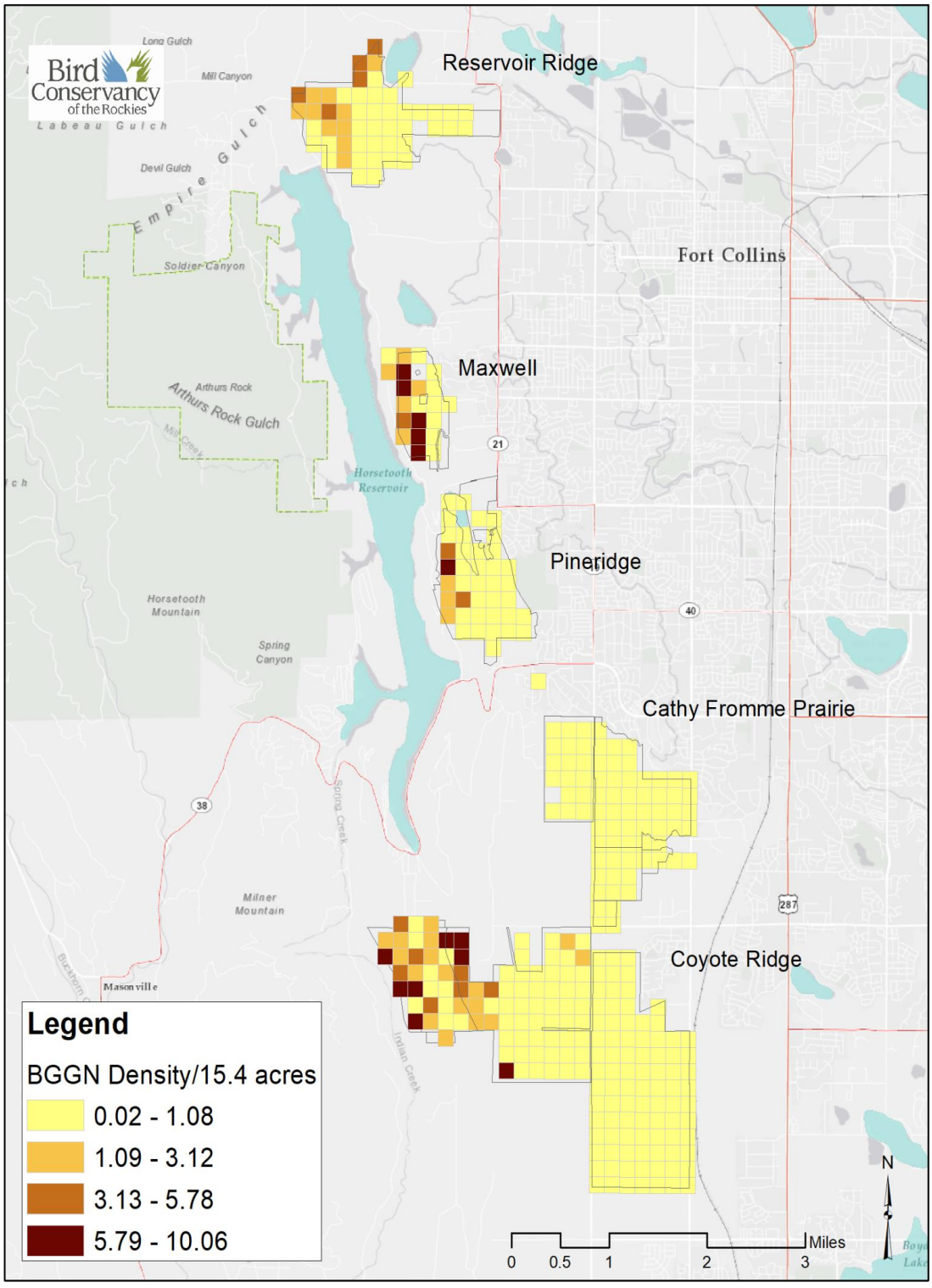

Figure 11: Density and distribution of Blue-gray Gnatcatcher in the Foothills/ Shrubland Natural Areas

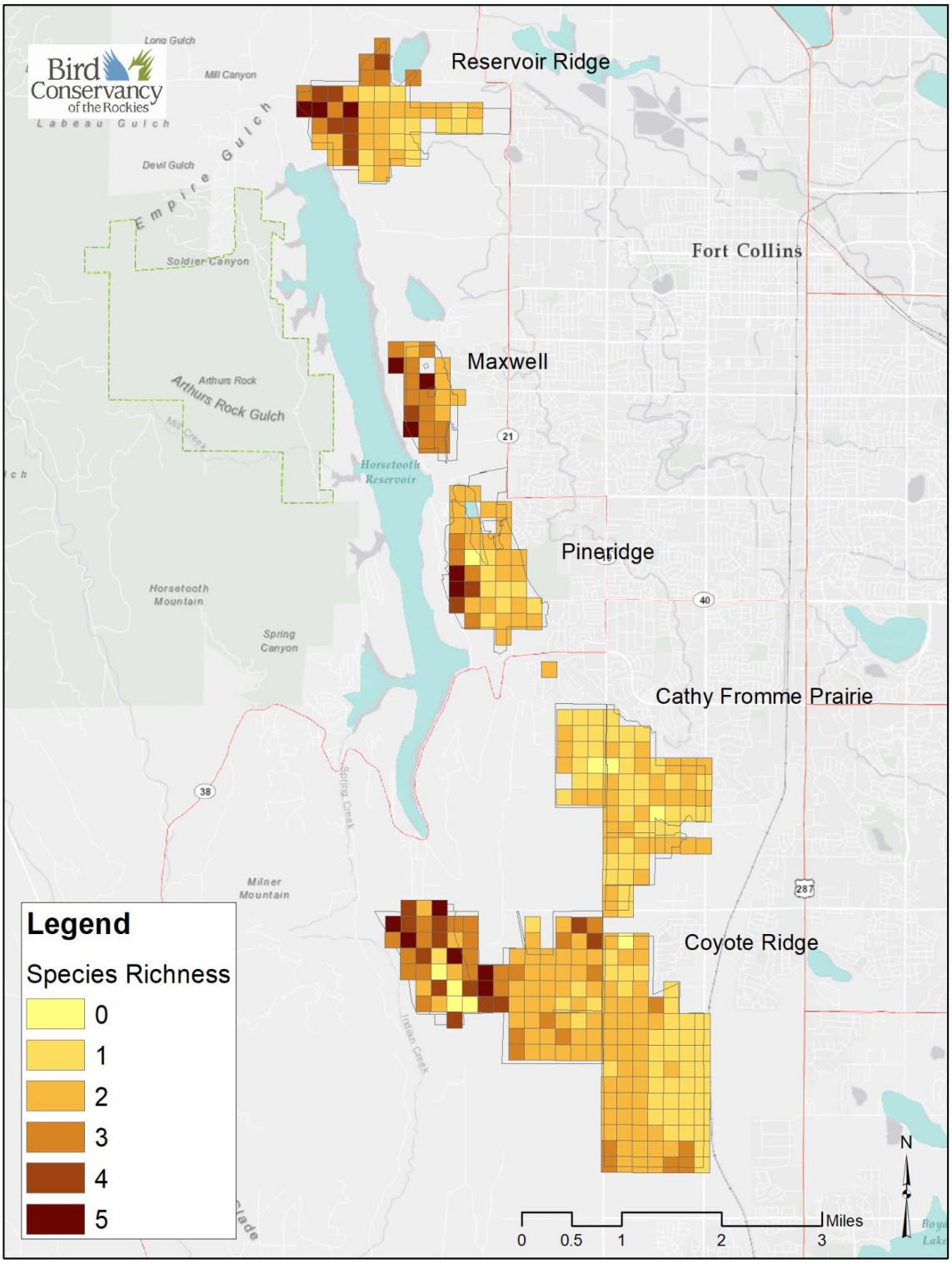

Figure 12: Distribution of focal species richness in the Foothill Natural Areas.

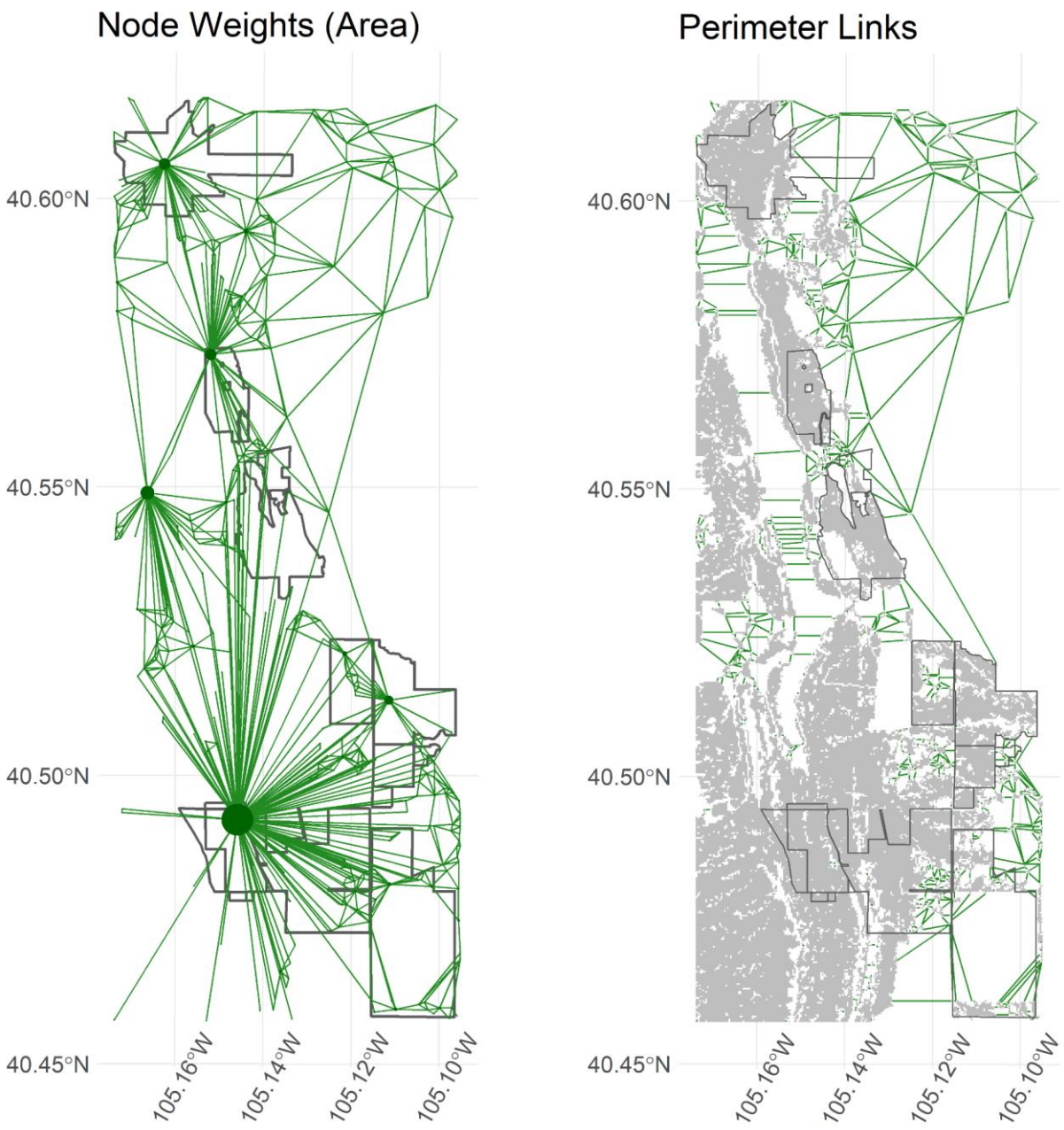

Figure 13. Foothill shrubland/grassland connectivity weighted by patch area (A) and shows perimeter links to surrounding patches (gray) (B) with natural area boundaries overlaid.

Discussion

We demonstrate how a focal species approach along with landscape connectivity models can be used as a management tool to assist with natural areas planning. Management that focuses on single species outcomes may be too narrow to meet conservation goals (Moilanen 2005). An alternative approach is to identify species that integrate ecological processes that contribute to the maintenance of the ecosystem function while also functioning as focal species (Lindenmayer et al. 2014). This will allow management actions aimed at conserving the focal species to also protect a larger number of species occurring in the management area. We show how species density relationships to landscape metrics and habitat variables along with predictive distribution models can be used as an effective tool to assist with management planning. Shrubland cohesion, grass cover and grass height influenced focal species bird density along both ends of the landscape and vegetation continuum. We found strong support for non-linear relationships between bird density, Shrub cover and shrub height. These non-linear relationships show bird density increasing up to an optimal level of shrub cover and shrub height and then decrease past a certain threshold.

The relationship between bird species richness, vertical and horizontal structural complexity of vegetation has been found to be important for shrubland birds (Weins and Rotenberry 1981). Foothill shrubland focal species showed a quadratic response to shrub cover and shrub height thus identifying an optimal level of shrub cover and height in relation to bird density. Grasshopper Sparrow and Vesper Sparrow showed a lower window of optimal shrub cover (20 - 25%) and shrub height (90 - 100 cm) compared to the other focal species. This is consistent with these two focal species habitat preferences which includes a grassland/ forb component. Grasshopper Sparrow generally avoids extensive shrub cover however some level of shrub cover is important for western populations. In Arizona Grasshopper Sparrow prefers grasslands with shrubs (Bock and Bock 1992). Vesper Sparrow generally occupies sparser more open grasslands with a shrub component and shrub height was found to be correlated with abundance (Rotenberry and Weins 1980). Yellow-breasted Chat showed a preference for an intermediate shrub cover (48%) and shrub height window (142 cm). In the west this species is found in riparian edges and shrubby habitats. Spotted Towhee and Blue-gray Gnatcatcher breed in dense shrub cover or in areas with thick undergrowth in woodlands. Spotted Towhee and Blue-gray Gnatcatcher shrub cover (61 - 70%) and shrub high window confirm that these species prefer areas with dense shrub cover and areas with shrub height between 107 - 115 cm.

Bird density increased with grass height for Grasshopper Sparrow, Vesper Sparrow and Yellow-breasted Chat. Overall the foothill shrubland Natural Areas will benefit from native grassland restoration along the eastern edges and open meadows. There are large patches of invasive grass

and forb species in a few of the Natural Areas that should be managed, as they will potentially spread further, displacing native grasses and forbs (Figs 14 & 15).

Figure 14: Large patch of Leafy Spurge (*Euphorbia esula*) in Maxwell Natural Area, 2020

Figure 15: Cheat Grass (*Bromus techtorum)* invading eastern-facing hogback hillsides of Maxwell Natural Area, 2020

Shrubland cohesion on average was low within our sampling plots and areas of high cohesion correspond with their spatial distribution on the western edges of the natural area properties. This variable was a strong predictor for shrubland focal species. Shrubland cohesion negatively influenced Grasshopper Sparrow and Vesper Sparrow density suggesting that these species occupy open grassland with scattered shrubs. In contrast shrubland cohesion had a positive relationship to density for Yellow-breasted Chat, Spotted Towhee and Blue-gray Gnatcatcher. These species benefit from maintaining the extensive shrubland habitat on the western edges of the foothill shrubland natural area properties.

The ability to characterize spatial variation in density at the sampling unit scale across the foothills/ shrubland natural areas will help inform conservation planning and quantify species response to vegetation and habitat covariates. The distribution models can be used to prioritize management actions and address key questions in conservation planning (Wilson et al. 2007). The predicted distribution maps (population size or density) can be summarized for any area of interest, such as administrative boundaries or

management units, and confidence intervals can be computed with the parametric bootstrap (Sillette et al. 2012, Royle et al. 2007).

The predictive distribution maps showed variation of high density and species richness across the natural area properties on an east west gradient corresponding to the transition of grasslands to shrublands. The Coyote Ridge/Gindler and Reservoir Ridge natural areas on the south and north ends of the foothill shrubland natural area properties contained high species richness corresponding to large native habitat patches.

The grassland/shrubland connectivity model looked at connectivity among patches and identified large contiguous patches in Gindler/Coyote Ridge, Reservoir Ridge and Maxwell Natural Areas. These large patches coincided with higher focal species richness and density. The largest shrubland/grassland patch occurred in the Gindler/Coyote Ridge Natural Areas and provides a high degree of connectivity to surrounding patches while maintaining high species density and richness. The connectivity model showed perimeter links among patches highlighting where the shortest distance between patches are. Thus identifying areas where patches can be linked to improve connectivity. There are opportunities to improve connectivity to Cathy Fromme Natural Area and the south eastern portion of Coyote Ridge Natural Area. Another large grassland/shrubland patch occurred in Reservoir Ridge Natural Area and within this natural area there is opportunity to restore native habitat and expand connectivity to the eastern portion of this property as well as improving connectivity along the southern corridor towards Maxwell Natural Area.

Maintaining the diversity of unique habitats such as short & tall native grasslands, shrublands, wet meadows and riparian habitats embedded in these foothill natural areas will be important for maintaining biodiversity.

Annual meetings with the Natural Areas Department, land managers, and BCR to share data & results and determine management and conservation goals using birds as indicators would help inform and direct future actions and survey efforts.

Acknowledgements

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Mule deer (*Odocoileus Hemionus*) in Coyote Ridge

Active nests found in the Cathy Fromme Natural Area. **L:** Lark Sparrow (*Chondestes grammacus)* **R:** Vesper Sparrow (*Pooecetes gramineus*)

Bumble Bee (*Bombus spp.*) and Locoweed (*Oxytropis spp.*) and globally imperiled Bell's Twinpod (*Physaria bellii*) both observed in Coyote Ridge Natural Area, 2020.

APPENDIX A - Species List

Number of detections for species recorded in the Foothills/ Shrubland Habitat in 2020.

Common Name	Scientific Name	2020 Detections
Canada Goose	*Branta canadensis*	17
Wood Duck	*Aix sponsa*	2
Mallard	*Anas platyrhynchos*	12
Wild Turkey	*Meleagris gallopavo*	1
Double-crested Cormorant	*Phalacrocorax auritus*	1
Great Blue Heron	*Ardea herodias*	2
Turkey Vulture	*Cathartes aura*	9
Bald Eagle	*Haliaeetus leucocephalus*	2
Northern Harrier*	*Circus hudsonius*	4
Cooper's Hawk	*Accipiter cooperii*	2
Swainson's Hawk	*Buteo swainsoni*	6
Red-tailed Hawk	*Buteo jamaicensis*	13
American Kestrel	*Falco sparverius*	10
Peregrine Falcon	*Falco peregrinus*	1
Prairie Falcon*	*Falco mexicanus*	1
Common Gallinule	*Gallinula galeata*	2
Killdeer	*Charadrius vociferus*	13
Long-billed Curlew	*Numenius americanus*	2
Western Sandpiper	*Calidris mauri*	1
Wilson's Snipe	*Gallinago delicata*	1
Rock Pigeon	*Columba livia*	6
Eurasian Collared-Dove	*Streptopelia decaocto*	7
Mourning Dove	*Zenaida macroura*	94
Great Horned Owl	*Bubo virginianus*	3
Burrowing Owl	*Athene cunicularia*	3
Common Nighthawk*	*Chordeiles minor*	1
Black-chinned Hummingbird	*Archilochus alexandri*	2
Broad-tailed Hummingbird*	*Selasphorus platycercus*	58
Red-headed Woodpecker*	*Melanerpes erythrocephalus*	1
Downy Woodpecker	*Picoides pubescens*	2
Northern Flicker	*Colaptes auratus*	20
Western Wood-Pewee*	*Contopus sordidulus*	7
Dusky Flycatcher	*Empidonax oberholseri*	1
Say's Phoebe	*Sayornis saya*	14
Western Kingbird*	*Tyrannus verticalis*	50
Eastern Kingbird	*Tyrannus tyrannus*	2

Loggerhead Shrike*	*Lanius ludovicianus*	2
Plumbeous Vireo	*Vireo plumbeus*	5
Blue Jay	*Cyanocitta cristata*	9
Woodhouse's Scrub Jay	*Aphelocoma woodhouseii*	3
Black-billed Magpie	*Pica hudsonia*	92
American Crow	*Corvus brachyrhynchos*	4
Common Raven	*Corvus corax*	51
Horned Lark*	*Eremophila alpestris*	143
Tree Swallow	*Tachycineta bicolor*	8
Violet-green Swallow	*Tachycineta thalassina*	4
Bank Swallow	*Riparia riparia*	2
Cliff Swallow	*Petrochelidon pyrrhonota*	9
Barn Swallow	*Hirundo rustica*	37
Black-capped Chickadee	*Poecile atricapillus*	7
Bushtit	*Psaltriparus minimus*	1
Red-breasted Nuthatch	*Sitta canadensis*	6
Rock Wren*	*Salpinctes obsoletus*	82
Canyon Wren	*Catherpes mexicanus*	1
House Wren	*Troglodytes aedon*	39
Blue-gray Gnatcatcher	*Polioptila caerulea*	58
Western Bluebird	*Sialia mexicana*	1
Mountain Bluebird	*Sialia currucoides*	2
American Robin	*Turdus migratorius*	66
Gray Catbird	*Dumetella carolinensis*	1
Northern Mockingbird	*Mimus polyglottos*	9
Brown Thrasher	*Toxostoma rufum*	4
European Starling	*Sturnus vulgaris*	40
Cedar Waxwing	*Bombycilla cedrorum*	2
Orange-crowned Warbler	*Vermivora celata*	1
Virginia's Warbler*	*Vermivora virginiae*	16
Yellow Warbler	*Dendroica petechia*	14
Yellow-rumped Warbler	*Dendroica coronata*	14
American Redstart	*Setophaga ruticilla*	3
Common Yellowthroat	*Geothlypis trichas*	8
Yellow-breasted Chat	*Icteria virens*	96
Western Tanager	*Piranga ludoviciana*	9
Green-tailed Towhee	*Pipilo chlorurus*	2
Spotted Towhee	*Pipilo maculatus*	292
Cassin's Sparrow*	*Peucaea cassinii*	5
Chipping Sparrow	*Spizella passerina*	11

Clay-colored Sparrow	*Spizella pallida*	1
Brewer's Sparrow	*Spizella breweri*	28
Vesper Sparrow	*Pooecetes gramineus*	358
Lark Sparrow	*Chondestes grammacus*	54
Lark Bunting*	*Calamospiza melanocorys*	29
Savannah Sparrow	*Passerculus sandwichensis*	17
Grasshopper Sparrow*	*Ammodramus savannarum*	131
Baird's Sparrow	*Centronyx bairdii*	1
Song Sparrow	*Melospiza melodia*	8
Lincoln's Sparrow	*Melospiza lincolnii*	1
White-crowned Sparrow	*Zonotrichia leucophrys*	1
Black-headed Grosbeak	*Pheucticus melanocephalus*	8
Blue Grosbeak	*Passerina caerulea*	21
Lazuli Bunting	*Passerina amoena*	11
Red-winged Blackbird	*Agelaius phoeniceus*	260
Western Meadowlark*	*Sturnella neglecta*	1039
Rusty Blackbird	*Euphagus carolinus*	1
Brewer's Blackbird*	*Euphagus cyanocephalus*	15
Common Grackle*	*Quiscalus quiscula*	35
Brown-headed Cowbird	*Molothrus ater*	89
Bullock's Oriole	*Icterus bullockii*	53
Baltimore Oriole	*Icterus galbula*	1
Cassin's Finch	*Carpodacus cassinii*	2
House Finch	*Carpodacus mexicanus*	42
Lesser Goldfinch	*Carduelis psaltria*	2
American Goldfinch	*Carduelis tristis*	82
	Total Detections	**3822**

Species with a * are Species of Continental Importance, Common Birds in Steep Decline, Regional Importance, or as Regional Stewardship Species as listed by Partners in Flight (PIF 2017) for Bird Conservation Region 18 (BCR 18).

APPENDIX B - Model selection tables for the density (λ) of 5 focal species at foothill/ shrubland natural areas (using data from 2009 - 2020). The model selection metrics are the number of parameters (K), value of the Akaike Information Criterion for small sample size (QAICc), difference between model and minimum AICc values (ΔQAICc) and the weight of each model (QAICcWt).

Grasshopper Sparrow				
Model	***K***	***QAICc***	***Delta_QAICc***	***QAICcWt***
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	9	3193.96	0	0.52
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	10	3194.1	0.14	0.48
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	9	3204.64	10.68	0
Shrub Cohe + Shrub Cov + Shrub Cov^2	8	3207.15	13.19	0
Shrub Cohe + Grass Cov + Shrub Height + Shrub Height^2	7	3212.26	18.3	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Height + Shrub Height^2	8	3212.33	18.37	0
Shrub Cohe + Grass Height + Shrub Height + ShrubHeight^2	7	3225.03	31.07	0
Shrub Cohe + Shrub Height + Shrub Height^2	6	3227.72	33.76	0
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	7	3233.96	40	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	8	3234.3	40.34	0
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	7	3252.62	58.66	0
Shrub Cohe + Shrub Cov + Shrub Cov^2	6	3257.1	63.14	0
Grass Cov + Shrub Cov + Shrub Cov^2	8	3293.65	99.69	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	9	3295.28	101.32	0
Shrub Cohe + Grass Cov	5	3299.29	105.33	0
Shrub Cohe + Grass Cov + Grass Height	6	3299.84	105.88	0
Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	7	3312.27	118.31	0
Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	8	3312.29	118.33	0
Grass Cov + Shrub Cov + Shrub Cov^2	6	3323.14	129.17	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	7	3324.57	130.61	0
Shrub Cohe + Grass Height	5	3327.51	133.55	0
Grass Cov + Shrub Height + Shrub Height^2	6	3332.63	138.67	0
Shrub Cohe	4	3333.44	139.47	0

Grass Cov + Grass Height + Shrub Height + Shrub Height^2	7	3334.59	140.63	0
Grass Height + Shrub Cov + Shrub Cov^2	6	3349.89	155.93	0
Shrub Cov + Shrub Cov^2	5	3352	158.04	0
Grass Height + Shrub Height + Shrub Height^2	6	3364.97	171.01	0
Grass Cov + Grass Height	5	3383.75	189.79	0
NULL	3	3424.49	230.53	0

Vesper Sparrow

Model	***K***	***QAICc***	***Delta_QAICc***	***QAICcWt***
Shrub Cohe + Grass Cov + Grass Height + ShrubCov+ Shrub Cov^2+ Shrub Height + Shrub Height^2	10	6118.01	0	1
Shrub Cohe + Grass Cov + Grass Height + Shrub Height + Shrub Height^2	8	6132.36	14.35	0
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	9	6132.37	14.36	0
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	9	6135.07	17.06	0
Shrub Cohe + Shrub Cov + Shrub Cov^2	8	6141.41	23.4	0
Shrub Cohe + Grass Cov + Shrub Height + Shrub Height^2	7	6145.88	27.87	0
Shrub Cohe + Grass Height + Shrub Height + ShrubHeight^2	7	6146.56	28.55	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	8	6149.98	31.97	0
Shrub Cohe + Shrub Height + Shrub Height^2	6	6152.99	34.98	0
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	7	6159.02	41.01	0
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	7	6164.83	46.82	0
Shrub Cohe + Shrub Cov + Shrub Cov^2	6	6167.15	49.14	0
Shrub Cohe + Grass Cov + Grass Height	6	6192.89	74.88	0
Shrub Cohe + Grass Height	5	6196.26	78.25	0
Shrub Cohe	4	6205.39	87.38	0
Shrub Cohe + Grass Cov	5	6206.27	88.26	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	9	6373.82	255.81	0
Grass Cov + Shrub Cov + Shrub Cov^2	8	6378.96	260.95	0
Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	8	6382.4	264.39	0
Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	7	6383.87	265.86	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	7	6389.75	271.74	0
Grass Height + Shrub Cov + Shrub Cov^2	6	6393.84	275.83	0

Grass Cov + Shrub Cov + Shrub Cov^2	6	6396.59	278.58	0
Shrub Cov + Shrub Cov^2	5	6397.27	279.27	0
Grass Height + Shrub Height + Shrub Height^2	6	6478.74	360.73	0
Grass Cov + Grass Height + Shrub Height + Shrub Height^2	7	6479.67	361.66	0
Grass Cov + Shrub Height + Shrub Height^2	6	6480.29	362.28	0
NULL	3	6485.96	367.95	0
Grass Cov + Grass Height	5	6487.21	369.2	0

Yellow-breasted Chat

Model	***K***	***QAICc***	***Delta_QAICc***	***QAICcWt***
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	8	2282.11	0	0.41
Shrub Cohe + Grass Cov + Grass Height + ShrubCov+ Shrub Cov^2 + Shrub Height + Shrub Height^2	9	2282.9	0.8	0.28
Shrub Cohe + Shrub Cov + Shrub Cov^2	7	2284.18	2.07	0.15
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	8	2285.41	3.3	0.08
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	6	2286.43	4.33	0.05
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	7	2287.92	5.81	0.02
Shrub Cohe + Shrub Cov + Shrub Cov^2	5	2290.3	8.2	0.01
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	6	2292.04	9.93	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Height + Shrub Height^2	7	2341.93	59.82	0
Shrub Cohe + Grass Height + Shrub Height + ShrubHeight^2	6	2343.08	60.97	0
Shrub Cohe + Grass Cov + Shrub Height + Shrub Height^2	6	2344.24	62.13	0
Shrub Cohe + Shrub Height + Shrub Height^2	5	2344.62	62.51	0
Shrub Cohe + Grass Cov + Grass Height	5	2390.39	108.28	0
Shrub Cohe + Grass Height	4	2391.52	109.41	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	8	2402.5	120.39	0
Shrub Cohe	3	2403.05	120.94	0
Shrub Cohe + Grass Cov	4	2403.14	121.04	0
Grass Cov + Shrub Cov + Shrub Cov^2	7	2407.38	125.28	0
Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	7	2407.81	125.71	0
Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	6	2411.22	129.11	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	6	2417.92	135.81	0
Grass Height + Shrub Cov + Shrub Cov^2	5	2419.76	137.66	0

Grass Cov + Shrub Cov + Shrub Cov^2	5	2425.04	142.93	0
Shrub Cov + Shrub Cov^2	4	2425.71	143.6	0
Grass Cov + Grass Height + Shrub Height + Shrub Height^2	6	2568.05	285.94	0
Grass Cov + Shrub Height + Shrub Height^2	5	2581.42	299.32	0
Grass Height + Shrub Height + Shrub Height^2	5	2599.73	317.63	0
Grass Cov + Grass Height	4	2735.56	453.45	0
NULL	2	2782.97	500.86	0
Blue-gray Gnatcatcher				
Model	***K***	***QAICc***	***Delta_QAICc***	***QAICcWt***
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	8	1187.83	0	0.47
Shrub Cohe + Grass Cov + Grass Height + ShrubCov+ Shrub Cov^2+ Shrub Height + Shrub Height^2	9	1188.91	1.07	0.27
Shrub Cohe + Shrub Cov + Shrub Cov^2	7	1191.78	3.95	0.06
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	6	1191.81	3.98	0.06
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	8	1191.98	4.15	0.06
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	7	1192.79	4.95	0.04
Shrub Cohe + Shrub Cov + Shrub Cov^2	5	1194.17	6.34	0.02
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	6	1194.62	6.78	0.02
Shrub Cohe + Grass Cov + Shrub Height + Shrub Height^2	6	1231.69	43.85	0
Grass Cov + Shrub Cov + Shrub Cov^2	7	1232.43	44.59	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Height + Shrub Height^2	7	1233.6	45.77	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	8	1234.15	46.32	0
Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	6	1241.55	53.71	0
Grass Cov + Shrub Cov + Shrub Cov^2	5	1242	54.17	0
Grass Height + Shrub Cov + Shrub Cov^2 + Shrub Height + Shrub Height^2	7	1242.48	54.65	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	6	1243.71	55.88	0
Shrub Cov + Shrub Cov^2	4	1247.64	59.8	0
Grass Height + Shrub Cov + Shrub Cov^2	5	1248.86	61.02	0
Shrub Cohe + Shrub Height + Shrub Height^2	5	1250.85	63.02	0
Shrub Cohe + Grass Height + Shrub Height + ShrubHeight^2	6	1251.91	64.07	0
Shrub Cohe + Grass Cov	4	1280.79	92.95	0
Shrub Cohe + Grass Cov + Grass Height	5	1281.18	93.35	0

Shrub Cohe	3	1297.92	110.09	0
Shrub Cohe + Grass Height	4	1299.47	111.64	0
Grass Cov + Shrub Height + Shrub Height^2	5	1365.58	177.75	0
Grass Cov + Grass Height + Shrub Height + Shrub Height^2	6	1365.8	177.97	0
Grass Height + Shrub Height + Shrub Height^2	5	1424.47	236.63	0
Grass Cov + Grass Height	4	1506.23	318.4	0
NULL	2	1550.48	362.65	0

Spotted Towhee

Model	***K***	***QAICc***	***Delta_QAICc***	***QAICcWt***
Shrub Cohe + Shrub Cov + Shrub Cov^2	7	4298.33	0	0.48
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	8	4299.89	1.56	0.22
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	8	4299.96	1.63	0.21
Shrub Cohe + Grass Cov + Grass Height + ShrubCov+ Shrub Cov^2+ Shrub Height + Shrub Height^2	9	4301.63	3.3	0.09
Shrub Cohe + Shrub Cov + Shrub Cov^2	5	4328.1	29.78	0
Shrub Cohe + Grass Height + Shrub Cov + Shrub Cov^2	6	4329.88	31.55	0
Shrub Cohe + Grass Cov + Shrub Cov + Shrub Cov^2	6	4330.03	31.7	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	7	4331.77	33.44	0
Shrub Cohe + Grass Cov + Shrub Height + Shrub Height^2	6	4442.55	144.22	0
Shrub Cohe + Grass Cov + Grass Height + Shrub Height + Shrub Height^2	7	4444.56	146.23	0
Shrub Cohe + Shrub Height + Shrub Height^2	5	4451.82	153.49	0
Shrub Cohe + Grass Height + Shrub Height + ShrubHeight^2	6	4453.68	155.35	0
Grass Cov + Shrub Cov + Shrub Cov^2	7	4456.04	157.71	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2+ Shrub Height + Shrub Height^2	8	4458.02	159.69	0
Shrub Cov + Shrub Cov^2 + Shrub Height + Shrub Height^2	6	4458.91	160.58	0
Grass Height + Shrub Cov + Shrub Co^2+ Shrub Height + Shrub Height^2	7	4460.93	162.6	0
Shrub Cov + Shrub Cov^2	4	4503.32	204.99	0
Grass Cov + Shrub Cov + Shrub Cov^2	5	4504.56	206.23	0
Grass Height + Shrub Cov + Shrub Cov^2	5	4505.31	206.98	0
Grass Cov + Grass Height + Shrub Cov + Shrub Cov^2	6	4506.51	208.18	0
Shrub Cohe + Grass Cov + Grass Height	5	4606.94	308.61	0
Shrub Cohe + Grass Cov	4	4610.07	311.75	0

Shrub Cohe + Grass Height	4	4611.96	313.64	0
Shrub Cohe	3	4613.55	315.22	0
Grass Cov + Grass Height + Shrub Height + Shrub Height^2	6	4840.08	541.75	0
Grass Cov + Shrub Height + Shrub Height^2	5	4844.2	545.87	0
Grass Height + Shrub Height + Shrub Height^2	5	4905.31	606.98	0
Grass Cov + Grass Height	4	5255.49	957.16	0
NULL	2	5307.94	1009.61	0