Evaluating avian focal species representation of desired conditions under the Coconino National Forest management plan:

Report

May 2021

Connecting People, Birds and Land

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Bird Conservancy of the Rockies

Connecting people, birds and land

Mission: Conserving birds and their habitats through science, education and land stewardship

Vision: Native bird populations are sustained in healthy ecosystems

Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education, and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship, and sustained through partnerships. Together, we are improving native bird populations, the land, and the lives of people.

Core Values:

1. **Science** provides the foundation for effective bird conservation.
2. **Education** is critical to the success of bird conservation.
3. **Stewardship** of birds and their habitats is a shared responsibility.

Goals:

1. Guide conservation action where it is needed most by conducting scientifically rigorous monitoring and research on birds and their habitats within the context of their full annual cycle.
2. Inspire conservation action in people by developing relationships through community outreach and science-based, experiential education programs.
3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

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Executive Summary

The current U.S. Forest Service planning rule directs individual national forests and grasslands to monitor focal species representing desired conditions that are identified in their forest plans but difficult to measure directly. Accordingly, local resource specialists typically designate focal species based on habitat descriptions that also represent desired conditions targeted by management. These habitat descriptions often reflect best available scientific literature describing species ecology, but they are not necessarily verified empirically within forest boundaries using sampling designs adopted for monitoring those focal species. Thus, whether we can infer changes in desired conditions from focal species population dynamics and trends is unclear.

The Coconino National Forest (CONF) identifies three focal songbird species in their current management plan (hereafter Forest Plan) – Grace's Warbler (*Setophaga graciae*), Black-throated Gray Warbler (*Setophaga nigrescens*), and Juniper Titmouse (*Baeolophus ridgwayi*). The rationale for designating these as focal species is predicated on habitat descriptions of "open, park-like, mature stands of pure ponderosa pine [*Pinus ponderosa*], and pine-oak habitats" for Grace's Warbler, "mature pinyon component of pinyon-juniper habitats" for Black-throated Gray Warbler, and "late-seral pinyon-juniper habitats, particularly the [juniper] snag component," for Juniper Titmouse. The plan for monitoring these species leverages ongoing long-term monitoring under the Integrated Monitoring in Bird Conservation Regions (IMBCR) program. At the start of our study, IMBCR had produced 10 years of data (2009–2018) representing populations for these and various other songbird species across the CONF landscape. These data provided a valuable opportunity to evaluate and empirically test focal species' habitat descriptions, as well as identify potential alternative or additional species for representing desired conditions. Our objectives were to 1) evaluate the consistency of focal species occupancy patterns with predictions representing their habitat descriptions in the Forest Plan, 2) evaluate whether relationships for other bird species were as consistent or more consistent with habitat descriptions as designated focal species, 3) identify species with occupancy relationships suggesting potential to serve as focal species for grasslands (a vegetation type currently lacking focal species), and 4) identify species relationships with additional environmental attributes not explicitly included in desired conditions and that therefore could confound interpretation of population trends to evaluate management? We used Bayesian hierarchical multi-species occupancy models to relate bird species occupancy with remotely sensed and field-measured vegetation covariates to meet these objectives.

Habitat relationships for the three designated focal species largely corroborated their habitat descriptions in the Forest Plan, but other species also exhibited habitat relationships at least as consistent with focal species' habitat descriptions. Grace's Warbler and Juniper Titmouse exhibited habitat relationships largely but not entirely consistent with their habitat descriptions. We identified Mountain Chickadee and Pygmy Nuthatch as potential additional focal species for ponderosa pine forest, and Ash-throated Flycatcher as an additional potential focal species for the juniper and snag components of pinyon-juniper forests. Black-throated Gray Warbler occupancy related positively with pinyon pine, but not with other components of its habitat description, whereas 13 other species exhibited statistically supported relationships more consistent with the mature pinyon pine component of pinyon-juniper forests. We also identified five species with empirical habitat relationships and ecological associations described in the literature suggesting potential for representing grasslands. Considering apparent limitations for any one species to represent desired conditions, we suggest using suites of focal species to represent desired conditions within each vegetation type. We suggest combining results from our study with all available information on species ecology to evaluate representation of desired conditions by potential focal species.

Acknowledgements

We thank Region 3 of the U. S. Forest Service for funding this study. We worked with Mark Bellis (Coconino National Forest) and Jamie Sanderlin (Rocky Mountain Research Station, U.S.D.A. Forest Service) to develop this analysis and identify appropriate remotely sensed data for covariates. We thank Josh Bahling and John Souther for their continued support of this project. We thank IMBCR field technicians who collected avian and vegetation point count data, and the many IMBCR partners that make the program possible. Bird Conservancy of the Rockies staff contributing to this work included Quresh Latif, Matthew McLaren, and Eric Chabot.

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Introduction

The U.S. Forest Service (hereafter USFS) manages forest vegetation structure and composition to maintain ecological integrity, support a diversity of plants and animals, and provide ecosystem services. Because wildlife populations are a central component of these objectives, forest management plans identify and target desired ecological conditions capable of supporting wildlife, and concomitantly identify the need to verify wildlife population persistence via population monitoring. The 2012 Planning Rule requires identifying focal species as one of several foci for monitoring effectiveness of management (36 CFR § 219.19). In particular, focal species are intended to inform ecological integrity and the presence or quality of ecological characteristics that are difficult to measure or monitor directly. As such, focal species population distribution and abundance should relate functionally with ecological characteristics of interest (e.g., vegetation attributes that provide important habitat features for a species). The current planning rule mandates monitoring of at least one focal species by each forest, with local resource specialists and forest planners being responsible for determining which species to monitor and which ecological characteristics they are intended to represent.

The Coconino National Forest (CONF) recently updated their forest management plan (USDA Forest Service 2018; *hereafter* Forest Plan) to align with the 2012 Planning Rule. Monitoring under the updated Forest Plan identifies three avian focal species intended to represent various forest conditions of interest for management: Grace's warbler (*Setophaga graciae*) represent "…open, park-like, mature stands of pure ponderosa pine [*Pinus ponderosa*], and pine-oak habitats," black-throated gray warbler (*Setophaga nigrescens*) represent "mature pinyon component of pinyon-juniper habitats," and juniper titmouse (*Baeolophus ridgwayi*) represent "late-seral pinyon-juniper habitats, particularly the [juniper] snag component." The Forest Plan also specifies criteria of stable or increasing focal species populations for evaluating whether management activities within their respective forest types are maintaining or promoting these conditions.

The CONF plans to evaluate focal species population trends using data from the Integrated Monitoring in Bird Conservation Regions (IMBCR) program (Pavlacky et al. 2017; administered by Bird Conservancy of the Rockies, hereafter Bird Conservancy). Monitoring under IMBCR follows a spatially balanced stratified sampling design (Stevens and Olsen 2004), allowing analysts to estimate avian population parameters at various spatial scales for particular objectives. Thus, IMBCR lays the foundation for cost-effective and meaningful focal species monitoring. Nevertheless, interpretation of population trends under the Forest Plan relies on habitat descriptions reflecting broad habitat associations described in the scientific literature but that have not been verified locally. Species can exhibit variation in habitat relationships across their range (Morrison 2012, Aarts et al. 2013). The lack of empirical verification of focal species' habitat descriptions within CONF boundaries therefore limits our ability to distinguish forest management effects from other potential forest-level drivers of population change.

Uncertainty regarding how well designated species actually represent desired conditions described in the Forest Plan also raises questions about their value as focal species. If empirical tests supported with sufficient data fail to corroborate expected relationships for Grace's Warbler, Black-throated Gray Warbler, or Juniper Titmouse populations with open ponderosa pine forests, pinyon pine forests, or juniper snags, respectively, CONF may need to reevaluate their selection as focal species and identify alternative or additional focal species. Fortunately, IMBCR provides data on a wide range of bird species representing various habitat associations and ecological traits. By quantifying habitat relationships for multiple species, we can evaluate how designated focal species represent desired conditions compared to available alternatives to inform potential refinements to focal species monitoring under the Forest Plan.

The Forest Plan covers three vegetation types that occur extensively enough across the landscape to be substantively represented in forest-wide IMBCR surveys: ponderosa pine forest, pinyon-juniper forest, and grasslands. None of the designated focal species in the Forest Plan represent grasslands. The previous plan identified pronghorn antelope (*Antilocapra americana*) as a management indicator species, but pronghorn was not retained as a focal species due to challenges with monitoring their populations and interpretation of possible population trends for evaluating management. No other species are identified as focal species for grasslands, so grassland monitoring focuses exclusively on vegetation and abiotic metrics. Considering the wide range of species represented by IMBCR, systematic analysis of available data could suggest potential avian focal species to represent grasslands.

With the above considerations, our analysis seeks to address the following questions:

1. Are relationships with vegetation attributes for designated focal species consistent with habitat descriptions identified by the CONF management plan and desired conditions that focal species are intended to represent?

2. Do other bird species covered by IMBCR exhibit relationships with vegetation attributes that are as consistent or more consistent with habitat descriptions and desired conditions identified by the Forest Plan?

3. Do any species covered by IMBCR exhibit ecological associations that indicate potential value to serve as focal species for grasslands?

4. Do selected (or alternative) focal species populations relate with additional environmental attributes not explicitly covered in focal species' habitat descriptions and therefore capable of confounding interpretation of population trends to evaluate management?

Here, we leveraged available IMBCR and remotely sensed vegetation data to address these questions. We then discuss how our results could inform future revisions and refinements of focal species monitoring under the CONF management plan.

Methods

Study area

Our study area and the sampling frame for data analyzed here consists of all lands within CONF boundaries. The Forest Plan defines ecological response units (ERUs), which constitute distinct vegetation types of management concern, and describes desired ecological conditions and management objectives for each ERU (Forest Plan pp. 43–73). Ponderosa pine forest corresponds with the Ponderosa Pine ERU, which primarily consists of two sub-types described as Ponderosa Pine Bunchgrass and Ponderosa Pine Gambel Oak. Pinyon-juniper forest consists of three distinct ERUs (Pinyon Juniper with Grass, Pinyon Juniper Evergreen Shrub, and Pinyon Juniper Woodland), and grasslands also consist of three ERUs (Semi-desert Grassland, Great Basin Grassland, and Montane/Subalpine Grassland). The general distribution of these three vegetation types is presented in Figure 1, and the Forest Plan provides more detailed descriptions and maps of particular ERUs. These three vegetation types represented a large majority but not 100% of lands within CONF boundaries. Including all lands in the sampling frame meant that monitoring data represented some reference conditions for evaluating species relationships with vegetation types and desired conditions of management concern (i.e., vegetation types other than forests and grasslands, e.g., deserts and shrublands).

Sampling

IMBCR is the largest breeding-bird monitoring program in North America that implements a spatially balanced sampling design with professional surveyors. The program relies on multiple governmental and NGO partners, including USFS Regions 1, 2, 3, and 4, for funding, data acquisition, data management, and knowledge generation relevant to land management and biological conservation. Sampling covers much of the Great Plains, intermountain regions, and western U.S., including some national forests in Region 3 of the U.S. Forest Service. Sampling design and data collection protocols are described in detail by Pavlacky et al. (2017) and Hanni et al. (2018).

Sampling for CONF followed the basic IMBCR design, wherein the primary sampling unit consists of a 0.62-mi^2 grid cell, within which bird surveys occur at points arranged in a 4×4 array and spaced evenly (820 ft) apart (Hanni et al. 2018). Surveyors collected data at a spatially balanced sample of 67 grid cells over a nine year period (2009–2017) representing CONF (Table 1, Figure 1), resulting in sampling of major vegetation types proportionate to their extent on the landscape (Table 2).

During each year of sampling, surveyors visited at least 6 points within each grid cell included in the sample (mean [SD] = 12.8 [3.1] points surveyed per grid cell). Surveyors visited each surveyed point within a grid cell once per year for 6 min during the breeding season (dates vary by elevation and state; Hanni et al. 2018) between 0.5 hours before to 5 hours after sunrise (all points within a grid cell are surveyed on the same day). Surveyors recorded all individual birds detected by species, along with distances to detected individuals and the timing of detections within the 6-min survey period (Hanni et al. 2018).

Table 1. Sampling effort by year for forest-wide bird monitoring within the Coconino National Forest. Primary sampling units are 0.62-mi^2 grid cells and secondary units are 410-ft radius circular point-centered plots, with 6–16 points (mean [SD] = 12.8 [3.1]) spaced evenly 820 ft apart nested within grid cells.

Year	Grid cells	Points
2009	54	664
2010	46	598
2011	49	565
2012	49	644
2013	50	669
2014	63	879
2015	39	522
2016	40	408
2017	48	667
All	67	1030

Table 2. Sampling effort by vegetation categories for 2009–2017 forest-wide bird monitoring within the Coconino National Forest. Primary sampling units are 0.61-mi^2 grid cells and secondary units are 410-ft radius circular point-centered plots, with 6–16 points (mean [SD] = 12.8 [3.1]) spaced evenly 820 ft apart within grid cells. Vegetation categories here represent "primary habitat types" described by Hanni et al. (2018) as follows: Ponderosa pine = PP; Pinyon-juniper = PJ and JW; Grassland = GR; Shrubland = DS, SA, SE, and SH; and Other = any other primary habitat type.

Vegetation type	**Survey occasions**	
	grid cell × year	**point × year**
Ponderosa pine	200	2028
Pinyon-juniper	241	2275
Grassland	93	365
Shrubland	79	555
Other	69	393
Total	438	5616

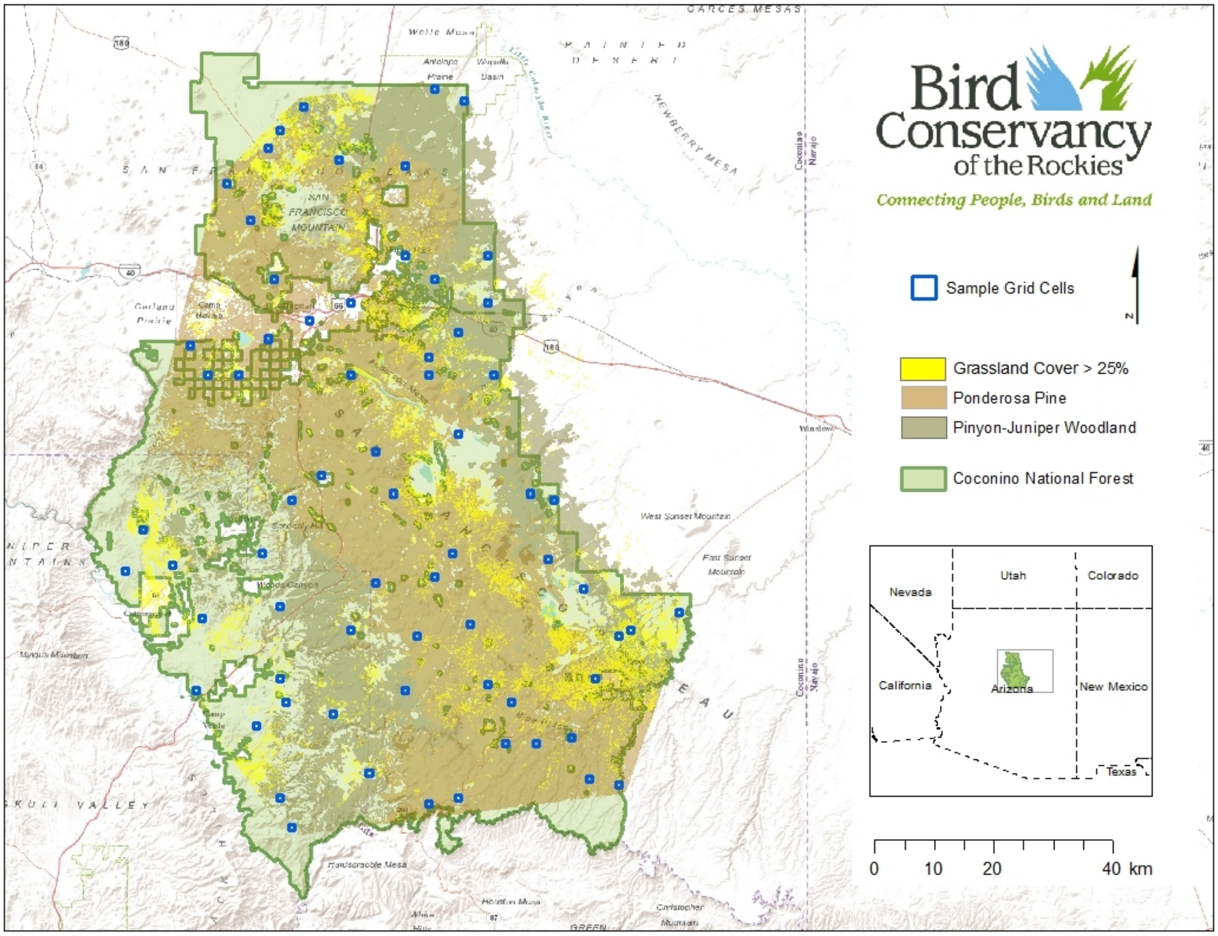

Figure 1. Distribution of sampling units for forest-wide bird monitoring within the Coconino National Forest. Each primary sampling unit for bird surveys consisted of a 0.61mi^2 grid cell containing a 4×4 array of evenly spaced survey points. Ponderosa pine are forested areas with a canopy dominated by ponderosa pine (*Pinus ponderosa*). Pinyon-juniper woodlands have canopy co-dominated by pinyon pine (*Pinus edulis*, *P. monophylla*, or *P. fallax*) and juniper (*Juniperus osteosperma*, *J. monosperma*, *J. deppeana*, or *J. scopulorum*; categorized in Region 3 Existing Vegetation Data). Areas are identified as grassland cover > 25% based on Multi-Resolution Land Characteristics Shrub Product provided by the National Land Cover Dataset.

Environmental data

We compiled 28 metrics of vegetation structure and composition at various spatial scales for use as covariates to estimate habitat relationships (Table 3). Nine of these covariates quantified remotely sensed vegetation attributes of 0.61-mi radius (776 ac) circular neighborhoods centered on grid cell centers. Seven covariates quantified remotely sensed attributes of 410-ft radius (12 ac) neighborhoods centered on survey points. The remaining 12 covariates quantified field-measured vegetation attributes for 164-ft radius (2 ac) circular plots centered on survey points. Field metrics were recorded in conjunction with IMBCR surveys (Hanni et al. 2018). Additionally, two vegetation metrics and two metrics describing the timing of surveys served as covariates of detection probability (see **Data analysis**). We initially compiled additional covariates quantifying canopy cover and patch structure for grid cells (776 ac neighborhoods), but these were strongly correlated with ponderosa pine forest

(PIPO1km; *r* > 0.7) and therefore excluded from analysis. In particular, the extent of canopy gaps (< 10% canopy cover) and open forest (10–40% canopy cover) were included in previous analyses (Latif and Pavlacky 2020, Latif et al. 2020) but not included here due to strong correlations with each other (*r* = -0.77) and with ponderosa pine forest (*r* = -0.85 and 0.73, respectively). Prior to deriving covariates based on canopy cover (CVGap, CVOpen, and CanCov), we adjusted raw canopy cover values to account for wildfires that had occurred between imagery years (2011 and 2016) and each year birds were surveyed. For wildfires that occurred after the imagery year but before a given bird-survey year, we multiplied canopy cover by percent canopy mortality derived from remotely sensed data within wildfire perimeters (MTBS 2020). We treated all canopy cover values for 2009 and 2010 as missing within perimeters of wildfires that occurred after these survey years but before 2011.

Predictions for evaluating focal species and identifying alternatives

We predicted species relationships with covariates based on habitat descriptions appearing in the administrative change that incorporated focal species monitoring into the Forest Plan (Table 4, Appendix A; Forest Plan Administrative Change #1 17 pp.). Habitat descriptions sometimes described a range of conditions under which the species could occur, which do not necessarily imply linear relationships with particular habitat features. Nevertheless, we did our best to develop predictions that represented major habitat components, while acknowledging some subjectivity in interpreting species' habitat descriptions. Moreover, we developed predictions bearing in mind the intention of focal species to represent particular desired conditions targeted by management as clearly as possible. Thus, where habitat descriptions indicated associations with a dominant tree species of a particular vegetation type (e.g., ponderosa pine for Grace's warbler), we predicted both a positive relationship with that species and negative relationships with species that dominate other vegetation types (e.g., pinyon pine and juniper for Grace's warbler).

To identify potential focal species for grasslands (Question 3), we looked for positive relationships with rangeland (identified in remotely sensed data; see Table 3) and herbaceous vegetation, and negative relationships with shrubs, whose encroachment into grasslands represents a major problem for grassland conservation (VanAuken 2009, Bestelmeyer et al. 2018). Recognizing the importance of heterogeneity in grasslands for supporting a range of species associated with various conditions within grasslands (Toombs et al. 2010), we only required potential grassland focal species to exhibit a positive relationship with at least one herbaceous vegetation covariate regardless of whether they also exhibited negative relationships with other herbaceous vegetation metrics. Considering the exploratory nature of this analysis, we also required potential focal species to be identified as grassland associates in the scientific literature (Birds of the World 2021).

Table 3. Covariates used in analyses evaluating species habitat relationships in the Coconino National Forest, Arizona, 2009–2017. Data sources are U.S. Forest Service Tree Canopy Cover (USFS TCC), Region 3 Existing Vegetation (R3 EVEG), Multi-Resolution Land Characteristics Shrub Product (MRLC Shrub), and IMBCR field measurements (IMBCR). Resolution indicates the size of the neighborhood (centered on the grid cell center or survey point) that each variable describes.

Level	Covariate (abbrev.)	Resolution (ac)	Description	Data source
Grid cell	Variation in gap size (CVGap)[4]	776	Coefficient of variation for size of patches with <10% canopy cover within neighborhood	USFS TCC

Level	Covariate (abbrev.)	Resolution (ac)	Description	Data source
	Variation in open forest patch size (CVOpen)[4]	776	Coefficient of variation for size of patches with 10-40% canopy cover within neighborhood	USFS TCC
	Ponderosa pine forest (PIPO1km)[1,2]	776	Percent of neighborhood with ponderosa pine (*Pinus pondersa*) listed as dominant or co-dominant	R3 EVEG
	Pinyon pine forest (PIED1km)[1,2]	776	Percent of neighborhood with pinyon pine (*Pinus edulis*) listed as dominant or co-dominant	R3 EVEG
	Juniper forest (JUOC1km)[1,2]	776	Percent of neighborhood with juniper (*Juniper spp.*) listed as dominant or co-dominant	R3 EVEG
	Rangeland (Range1km)[3,a]	776	Percent of neighborhood classified as rangeland, defined as areas with <25% canopy cover that exclude forested areas and urban and agricultural development	MLRC Shrub
	Annual herbaceous cover (Annual1km)[3]	776	Percent annual herbaceous cover (grasses and forbs) within areas classified as rangeland[e]	MRLC Shrub
	Perennial herbaceous cover (Perennial1km)[3]	776	Percent perennial herbaceous cover (grasses and forbs) within areas classified as rangeland[e]	MRLC Shrub
	Shrub cover (Shrub1km)[3,b]	776	Percent shrub cover within areas classified as rangeland[e]	MRLC Shrub
Point	Canopy cover (CanCov)[1,2,c]	12	Percent canopy cover	USFS TCC
	Canopy height (CanHt)[1,2]	2	Mean height to the top of overstory trees (m)	IMBCR
	Presence of snags (PSnag)[1,2,d]	2	Presence of snags within 50 m of survey points	IMBCR
	Count of snags where present (Nsnag)[1,2,d]	2	Log count of snags within 50 m of survey points where present	IMBCR
	Ponderosa pine forest (PIPO125m)[1,2]	12	Percent of neighborhood with ponderosa pine (*Pinus pondersa*) listed as dominant or co-dominant in USFS R3 existing vegetation data layer	R3 EVEG
	Pinyon pine forest (PIED125m)[1,2]	12	Percent of neighborhood with pinyon pine (*Pinus edulis*) listed as dominant or co-dominant	R3 EVEG
	Pinyon-juniper forest (JUOC125m)[1,2]	12	Percent of neighborhood with juniper (*Juniper spp.*) listed as dominant or co-dominant	R3 EVEG
	Pinyon pine canopy (PIED50m)	2	Percent of canopy consisting of pinyon pine (relative cover)	IMBCR
	Juniper canopy (JUOC50m)	2	Percent of canopy consisting of juniper (relative cover)	IMBCR
	Gambel oak canopy (QUGA50m)[1,2]	2	Percent of canopy consisting of Gambel oak (relative cover)	IMBCR

Level	Covariate (abbrev.)	Resolution (ac)	Description	Data source
	Shrub-sapling cover (ShrubCov)	2	percent cover of woody vegetation (within 0.25-3m) within a 50m radius of the survey point	IMBCR
	Shrub-sapling height (ShrubHt)	2	mean height of woody vegetation (within 0.25-3m) within a 50m radius of the survey point (zero for points without shrubs)	IMBCR
	Ladder fuels (Ladder)[4]	2	Percent of shrub-sapling layer (0.25-3m) consisting of ladder fuel species, i.e., conifer, juniper, and Gambell's oak saplings	IMBCR
	Rangeland (Range125m)[3]	12	Percent of neighborhood classified as rangeland, defined as areas with <25% canopy cover that exclude forested areas and urban and agricultural development	MLRC Shrub
	Annual herbaceous cover (Annual125m)[3]	12	Percent annual herbaceous cover (grasses and forbs) within areas classified as rangeland[e]	MRLC Shrub
	Perennial herbaceous cover (Perennial125m)[3]	12	Percent perennial herbaceous cover (grasses and forbs) within areas classified as rangeland[e]	MRLC Shrub
	Forb cover (ForbCov)[4]	2	Percent cover of forbs	IMBCR
	Grass cover (GrassCov)[3]	2	Percent cover of live grasses	IMBCR
	Herbaceous (HerbHt)[3]	2	Average height of live grasses and forbs	IMBCR
Detection	Canopy cover (CCov_IMBCR)	2	Percent canopy cover measured in the field	IMBCR
	Shrub-sapling volume (ShrubVol)	2	Cube root of volume (m^3), where volume = area covered (max = 7854 m^2, i.e., plot area) × average shrub height (m) for woody shrub and seedling trees species	IMBCR
	Day of year (DOY)[c]	--	Number of days elapsed since January 1	IMBCR
	Time since sunrise (Time)[c]	--	Number of minutes elapsed since sunrise	IMBCR

[a]Extent of rangeland was negatively correlated with canopy cover, so we analyzed relationships with rangeland metrics separately from relationships with canopy metrics (see **Data analysis** for details).
[b]The MRLC shrub product adjusts shrub cover values in pinyon-juniper woodlands to correct for measurement bias.
[c]Effects of CanCov, DOY, and Time were represented as a quadratic ($x + x^2$) to allow for non-linear relationships in analysis models.
[d]We only found snags at 43% of survey points. We therefore broke up snag counts into two metrics, 1) presence/absence and 2) count given presence, to distinguish species relationships with a few snags versus relationships with many snags.
[e]Rangeland is defined in the MRLC shrub product as areas with <25% canopy cover that exclude forested areas and urban and agricultural development.
[1-4]Indicates the numbered question(s) that each covariate is intended to address (see **Introduction**).

Table 4. Predicted habitat relationships for focal species designed to test habitat descriptions in the Coconino Forest Plan. Habitat features were represented during data analysis by ≥ 1 covariate (for full names and descriptions, see Table 3). Predicted relationships were positive (+), negative (-), or non-linear with population occupancy maximized at intermediate conditions (∩). The language in habitat descriptions upon which we based each prediction is also listed. Grassland focal species are not specified in the Coconino Forest Plan, but we specify here relationships we looked for to identify potential grassland focal species.

Species	Habitat feature (Covariates)	Prediction	Habitat descriptions
Grace's warbler	Canopy cover (CanCov)	- or ∩	...open, park-like ... habitats.
	Ponderosa pine (PIPO1km, PIPO125m)	+	…pure ponderosa pine … pine-oak habitats.
	Canopy height (CanHt)	+	…mature stands…
	Gambell oak (QUGA50m)	+	…pine-oak habitats.
Black-throated gray warbler	Pinyon pine (PIED1km, PIED125m, PIED50m)	+	…pinyon component of pinyon-juniper habitats. … more frequently in … stands that contain higher densities higher densities of mature pinyon pine….
	Juniper (JUOC1km, JUOC125m, JUOC50m)	-	…pinyon component of pinyon-juniper habitats … may avoid … stands comprised primarily of juniper ….
	Canopy height (CanHt)	+	…mature pinyon pine … more frequently in taller … stands ….
Juniper titmouse	Juniper (JUOC1km, JUOC125m, JUOC50m)	+	…strongly associated with … Utah and one-seed junipers.
	Canopy height (CanHt)	+	… late seral … habitats….
	Snags (PSnag, NSnag)	+	… snag component.
Potential grassland species	Rangeland (Range1km, Range 125m)	+	--
	Herbaceous vegetation (Annual1km, Annual125m, Perennial1km, Perennial125m, GrassCov, ForbCov, HerbHt)	+[a]	--
	Shrubs (ShrubCov, ShrubHt)	-	--

[a]To allow identification of species capable of representing different components of grasslands, we expected potential grassland focal species to exhibit a positive relationship with at least one metric of herbaceous vegetation even if they also exhibited negative relationships with other herbaceous vegetation metrics.

Data analysis

We evaluated our predictions within an analysis framework focused on species occupancy of grid cells and survey points within occupied grid cells. The Forest Plan specifies trends in both occupancy and abundance as metrics for focal species monitoring. We focus here on occupancy for two reasons: 1) occupancy and abundance are related (MacKenzie and Nichols 2004, Clare et al. 2015; Figure 2), so analyzing both was unnecessary to meet our objectives, and 2) established tools for analyzing occupancy readily facilitate multi-species analysis and analysis of vital rates underlying observed occupancy patterns (i.e., occupancy dynamics; Dorazio et al. 2010, Latif and Pavlacky 2020). Our multi-species framework allowed us to address Question 2 (see **Introduction**) by facilitating simultaneous analyses of habitat relationships for designated focal species and for potential alternative species. Additionally, habitat relationships with colonization and extirpation (components of occupancy trend over time) supported more robust tests of our predictions than would habitat relationships of occupancy alone.

We used a dynamic multi-species hierarchical framework to model species occupancy and occupancy dynamics (Dorazio et al. 2010; model structure detailed in Appendix B). We extended community models (Dorazio et al. 2006, Iknayan et al. 2014) to estimate occupancy at multiple scales (Mordecai et al. 2011, Pavlacky et al. 2012), mirroring our hierarchical sampling design (Pavlacky et al. 2017). Community models included individual occupancy models for each species, while allowing information sharing across species to improve estimates for individual species. To quantify occupancy dynamics, we estimated initial occupancy and subsequent annual occupancy changes of colonization (probability of an unoccupied cell becoming occupied in the following year) and extirpation (probability of an occupied cell becoming unoccupied in the following year; MacKenzie et al. 2003, Royle and Kéry 2007). We excluded from our analysis raptors, owls, grouse, cranes, and water birds not readily detectable with our survey methods. We also only included species that breed in our study area and excluded detections flagged as likely representing migrants (Hanni et al. 2018). We followed the multi-scale parameterization developed by Green et al. (2019), whereby we modeled annual colonization and extirpation rates at a grid cell level, and conditioned point level occupancy on the occupancy status of the grid cell.

We tested our predictions (Table 4) against covariate relationships with occupancy and annual dynamics. We considered predictions corroborated where a covariate relationship with occupancy and colonization was statistically supported and its direction matched our prediction. Additionally, to corroborate a prediction, we evaluated whether relevant covariate relationships with extirpation were statistically supported and opposite in direction to that of our prediction. We considered a relationship statistically supported if the 95% Bayesian credible interval (BCI) for the corresponding parameter estimate excluded zero. In cases where supported habitat relationships for multiple species matched our predictions, we also considered the magnitude of these relationships and the number of relationships (where multiple covariates represented a given habitat feature) for evaluating and comparing potential focal species. Additionally, we considered relationships with components of occupancy dynamics (colonization and extirpation) particularly relevant to informing interpretation of focal species population trends. Thus, we considered species exhibiting such relationships with desired conditions to be of particular value as focal species.

To avoid difficulties of interpreting models in the presence of multicollinearity, we avoided including correlated covariates ($r \geq 0.7$) for a given parameter (i.e., grid cell occupancy, colonization, extirpation, point occupancy, or detectability) in the same model (Neter et al. 1996). We made one exception to this rule – we included canopy height (CanHt) in the same model with canopy cover (CanCov; $r = 0.71$) because both were critical for addressing Questions 1, 2, and 4 and because we found informative species relationships with both in the same model (i.e., relationships consistent with species ecology) despite their correlation in initial analyses. In contrast, we excluded other covariates entirely from our analysis (noted above) and we also excluded rangeland metrics (Range1km, Range125m) from our primary model used to address Questions 1, 2, and 4 because rangeland metrics were correlated with several canopy metrics (PIPO1km, CanHt, CanCov). Considering the importance of rangeland metrics for identifying potential grassland focal species, we implemented a separate analysis for addressing Question 3 that included rangeland metrics while excluding most canopy metrics (i.e., PIPO1km, PIED1km, JUOC1km, CanCov, CanHt, PSnag, NSnag, PIPO125m, PIED125m, JUOC125m, PIED50m, JUOC50m, and QUGA50m were excluded; hereafter grassland model).

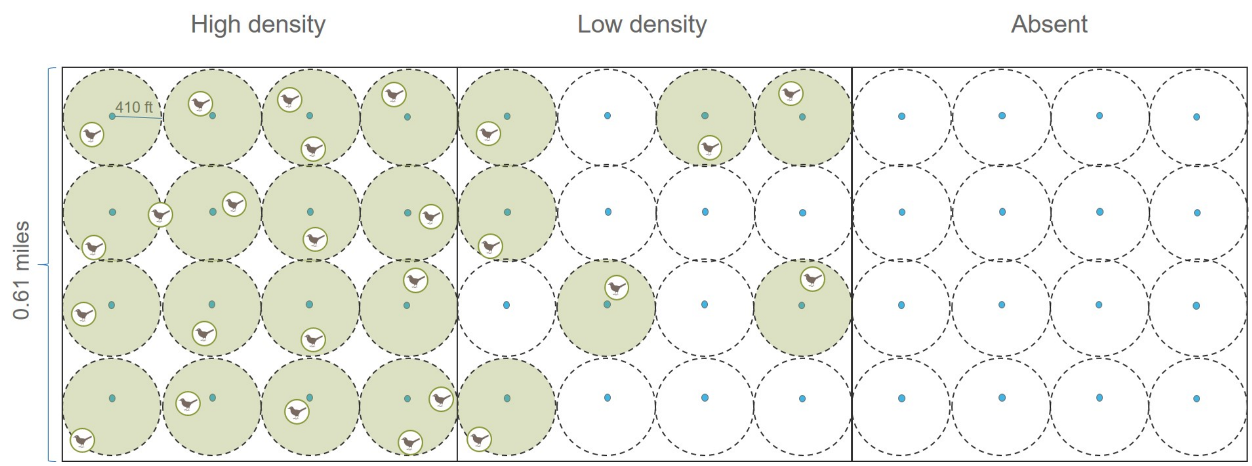

Figure 2. Relationship of grid cell and point occupancy with population density. We considered a point occupied if at least one member of the species was present within 410 ft of the point during a survey, and a grid cell occupied if at least one point is occupied within the grid cell. If population density is high enough, all points in a grid cell will be occupied. At lower densities, only a subset of points would be occupied. Where the species is absent, all points and the grid cell as a whole would be unoccupied. Thus, occupancy of points and grid cells relate with variation in population density at different spatial scales. Note that the relationship between occupancy and density is especially strong when surveying points only once per year and estimating detectability within a survey (as with IMBCR). For repeat-survey protocols, the size of the territory and extent of individual space use over the course of a breeding season also influences the correspondence of occupancy with density.

Results

We detected 130 species during the study period. The five most commonly detected species were Chipping Sparrow, Dark-eyed Junco, Plumbeous Vireo, Grace's Warbler, and Ash-throated Flycatcher (Appendix C). For Grace's warbler, Black-throated Gray Warbler, and Juniper Titmouse (designated focal species), we recorded 1092, 427, and 884 detections respectively (see Appendix C for other species detection totals). Bird surveys sampled a substantive range of covariate values for both grid cells and survey points (Table 5).

We found statistically supported relationships for all three designated focal species (Figures 3, 4) that largely corroborated our predictions representing their habitat descriptions (Tables 6–8). For each designated focal species, however, we identified one or more alternative species with habitat relationships at least as consistent with predictions for focal species as the designated focal species themselves (Tables 6–8). Posterior median detectability estimates for a 6-min survey ranged 0.48–0.97 across species with the primary model and 0.34–0.97 with the grassland model, with 51 and 59 species exhibiting statistically supported covariate relationships with detectability in primary and grassland models, respectively (Appendix D).

Grace's Warbler and alternative focal species for ponderosa pine forest

Consistent with our predictions for Grace's warbler, we found positive relationships with ponderosa pine, Gambel oak, and canopy height, an association with intermediate levels of canopy cover, and a negative relationship with juniper, although we found no evidence for any relationship with pinyon pine (Table 6, Figures 3, 5). Additionally, we found unanticipated relationships for Grace's warbler with snags and herbaceous vegetation (Table 6, Figure 5).

Mountain Chickadee and Pygmy Nuthatch relationships matched the same number of Grace's Warbler predictions as did Grace's Warbler relationships, although species differed slightly in magnitude and which predictions they matched (Table 6). In contrast with Grace's Warbler, Mountain Chickadee and Pygmy Nuthatch occupancy related negatively with pinyon pine and neither species associated notably with Gambel oak (Table 6, Figure 3, Figures E9 and E10 in Appendix E). Additionally, both species exhibited somewhat stronger positive relationships with ponderosa pine than Grace's Warbler (compare Figures E9 and E10 with Figure 5). Like Grace's Warbler, each of these species exhibited relationships with various habitat features not explicitly mentioned in the habitat description for Grace's Warbler (Table 6, Figures E9 and E10 in Appendix E).

Black-throated Gray Warbler and alternatives for pinyon pine

Positive relationships with pinyon pine were consistent with our predictions for black-throated gray warbler (Table 7, Figures 4, 6). Nevertheless, relations with canopy height (none supported) and ponderosa pine (variable across scales) failed to clearly support our predictions for this species, and a positive relationship with juniper contradicted our prediction (Table 7, Figures 4, 6). We also found unanticipated relationships for black-throated gray warbler with shrubs and canopy cover (Table 7, Figure 6).

We identified 13 other species with occupancy relationships that were more consistent with our predictions for Black-throated Gray Warbler than the focal species itself (Table 7, Figure 4). These 13 species exhibited positive relationships with pinyon pine while also exhibiting relationships we expected but did not find for Black-throated Gray Warbler (Figure 4, Appendix E). In particular, Common Raven was the only species with habitat relationships consistent with all four of our expectations representing the habitat description for Black-throated Gray Warbler (Table 7). Additionally, Black-headed Grosbeak relationships were consistent with all of our expectations except for juniper (Table 7). Black-throated Gray Warbler relationships with pinyon pine were stronger, more consistently supported across scales, and involved occupancy dynamics (i.e., parameters particularly relevant to interpreting population trends) more so than those for other species, however. The 13 species identified as potential alternatives to Black-throated Gray Warbler also exhibited various relationships with habitat features not explicitly mentioned in the habitat description for Black-throated Gray Warbler (Table 7, Appendix E).

Juniper Titmouse and alternatives for juniper

Juniper Titmouse relationships with juniper (positive), ponderosa pine (negative), and snags (positive) corroborated our predictions (Table 8, Figures 4, 7), but relationships with pinyon pine (mixed across scales) and canopy height failed to provide clear evidence for evaluating predictions for this species (Table 8, Figures 4, 7). We also found unanticipated relationships for Juniper Titmouse with shrubs, ladder fuels, and herbaceous vegetation (Table 8, Figure 7). Ash-throated Flycatcher also exhibited relationships consistent with our expectations representing the Juniper Titmouse habitat description, along with other relationships not mentioned in the focal species' habitat description (Table 8). Specifics of which covariates related with occupancy and at which scales differed between these two species, however (compare Figure 7 with Figure E1 in Appendix E).

Potential grassland focal species

We identified 13 species that exhibited statistically supported habitat relationships with rangeland and herbaceous vegetation consistent with our expectations for potential grassland focal species, of which five are described in the literature as grassland associates: Lark Sparrow (Martin and Parrish 2020), Canyon Towhee (Johnson and Haight 2020), Eastern Meadowlark (Jaster et al. 2020), Rufous-crowned Sparrow (Collins 2020), and Western Meadowlark (David and Lanyon 2020; Table 9, Figure 8, Appendix F). None of these species exhibited consistently negative relationships with shrubs. Lark Sparrow did exhibit negative relationships with shrub cover at both coarse and fine spatial scales but related positively with shrub height. Species varied in how they related with herbaceous vegetation; some species associated more so with perennial herbaceous vegetation (Lark Sparrow, Western Meadowlark), whereas others related more with annual vegetation (Canyon Towhee, Rufous-crowned Sparrow; Figure 8, Appendix F).

Table 5. Summary values (mean, standard deviation [SD], and range) for covariates used in multi-species occupancy models for evaluating focal species habitat descriptions. For complete variable names and descriptions, see Table 3.

Scale	Variable	Mean (SD, range)	*n*
Grid cell	CVOpen	174.96 (68.07, 25.71-341.79)	438
	CVGap	169.49 (57.08, 44.18-306.56)	438
	PIPO1km	38.62 (43.45, 0-100)	438
	PIED1km	3.36 (11.27, 0-72.46)	438
	JUOC1km	25.93 (33.57, 0-100)	438
	percRange1km	58.21 (42.51, 0-100)	438
	Annual1km	0.96 (1.43, 0-6.52)	438
	Perennial1km	18.45 (6.32, 0-33.2)	438
	Shrub1km	18.75 (8.88, 0-52.85)	438
Point	CanCov	9.28 (11.9, 0-70.4)	5616
	CanHt	9.01 (6.14, 0-45)	5616
	Psnag[a]	0.43	5616
	NSnag[a]	3.55 (8.85, 1-200)	2414
	PIPO125m	38.95 (46.96, 0-100)	5616
	PIED125m	2.04 (12.85, 0-100)	5616
	JUOC125m	26.06 (40.62, 0-100)	5616
	PIED50m	6.89 (17.02, 0-100)	5616
	JUOC50m	41.21 (43.26, 0-100)	5616
	QUGA50m	2.56 (6.75, 0-90)	5616
	ShrubCov	8.26 (8.95, 0-80)	5616
	ShrubHt	1.07 (0.63, 0-3)	5616
	Ladder	48.63 (40.91, 0-100)	5616
	Range125m	58.37 (45.63, 0-100)	5616
	Annual125m	0.73 (1.53, 0-10.62)	5616
	Perennial125m	13.2 (9.47, 0-38)	5616
	ForbCov	4.52 (6.57, 0-80)	5616
	GrassCov	20.97 (15.89, 0-98)	5616
	HerbHt	15.45 (9.46, 0-106)	5616
Detection	CCov_IMBCR	16.49 (12.79, 0-80)	5616
	ShrubVol	7.54 (3.9, 0-21.12)	5616
	DOY	150.1 (18.18, 119-191)	5616
	Time[b]	104.96 (72.49, -40.55-364.47)	3789

[a]Presence of snags (PSnag) is binary, so only the proportion is summarized. The number of snags (NSnag) was conditional (i.e., only functioned as a covariate) where snags were present (PSnag = 1), so the sample size represents the number of points with at least one snag.
[b]Values for Time were missing for some surveys, in which case values were imputed with the mean for analysis.

Table 6. Consistency of habitat relationships for Grace's Warbler and potential alternative focal species with predictions representing Grace's warbler habitat described in the Coconino Forest Plan. The direction of predicted relationships and unanticipated relationships with habitat features were represented as positive [+], negative [-], or peak occupancy at intermediate levels [∩]. Some habitat features are represented by multiple covariates potentially measured at various scales (see Table 4). Relationships with these features were described as "mixed" if the direction differed among covariates representing that feature.

Species	**Evidence for predicted habitat relationships (predicted direction)**						**Unanticipated relationships**
	Ponderosa pine (+)	**Canopy height (+)**	**Gambel oak (+)**	**Canopy cover (∩)**	**Pinyon pine (-)**	**Juniper (-)**	
Grace's Warbler[a]	supported	supported	supported	supported	none	supported	Snags (mixed); Herbaceous vegetation (mixed)
Mountain Chickadee	supported	supported	none	supported	supported	supported	Snags (-); Shrubs (mixed); Forb cover (-)
Pygmy Nuthatch	supported	supported	none	supported	supported	supported	Shrubs (-); Herbaceous vegetation (mixed)

[a]Grace's warbler is designated as a focal species in the Coconino Forest Plan. All predictions here represent the habitat description for this species in the Forest Plan.

Table 7. Consistency of habitat relationships for Black-throated Gray Warbler and potential alternative focal species with predictions representing Black-throated Gray Warbler habitat described in the Coconino Forest Plan. The direction of predicted relationships and unanticipated relationships with habitat features were represented as positive [+], negative [-], or peak occupancy at intermediate levels [∩]. Some habitat features are represented by multiple covariates potentially measured at various scales (see Table 4). Relationships with these features were described as "mixed" if the direction differed among covariates representing that feature.

Species	**Evidence for predicted habitat relationships (predicted direction)**				**Unanticipated relationships**
	Pinyon pine (+)	**Juniper (-)**	**Ponderosa pine (-)**	**Canopy height (+)**	
Black-throated Gray Warbler[a]	supported	contradicted	mixed	none	Canopy cover (∩); Shrubs (+)
Common Raven	supported	supported	supported	supported	Canopy cover (∩); Shrubs (-)
Black-headed Grosbeak	supported	none	supported	supported	Canopy cover (∩); Gambell oak (+); Shrubs (+)
White-throated Swift	supported	none	supported	none	Herbaceous vegetation (+)
Scott's Oriole	supported	none	supported	none	Shrubs (+)
Bushtit	supported	none	supported	none	Shrubs (+); Herbaceous vegetation (-)
Rock Wren	supported	none	supported	none	Canopy cover (-); Shrubs (-)

Species	Evidence for predicted habitat relationships (predicted direction)				Unanticipated relationships
	Pinyon pine (+)	Juniper (-)	Ponderosa pine (-)	Canopy height (+)	
Black-chinned Sparrow	supported	none	supported	none	Canopy cover (-); Gambel oak (+); Shrubs (+); Perennial herbaceous cover (-)
Rufous-crowned Sparrow	supported	contradicted	supported	none	Canopy cover (-); Shrubs (+); Herbaceous vegetation (mixed)
Bewick's Wren	supported	contradicted	supported	none	Canopy cover (∩); Gambell oak (+); Shrubs (+); Ladder fuel shrubs & saplings (+); Herbaceous vegetation (-)
Spotted Towhee	supported	contradicted	supported	none	Shrubs (+); Herbaceous vegetation (mixed)
Yellow-rumped Warbler	supported	supported	contradicted	none	Canopy cover (∩); Canopy gap variation (-); Snags (mixed); Gambell oak (+); Shrubs (mixed); Herbaceous vegetation (-)
Hepatic Tanager	supported	none	contradicted	none	Canopy cover (∩); Canopy gap variation (+)
Gray Flycatcher	supported	contradicted	mixed	none	Canopy cover (∩); Ladder fuel shrubs & saplings (+); Herbaceous vegetation (mixed)

[a]Black-throated Gray Warbler is a designated focal species in the Coconino Forest Plan. All predictions represent the habitat description for this species in the Forest Plan.

Table 8. Consistency of habitat relationships for Juniper Titmouse and one potential alternative focal species with predictions representing Juniper Titmouse habitat described in the Coconino Forest Plan. The direction of predicted relationships and unanticipated relationships with habitat features are represented as positive [+], negative [-], or peak occupancy at intermediate levels [∩]. Some habitat features are represented by multiple covariates potentially measured at various scales (see Table 4). Relationships with these features were described as “mixed” if the direction differed among covariates representing that feature.

Species	Evidence for predicted habitat relationships (predicted direction)					Unanticipated relationships
	Juniper (+)	Pinyon pine (-)	Ponderosa pine (-)	Canopy height (+)	Snags (+)	
Juniper Titmouse[a]	supported	mixed	supported	none	supported	Shrubs (+); Ladder fuel shrubs & saplings (+); Herbaceous vegetation (-)

Species	Evidence for predicted habitat relationships (predicted direction)					Unanticipated relationships
	Juniper (+)	Pinyon pine (-)	Ponderosa pine (-)	Canopy height (+)	Snags (+)	
Ash-throated Flycatcher	supported	mixed	supported	none	supported	Canopy cover (-); Gambell oak (-); Shrubs (+); Herbaceous vegetation (-)

[a]Juniper Titmouse is a designated focal species in the Coconino Forest Plan. All predictions represent the habitat description for this species in the Forest Plan.

Table 9. Potential grassland focal species identified based on the consistency of their habitat relationships with expectations for a species to represent grasslands. The direction of expected relationships with habitat features are represented as positive [+], negative [-], or mixed. Each habitat feature was represented by multiple covariates measured at various scales (see Table 4). Mixed relationships are those where we found both positive and negative relationships with covariates representing the feature of interest. The table also lists whether or not each species is described in the literature (Birds of the World species account) as associated with grasslands.

Species	Evidence for habitat relationships (expected direction)			Grassland associate in literature?
	Rangeland (+)	Herbaceous vegetation (+ or mixed)	Shrubs (-)	
Ladder-backed Woodpecker	supported	supported	none	no
Lark Sparrow	supported	supported	mixed	yes
Canyon Towhee	supported	supported	none	yes
Eastern Meadowlark	supported	supported	none	yes
Mourning Dove	supported	supported	none	no
Gray Flycatcher	supported	supported	none	no
Blue-gray Gnatcatcher	supported	supported	none	no
Northern Mockingbird	supported	supported	mixed	no
Phainopepla	supported	supported	none	no
Black-throated Sparrow	supported	supported	mixed	no
Rufous-crowned Sparrow	supported	supported	none	yes
Western Meadowlark	supported	supported	none	yes
Scott's Oriole	supported	supported	mixed	no

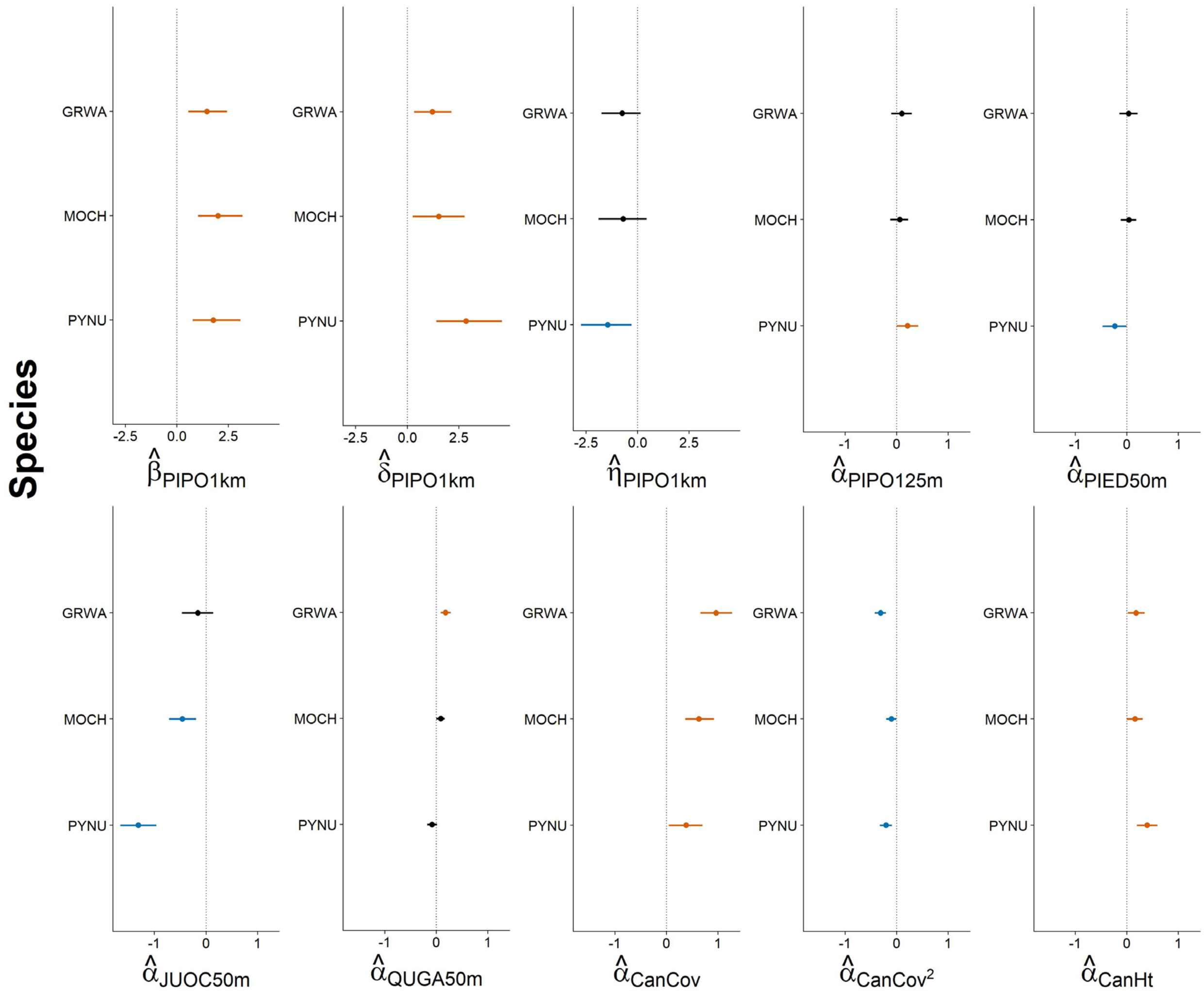

Figure 3. Estimated covariate relationships (posterior medians and 95% BCIs) with occupancy for Grace's Warbler (GRWA), Mountain Chickadee (MOCH), and Pygmy Nuthatch (PYNU). GRWA is the focal species identified to represent ponderosa pine forest in the Coconino Forest Plan. Relationships shown are those relevant to the habitat description for Grace's Warbler in the Coconino Forest Plan. MOCH and PYNU are the two species that exhibited habitat relationships at least as consistent with the Grace's Warbler habitat description as Grace's Warbler. Covariate relationships are for initial grid cell occupancy (β), grid cell colonization (δ), grid cell extirpation (η), and point occupancy (α; for complete covariate names and descriptions, see Table 3). Colors indicate statistically supported positive (red) and negative (blue) relationships. Because all covariates were scaled the same prior to analysis (mean = 0, SD = 1), relationship magnitudes are comparable across panels in this figure.

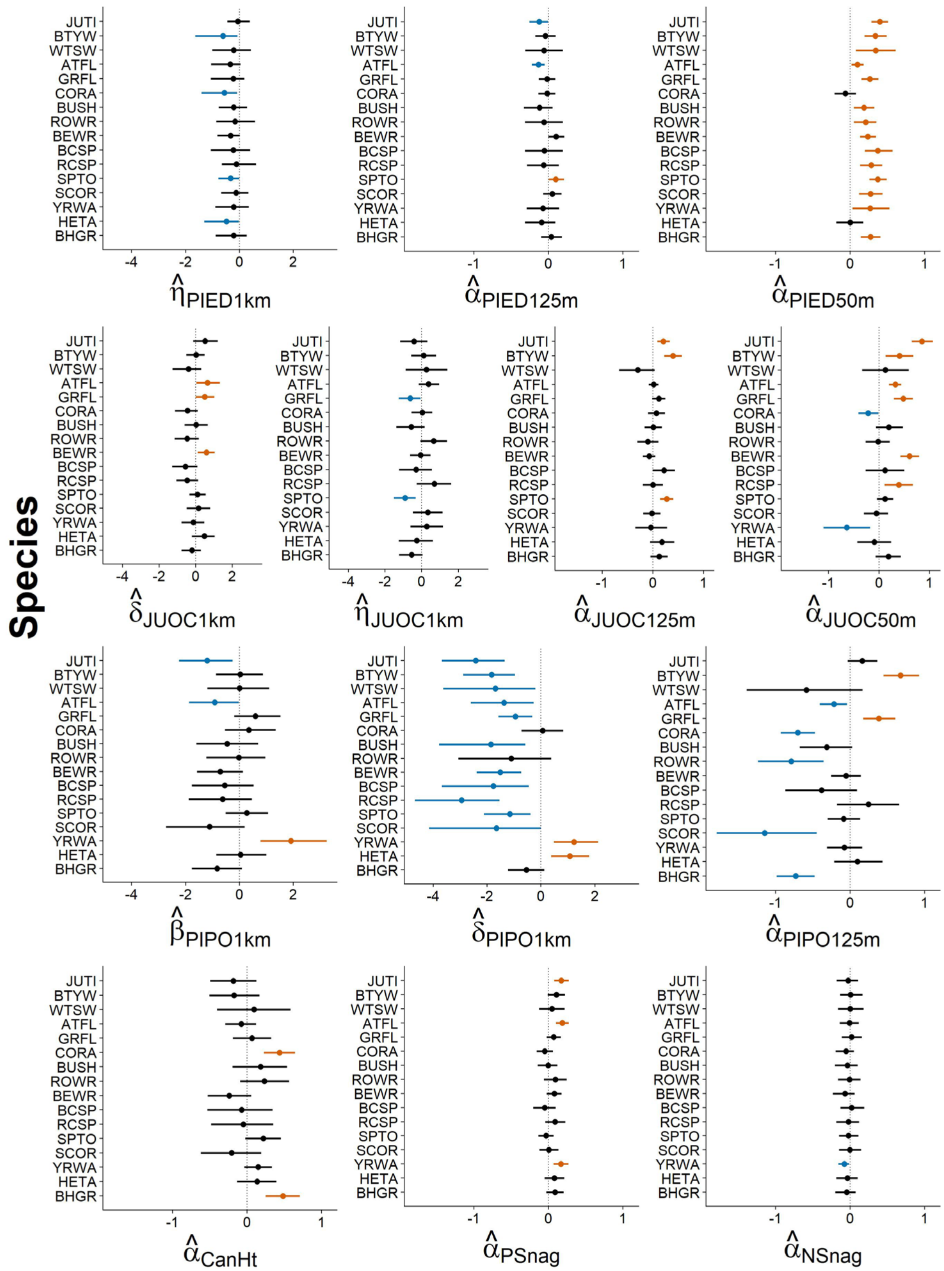

Figure 4. Estimated covariate relationships (posterior medians and 95% BCIs) with occupancy for Juniper Titmouse (JUTI), Black-throated Gray Warbler (BTYW), and 14 other species associated with pinyon-juniper forests (for full species names, see Appendix B). JUTI and BTYW are focal species identified in the Coconino Forest Plan to represent the juniper and pinyon components, respectively, of pinyon juniper forests. Relationships shown are those relevant to the habitat descriptions for JUTI and BTYW in the Coconino Forest Plan. The other 14 species are those that exhibited habitat relationships at least as consistent with either JUTI or BTYW habitat descriptions as JUTI and BTYW. Covariate relationships are for initial grid cell occupancy (β), grid cell colonization (δ), grid cell extirpation (η), and point occupancy (α; for complete covariate names and descriptions, see Table 3). Colors indicate statistically supported positive (red) and negative (blue) relationships. Because all covariates were scaled the same prior to analysis (mean = 0, SD = 1), relationship magnitudes are comparable across panels in this figure.

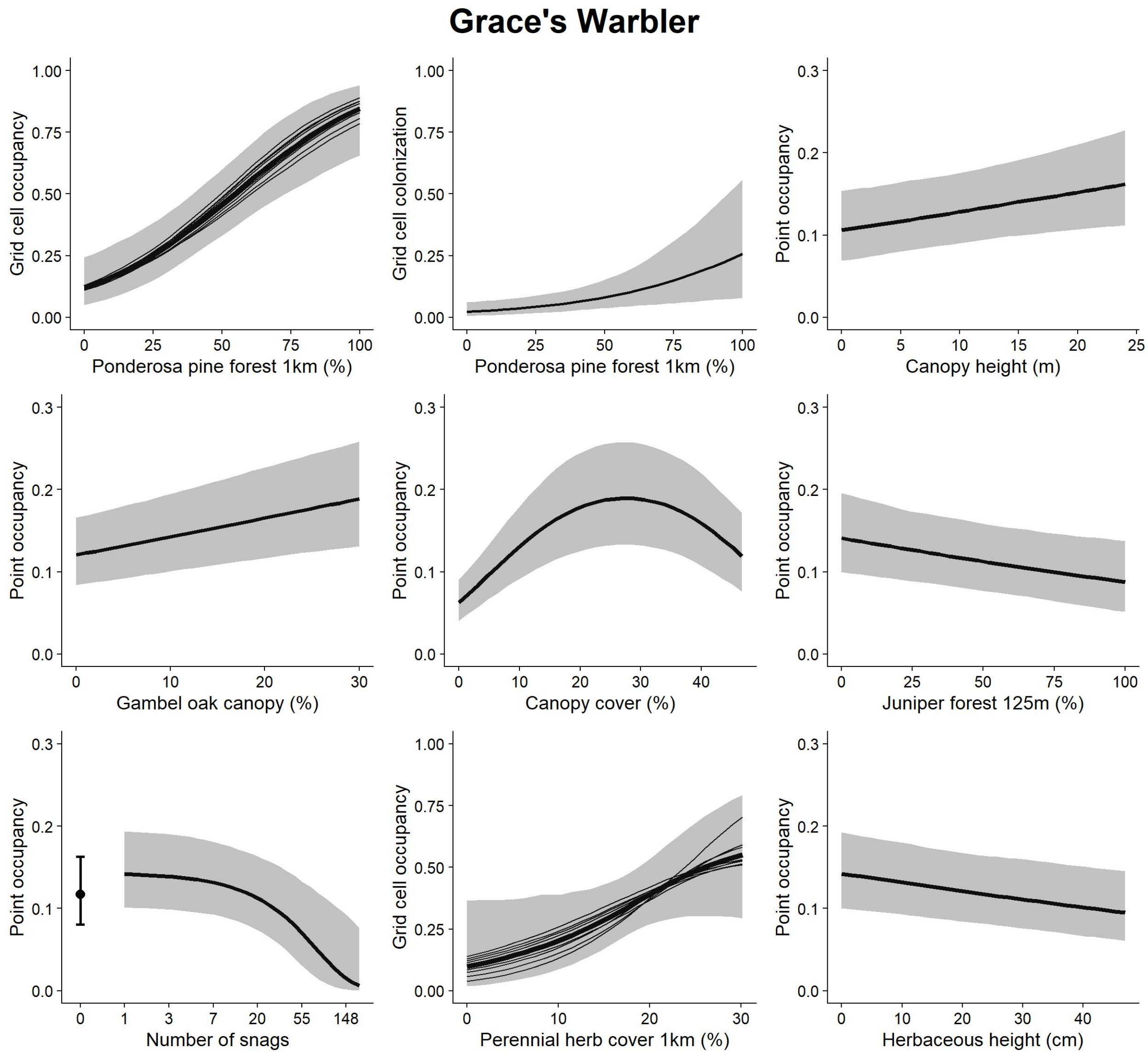

Figure 5. Statistically supported occupancy relationships with covariates for Grace's Warbler. Lines and ribbons are posterior median and 95% credible bands for predicted occupancy. For snags, the point and error bar show predicted occupancy where snags are absent. For grid cell occupancy, thinner lines show occupancy for individual years of the study, and the thicker line shows mean occupancy across years (95% credible band is for mean occupancy). Because panels depict covariate relationships for different parameters, relationships are not necessarily comparable across panels but are shown together to assist interpretation of supported relationships and evaluation of predictions for this species.

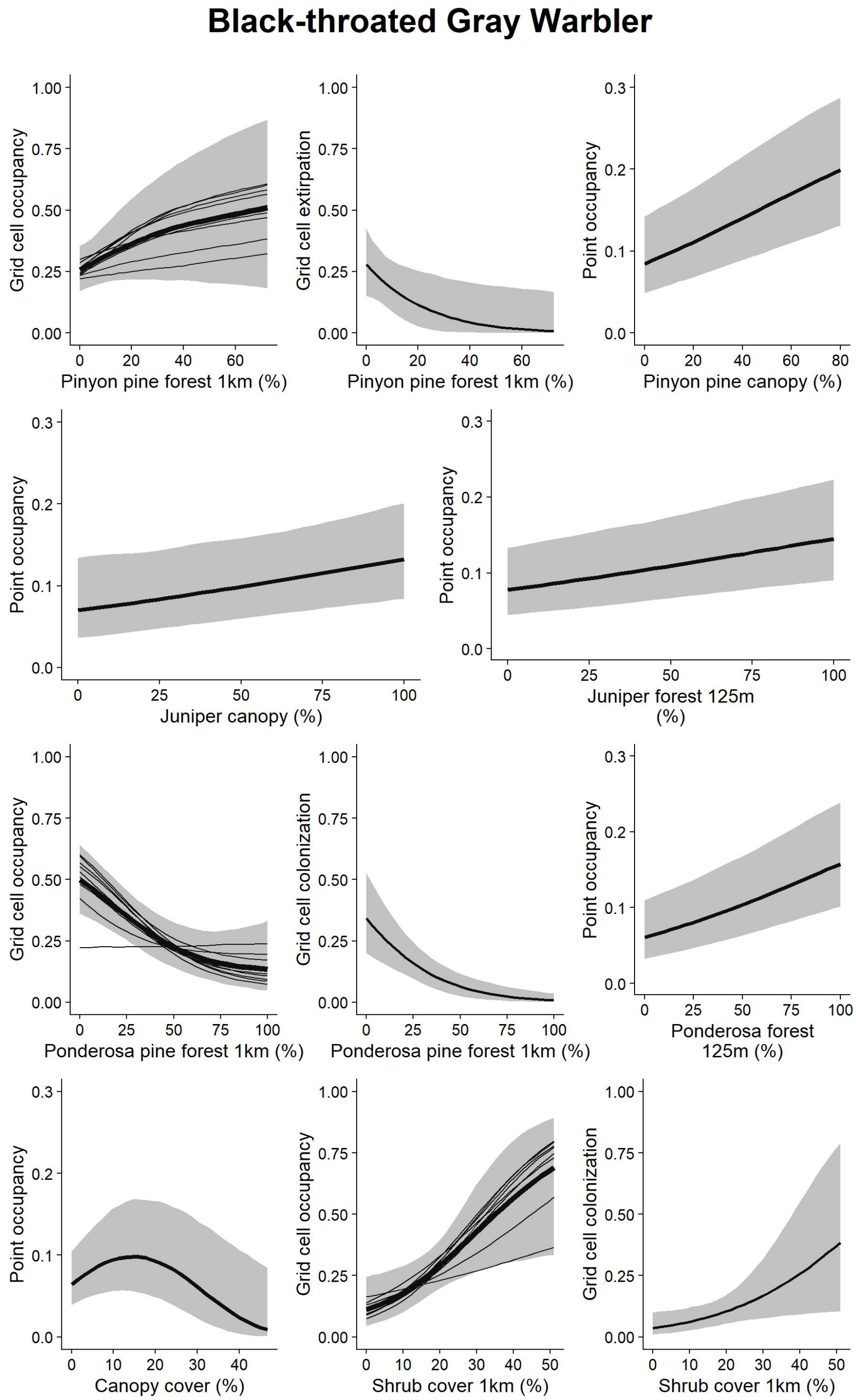

Figure 6. Statistically supported occupancy relationships with covariates for Black-throated Gray Warbler. Lines and ribbons are posterior median and 95% credible bands for predicted occupancy. For grid cell occupancy, thinner lines show occupancy for individual years of the study, and the thicker line shows mean occupancy across years (95% credible band is for mean occupancy). Because panels depict covariate relationships for different parameters, relationships are not necessarily comparable across panels but are shown together to assist interpretation of supported relationships and evaluation of predictions for this species.

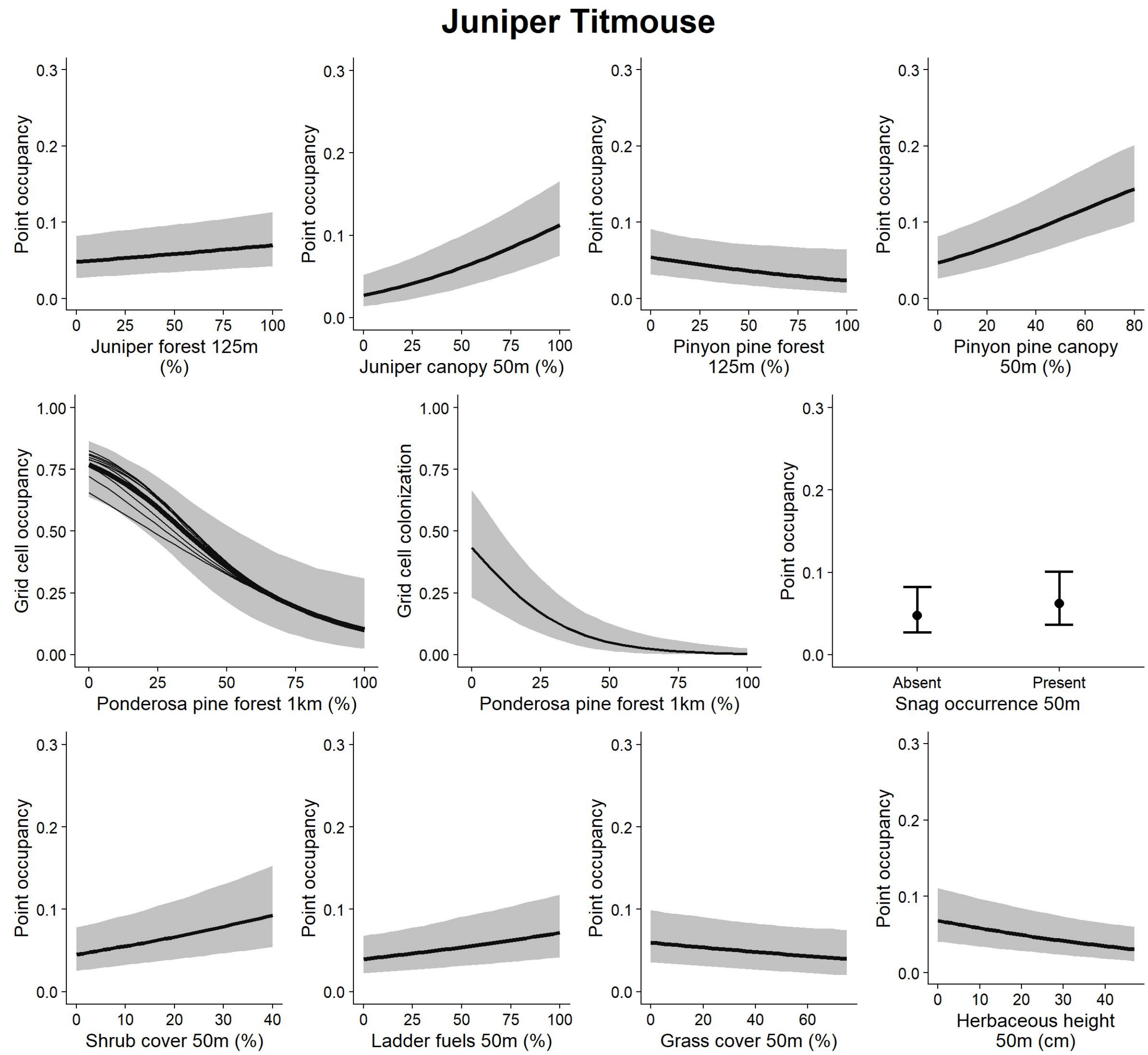

Figure 7. Statistically supported occupancy relationships with covariates for Juniper Titmouse. Lines and ribbons are posterior median and 95% credible bands for predicted occupancy. For grid cell occupancy, thinner lines show occupancy for individual years of the study, and the thicker line shows mean occupancy across years (95% credible band is for mean occupancy). Because panels depict covariate relationships for different parameters, relationships are not necessarily comparable across panels but are shown together to assist interpretation of supported relationships and evaluation of predictions for this species.

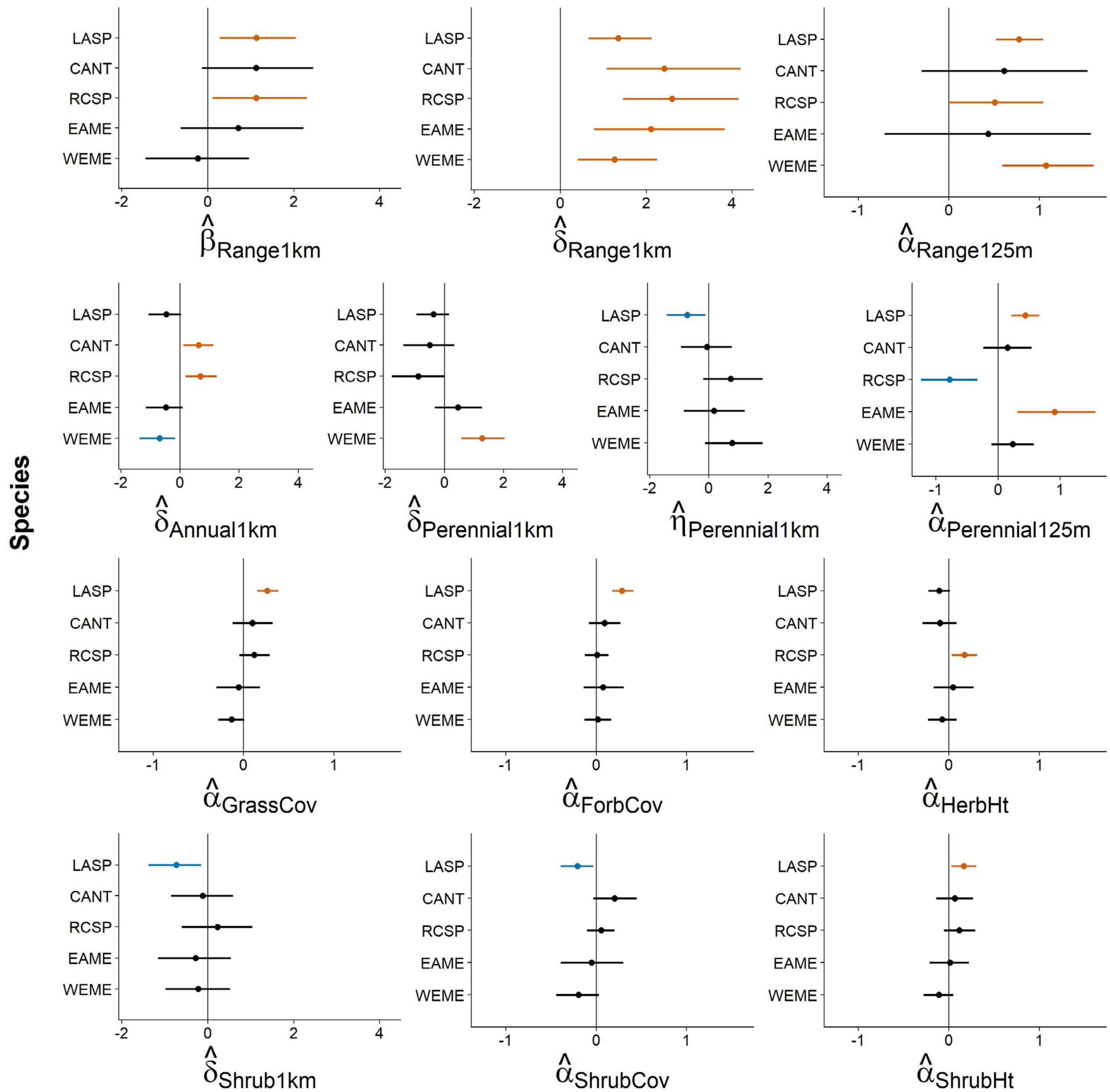

Figure 8. Estimated covariate relationships (posterior medians and 95% BCIs) with occupancy for potential grassland focal species. Species represented are those whose habitat relationships met expectations for grassland focal species and that are described as grassland associates in the literature. Relationships shown are those relevant to evaluating the extent to which species could represent components of grasslands. Covariate relationships are for initial grid cell occupancy (β), grid cell colonization (δ), grid cell extirpation (η), and point occupancy (α; for complete covariate names and descriptions, see Table 3). Colors indicate statistically supported positive (red) and negative (blue) relationships. Because all covariates were scaled the same prior to analysis (mean = 0, SD = 1), relationship magnitudes are comparable across panels in this figure.

Discussion

Habitat relationships for the three designated focal species largely corroborated their habitat descriptions in the Forest Plan, but other species also exhibited habitat relationships at least as consistent with focal species' habitat descriptions. Grace's Warbler habitat relationships matched its habitat description relatively well. Relationships for Mountain Chickadee and Pygmy Nuthatch, however, suggest they could also represent open, park-like mature stands of ponderosa pine forest at least as well as Grace's Warbler, albeit perhaps less so pine-oak forests. Juniper Titmouse and Ash-throated Flycatcher both exhibited habitat relationships suggesting similar potential for representing juniper and snag components of pinyon-juniper forests. Although Black-throated Gray Warbler occupancy related positively with pinyon pine, their habitat relationships did not provide clear corroboration of other aspects of habitat described in the Forest Plan. Thirteen other species exhibited relationships suggesting even better representation of the mature pinyon pine component of pinyon-juniper forests. Five species are described in the literature as grassland associates and exhibited habitat relationships consistent with our expectations for a grassland focal species. Designated focal species and their alternatives also exhibited additional habitat relationships not explicitly described in the Forest Plan. While not necessarily of direct concern to management, these relationships may suggest additional population drivers capable of explaining population trends and thus confounding their interpretation for evaluating forest management.

A small suite of species may better represent conditions of management concern within ponderosa pine forests. The Forest Plan identifies both pure ponderosa pine and pine-oak forests as conditions intended for Grace's Warbler to represent. Both Mountain Chickadee and Pygmy Nuthatch, however, exhibited stronger relationships (both in magnitude and statistical clarity) with ponderosa pine and negative relationships with pinyon pine suggesting stronger specialization towards pure ponderosa pine forest. Conversely, neither species exhibited supported relationships with Gambel oak, suggesting Grace's Warbler may better represent pine-oak forests. Considering these complementary strengths and limitations, monitoring all three species may provide better information for evaluating management of ponderosa pine forests than any one species alone. The 4FRI wildlife subgroup identified all 3 species as focal species (in addition to 17 others) to represent ponderosa pine based on information provided by Latif and Pavlacky (2020).

Expanding the suite of focal species representing pinyon-juniper forest would also likely improve representation of various desired conditions within this vegetation type. We found limited evidence corroborating the value of Black-throated Gray Warbler as a focal species to represent the "mature pinyon component of pinyon-juniper habitats." Black-throated Gray Warbler did exhibit clearer and more consistently positive relationships with pinyon pine covariates across scales compared to relationships with other tree species covariates and pinyon pine covariate relationships exhibited by other bird species. Nevertheless, Common Raven, Black-headed Grosbeak, and 11 other species exhibited habitat relationships suggesting they could represent other desired conditions within mature pinyon pine forests better than Black-throated Gray Warbler. Multiple species may therefore represent this component of pinyon-juniper forests better than any one species alone. Similarly, monitoring Juniper Titmouse and Ash-throated Flycatcher together may improve focal species representation of late-seral juniper forests with snags.

Monitoring a suite of grassland focal species represented in IMBCR data could offer a more effective approach to monitor grassland fauna than previously considered. The CONF opted to abandon monitoring of grassland fauna due to challenges with monitoring previously identified management indicator species (e.g., pronghorn, Vesper Sparrow) and limitations in how broadly those species represent grasslands. Monitoring vegetation alone, however, can be severely limited for fully assessing ecosystem services, especially wildlife habitat (Schwartz et al. 2015). The five potential grassland focal species identified here (Lark Sparrow, Canyon Towhee, Eastern Meadowlark, Rufous-crowned Sparrow, and Western Meadowlark) were not previously considered and together appear to represent various components of grassland systems within CONF boundaries (considering occupancy relationships observed here). Further consideration of these species could therefore provide a starting point for reinstatement of faunal monitoring to inform grassland management. With the current design for forest-wide monitoring, a minority of sampling units represent grasslands (Table 2). Nevertheless, we had sufficient data to discern covariate relationships relevant to identifying potential grassland focal species, suggesting forest-wide monitoring could provide sufficient power to discern population trends of similar magnitude for these species.

In addition to more comprehensively representing desired conditions, monitoring suites of focal species can help account for incidental relationships when interpreting population trends for evaluating management. Focal species populations need to be closely and functionally related with desired conditions in order to meaningfully infer changes in those conditions from population change (Schwartz et al. 2015). Focal species relationships with incidental habitat features could dilute relationships with desired conditions and raises the possibility of alternative explanations for any observed population changes. In some cases, seemingly incidental habitat features may in fact be additionally relevant to management. For example, canopy openings facilitate herbaceous vegetation such that relationships with herbaceous vegetation could further reflect associations with open, park-like conditions within ponderosa pine forests (e.g., for Grace's Warbler). Nevertheless, relationships with features not directly relevant to desired conditions could complicate interpretation of focal species population trends. By monitoring multiple focal species that differ in their relationships with incidental environmental features, however, consistency of trends across species can help differentiate changes in desired conditions versus incidental features. Population changes experienced consistently by multiple focal species can more clearly imply changes to desired conditions. In contrast, population changes for only one species may be more easily attributed to drivers specific to that species.

Study strengths and limitations

We provide particularly relevant data and analysis to inform focal species selection and monitoring under the Forest Plan. Our relatively large dataset generated with a rigorous sampling design allowed us to clearly establish statistical relationships with relevant environmental conditions. Additionally, by relating both spatial pattern and temporal occupancy dynamics with environmental attributes, habitat relationships estimated here have strong potential for explaining and predicting population trends (Briscoe et al. 2021).

To provide useful information for evaluating management, however, focal species need to be both statistically and functionally related with desired conditions. Observational data such as ours support estimation of primarily statistical relationships, which can but do not necessarily reflect functional relationships. Additionally, we were limited to vegetation data collected via remote sensing or IMBCR field surveys. Thus, covariates included in our analyses did not necessarily quantify desired conditions at scales or in a manner most relevant to management decisions or species ecology, further limiting our ability to measure functional relationships with desired conditions. In fact, focal species in principle are supposed to represent desired conditions that are difficult to measure directly, making measurement of functional relationships with these conditions also potentially difficult. Mature forests and Gambel oak are examples of desired conditions that we represented in a relatively limited manner with a single covariate at a single scale each.

Considering these limitations, we recommend considering all relevant data and literature describing species relationships and ecology when selecting focal species. Relationships consistently observed across multiple studies and analyses will be most reliable for identifying and understanding species functional relationships and predicting their responses to management activities (e.g., Latif and Pavlacky 2020). Focal species deliberations and selections by neighboring national forests with similar conditions of management concern may also be helpful. The 4FRI wildlife subgroup has identified a suite of focal species to represent ponderosa pine forest that includes all three identified here (Grace's Warbler, Mountain Chickadee, and Pygmy Nuthatch). Another species they identify, Plumbeous Vireo, exhibited in our analysis all of the relationships predicted for Grace's Warbler except for relationships with Gambel oak and canopy height (see data archive in Appendix D). Considering also associations with ponderosa pine described in the literature (Latif and Pavlacky 2020), Plumbeous Vireo may be useful to include as an additional focal species representing ponderosa pine forest under the Forest Plan. Regardless, Plumbeous Vireo offers a useful example of how considering other information sources along with our study could inform focal species selection. Additionally, short-term hypothesis-driven research could supplement forest-wide monitoring to test expected relationships with desired conditions, and thereby strengthen the foundation for focal species monitoring.

Informing forest management and monitoring

We focused our study on species relationships with desired conditions, which represents one of several factors national forests could consider when selecting focal species. Other desirable attributes for focal species include low inter-annual population variability (to facilitate trend detection), ease of monitoring, and background knowledge about regional or global trends (Schwartz et al. 2015). IMBCR data will likely support identification and estimation of population trends similar in magnitude to statistical relationships with desired conditions documented here. Further analyses of IMBCR data for candidate focal species could presumably inform ease of monitoring, evaluation of associated costs, and the extent to which inter-annual variation might confound or obscure population trends. Regional monitoring could provide reference data to evaluate whether observed forest-wide trends reflect forest management versus regional or broader factors. Although IMBCR provides a framework to allow regional monitoring (e.g., consider U.S. Forest Service Regions 1, 2, and 4), IMBCR does not currently cover enough of U.S. Forest Service Region 3 to provide such reference data. The CONF monitoring program exemplifies how forests can leverage IMBCR to implement monitoring of focal species and verify their utility for evaluating forest-wide management programs. More complete IMBCR coverage of Region 3 could allow comparison of forest-specific against regional trends, thereby increasing the value of forest-specific monitoring.

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Appendix A

Habitat descriptions for focal species copied from the administrative change incorporating focal species monitoring into the Coconino Forest Plan (Forest Plan Administrative Change #1). The reference list for citations in these descriptions appears in the Forest Plan (Chapter 3, Final EIS Volume IIb).

Grace's Warbler

Grace's warbler is proposed as an indicator for open, park-like, mature stands of pure ponderosa pine, and in pine-oak habitats. It is strongly associated with this forest structure found historically in northern Arizona (Szaro and Balda 1986, Stacier and Guzy 2002). Monitoring for this species would allow the forest to assess overstory response to prescribed cutting and burning that aims to restore ponderosa pine forests and reduce fuel loads. Restoration of the pine types would be expected to have a positive influence on populations of Grace's warblers, so they would be expected to be stable or increasing.

Black-throated Gray Warbler

The black-throated gray warbler is recommended as the focal species for the mature pinyon component of pinyon-juniper habitats. In Arizona, it occurs more frequently in taller pinyon-juniper stands that contain higher densities of mature pinyon pine, and may avoid drier stands comprised primarily of juniper (Corman and Wise-Gervais 2005). Forest Plan objectives call for between 1,000 and 10,000 acres of mechanical treatment over 10 years in Pinyon-Juniper with Grass, and a minimum of 3,750 acres treated using naturally-ignited wildfire in both Pinyon Juniper with Grass and Pinyon Juniper Evergreen Shrub. Pinyon trees are not usually targeted for removal using thinning or burning, but can be removed under fuelwood and Christmas tree permits. Monitoring for this species would determine if higher-density mature pinyon pine are being maintained in the Coconino NF, particularly in response to management of naturally-ignited wildfires. With implementation of the Forest Plan, the status of the black-throated gray warbler would be expected to be stable, since plan components strive to maintain old-growth structure within the pinyon-juniper types.

Juniper Titmouse

Juniper titmice are indicators for late seral pinyon-juniper habitats, particularly the snag component. In Arizona, they are strongly associated with dry woodlands that contain Utah and one-seed junipers (Corman and Wise-Gervais 2005). The titmouse is a cavity-nester that nests primarily in juniper trees ranging in height from 10 to 59 feet (Corman and Wise-Gervais 2005). Forest plan objectives for mechanical treatment and fire focus on Pinyon Juniper with Grass and Pinyon Juniper Evergreen Shrub, rather than Pinyon Juniper Woodland. Monitoring this species would determine if pinyon-juniper stands with cavity-producing junipers are being maintained in the forest. With implementation of the Forest Plan components, the status of the juniper titmouse would be expected to be stable.

Appendix B.

We analyzed bird species occupancy using a model that incorporates multiscale dynamics (Green et al. 2019) implemented within a hierarchical multispecies framework (Dorazio et al. 2010). For detection data, **y**, element $y_{ijkt} = 1$ indicates species *i* ($i = 1, \ldots, M$; $M = 131$) was detected at point *j* ($j = 1, \ldots, J$; $J = 16$) within grid *k* ($k = 1, \ldots, K$; $K = 67$) in year *t* ($t = 1, \ldots, T$; $T = 9$). Using removal sampling to estimate detectability (Rota et al. 2009), we compiled a parallel array, **R**, with elements indicating time to detection or the end of the survey ($r_{ijkt} \in \{1, 2, \ldots, 6\}$ when $y_{ijkt} = 1$, or $r_{ijkt} = 6$ when $y_{ijkt} = 0$). We modeled data generation as

$$y_{ijkt}|u_{ijkt} \sim Binomial\left(r_{ijkt}, p_{ijkt} \times u_{ijkt}\right),$$

where p_{ijkt} was the probability of detecting species *i* during a one-minute interval given occupancy of point *j* in grid *k* and year *t* (i.e., given $u_{ijkt} = 1$). We modeled point occupancy as

$$u_{ijkt}|z_{ikt} \sim Bernoulli\left(\theta_{ijkt} \times z_{ikt}\right),$$

where θ_{ijkt} is the point occupancy probability for species *i* given grid *k* is occupied in year *t*. We modeled grid cell occupancy during the initial year of the study as

$$z_{ik1}|w_i \sim Bernoulli(\psi_{ik} \times w_i),$$

where ψ_{ik} is the cell occupancy probability in year 1 for species *i* given that species *i* belongs in the super community. We modeled grid cell occupancy in subsequent years ($t = 2, 3, \ldots, 9$) as

$$z_{ikt}|w_i \sim Bernoulli\begin{Bmatrix} \phi_{ik(t-1)} \times w_i & z_{ik(t-1)} = 1 \\ \gamma_{ik(t-1)} \times w_i & z_{ik(t-1)} = 0 \end{Bmatrix},$$

where γ_{ikt} and φ_{ikt} are cell-level colonization and persistence probabilities for species *i*, respectively, given that species *i* belongs to the super community. Finally, We modeled whether species *i* belonged to the super community as $w_i \sim Bernoulli(\Omega)$ (Dorazio et al. 2010). Modeling occupancy for more species than was actually observed and then conditioning occupancy estimates on membership in the super community is known as data augmentation (Dorazio et al. 2010). Data augmentation allows estimation of community-level parameters (e.g., species richness), but we did not draw inference to the community for this study, so this aspect of our model had no bearing on our conclusions.

We modeled occupancy and annual grid cell occupancy dynamics as logit-linear functions of covariates:

$$logit\left(\theta_{ijkt}\right) = \mathbf{w}_{\boldsymbol{jkt}}\boldsymbol{\alpha}_{\boldsymbol{i}},$$

$$logit(\psi_{ik}) = \mathbf{x}_{\boldsymbol{kt}}\boldsymbol{\beta}_{\boldsymbol{i}},$$

$$logit(\gamma_{ikt}) = \mathbf{x}_{\boldsymbol{kt}}\boldsymbol{\delta}_{\boldsymbol{it}} + \delta_{dev,it},$$

$$logit(\phi_{ikt}) = \mathbf{x}_{\boldsymbol{kt}}\boldsymbol{\eta}_{\boldsymbol{it}} + \eta_{dev,it},$$

where **w** and **x** are point- and grid-specific covariate vectors, respectively, and $\boldsymbol{\alpha}_i$, $\boldsymbol{\beta}_i$, $\boldsymbol{\delta}_{it}$, and $\boldsymbol{\eta}_{it}$ are species-specific vectors whose elements are logit-linear regression parameters. Additionally, $\delta_{dev,it}$ and $\eta_{dev,it}$ quantified logit-linear deviations from mean colonization and extirpation, respectively, for each species in each year *t*, allowing occupancy dynamics to vary among years ($\delta_{dev,it}$ and $\eta_{dev,it}$ were distributed *Normal*$[0,\sigma_t]$). We also modeled detectability as a logit-linear function of covariates while also allowing variation among years:

$$logit(p_{ijkt}) = \mathbf{w}_{\boldsymbol{jkt}}\boldsymbol{\zeta_i} + \zeta_{dev,it},$$

where **w** is a point-specific covariate vector, $\boldsymbol{\zeta}_i$ is a species-specific vector of regression parameters, and $\zeta_{dev,it}$ quantifies yearly logit-linear deviations from mean detectability ($\zeta_{dev,it} \sim Normal[0, \sigma_t]$). We modeled all regression parameters as species-specific normal random effects, and deviation parameters as species-specific normal random effects within each year. Allowing detectability to vary by year reduced biased estimation of parameters quantifying population dynamics across years (Monroe et al. 2019, Zhao and Royle 2019).

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Appendix C.

Species detection summaries ("Detections" = number of point surveys the species was recorded).

Common name	Taxonomic name	Code	Detections (max = 5616)
Rock Pigeon	*Columba livia*	ROPI	36
Band-tailed Pigeon	*Patagioenas fasciata*	BTPI	14
Eurasian Collared-Dove	*Streptopelia decaocto*	EUCD	80
White-winged Dove	*Zenaida asiatica*	WWDO	25
Mourning Dove	*Zenaida macroura*	MODO	934
Greater Roadrunner	*Geococcyx californianus*	GRRO	39
Common Nighthawk	*Chordeiles minor*	CONI	39
Common Poorwill	*Phalaenoptilus nuttallii*	COPO	2
White-throated Swift	*Aeronautes saxatalis*	WTSW	59
Black-chinned Hummingbird	*Archilochus alexandri*	BCHU	58
Anna's Hummingbird	*Calypte anna*	ANHU	40
Costa's Hummingbird	*Calypte costae*	COHU	8
Broad-tailed Hummingbird	*Selasphorus platycercus*	BTHU	642
Lewis's Woodpecker	*Melanerpes lewis*	LEWO	10
Acorn Woodpecker	*Melanerpes formicivorus*	ACWO	219
Gila Woodpecker	*Melanerpes uropygialis*	GIWO	5
Williamson's Sapsucker	*Sphyrapicus thyroideus*	WISA	24
American Three-toed Woodpecker	*Picoides dorsalis*	ATTW	7
Downy Woodpecker	*Dryobates pubescens*	DOWO	16
Ladder-backed Woodpecker	*Dryobates scalaris*	LBWO	46
Hairy Woodpecker	*Dryobates villosus*	HAWO	360
Northern Flicker	*Colaptes auratus*	NOFL	463
Ash-throated Flycatcher	*Myiarchus cinerascens*	ATFL	1083
Brown-crested Flycatcher	*Myiarchus tyrannulus*	BCFL	2
Cassin's Kingbird	*Tyrannus vociferans*	CAKI	214
Western Kingbird	*Tyrannus verticalis*	WEKI	61
Olive-sided Flycatcher	*Contopus cooperi*	OSFL	18
Western Wood-Pewee	*Contopus sordidulus*	WEWP	516
Hammond's Flycatcher	*Empidonax hammondii*	HAFL	1
Gray Flycatcher	*Empidonax wrightii*	GRFL	786
Dusky Flycatcher	*Empidonax oberholseri*	DUFL	6
Cordilleran Flycatcher	*Empidonax occidentalis*	COFL	310
Black Phoebe	*Sayornis nigricans*	BLPH	4
Say's Phoebe	*Sayornis saya*	SAPH	36
Loggerhead Shrike	*Lanius ludovicianus*	LOSH	44
Bell's Vireo	*Vireo bellii*	BEVI	5
Gray Vireo	*Vireo vicinior*	GRVI	356

Hutton's Vireo	*Vireo huttoni*	HUVI	3
Plumbeous Vireo	*Vireo plumbeus*	PLVI	1093
Warbling Vireo	*Vireo gilvus*	WAVI	120
Pinyon Jay	*Gymnorhinus cyanocephalus*	PIJA	209
Steller's Jay	*Cyanocitta stelleri*	STJA	691
Woodhouse's Scrub-Jay	*Aphelocoma woodhouseii*	WOSJ	559
Clark's Nutcracker	*Nucifraga columbiana*	CLNU	9
American Crow	*Corvus brachyrhynchos*	AMCR	114
Common Raven	*Corvus corax*	CORA	410
Horned Lark	*Eremophila alpestris*	HOLA	143
Tree Swallow	*Tachycineta bicolor*	TRES	1
Violet-green Swallow	*Tachycineta thalassina*	VGSW	874
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	NRWS	25
Purple Martin	*Progne subis*	PUMA	136
Barn Swallow	*Hirundo rustica*	BARS	63
Cliff Swallow	*Petrochelidon pyrrhonota*	CLSW	16
Mountain Chickadee	*Poecile gambeli*	MOCH	944
Bridled Titmouse	*Baeolophus wollweberi*	BRTI	1
Juniper Titmouse	*Baeolophus ridgwayi*	JUTI	884
Verdin	*Auriparus flaviceps*	VERD	60
Bushtit	*Psaltriparus minimus*	BUSH	235
Red-breasted Nuthatch	*Sitta canadensis*	RBNU	58
White-breasted Nuthatch	*Sitta carolinensis*	WBNU	875
Pygmy Nuthatch	*Sitta pygmaea*	PYNU	1055
Brown Creeper	*Certhia americana*	BRCR	145
Rock Wren	*Salpinctes obsoletus*	ROWR	162
Canyon Wren	*Catherpes mexicanus*	CANW	16
House Wren	*Troglodytes aedon*	HOWR	306
Bewick's Wren	*Thryomanes bewickii*	BEWR	626
Cactus Wren	*Campylorhynchus brunneicapillus*	CACW	49
Blue-gray Gnatcatcher	*Polioptila caerulea*	BGGN	111
Black-tailed Gnatcatcher	*Polioptila melanura*	BTGN	9
Golden-crowned Kinglet	*Regulus satrapa*	GCKI	5
Ruby-crowned Kinglet	*Regulus calendula*	RCKI	27
Western Bluebird	*Sialia mexicana*	WEBL	803
Mountain Bluebird	*Sialia currucoides*	MOBL	83
Townsend's Solitaire	*Myadestes townsendi*	TOSO	115
Hermit Thrush	*Catharus guttatus*	HETH	264
American Robin	*Turdus migratorius*	AMRO	763
Curve-billed Thrasher	*Toxostoma curvirostre*	CBTH	15
Crissal Thrasher	*Toxostoma crissale*	CRTH	29

Northern Mockingbird	*Mimus polyglottos*	NOMO	758
European Starling	*Sturnus vulgaris*	EUST	21
Phainopepla	*Phainopepla nitens*	PHAI	274
Olive Warbler	*Peucedramus taeniatus*	OLWA	54
House Sparrow	*Passer domesticus*	HOSP	37
Evening Grosbeak	*Coccothraustes vespertinus*	EVGR	2
House Finch	*Haemorhous mexicanus*	HOFI	711
Cassin's Finch	*Haemorhous cassinii*	CAFI	2
Red Crossbill	*Loxia curvirostra*	RECR	139
Pine Siskin	*Spinus pinus*	PISI	190
Lesser Goldfinch	*Spinus psaltria*	LEGO	537
Black-throated Sparrow	*Amphispiza bilineata*	BTSP	643
Lark Sparrow	*Chondestes grammacus*	LASP	521
Chipping Sparrow	*Spizella passerina*	CHSP	1407
Black-chinned Sparrow	*Spizella atrogularis*	BCSP	174
Dark-eyed Junco	*Junco hyemalis*	DEJU	1175
Vesper Sparrow	*Pooecetes gramineus*	VESP	95
Canyon Towhee	*Melozone fusca*	CANT	85
Abert's Towhee	*Melozone aberti*	ABTO	1
Rufous-crowned Sparrow	*Aimophila ruficeps*	RCSP	193
Green-tailed Towhee	*Pipilo chlorurus*	GTTO	68
Spotted Towhee	*Pipilo maculatus*	SPTO	789
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	YHBL	1
Eastern Meadowlark	*Sturnella magna*	EAME	60
Western Meadowlark	*Sturnella neglecta*	WEME	264
Hooded Oriole	*Icterus cucullatus*	HOOR	3
Bullock's Oriole	*Icterus bullockii*	BUOR	36
Baltimore Oriole	*Icterus galbula*	BAOR	1
Scott's Oriole	*Icterus parisorum*	SCOR	341
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL	12
Brown-headed Cowbird	*Molothrus ater*	BHCO	537
Brewer's Blackbird	*Euphagus cyanocephalus*	BRBL	26
Great-tailed Grackle	*Quiscalus mexicanus*	GTGR	9
Orange-crowned Warbler	*Leiothlypis celata*	OCWA	1
Lucy's Warbler	*Leiothlypis luciae*	LUWA	135
Virginia's Warbler	*Leiothlypis virginiae*	VIWA	101
MacGillivray's Warbler	*Geothlypis tolmiei*	MGWA	13
Common Yellowthroat	*Geothlypis trichas*	COYE	2
Yellow Warbler	*Setophaga petechia*	YEWA	5
Yellow-rumped Warbler	*Setophaga coronata*	YRWA	889
Grace's Warbler	*Setophaga graciae*	GRWA	1092
Black-throated Gray Warbler	*Setophaga nigrescens*	BTYW	427

Red-faced Warbler	*Cardellina rubrifrons*	RFWA	180
Painted Redstart	*Myioborus pictus*	PARE	2
Hepatic Tanager	*Piranga flava*	HETA	214
Summer Tanager	*Piranga rubra*	SUTA	6
Western Tanager	*Piranga ludoviciana*	WETA	752
Northern Cardinal	*Cardinalis cardinalis*	NOCA	22
Pyrrhuloxia	*Cardinalis sinuatus*	PYRR	1
Black-headed Grosbeak	*Pheucticus melanocephalus*	BHGR	376
Blue Grosbeak	*Passerina caerulea*	BLGR	9
Lazuli Bunting	*Passerina amoena*	LAZB	4

Appendix D.

Data supplement – we provide a zip file ("Data_supplement.zip") containing 1) R scripts for data compilation, analysis, results summaries, and plots, 2) data contained in the R workspace needed to run scripts, and 3) an Excel files ("Occupancy_model_estimates.xlsx") containing all model parameter estimates.

Appendix E.

This appendix contains figures presenting statistically supported occupancy relationships with covariates for alternatives to the focal species currently designated in the Coconino Forest Plan. Species represented here are those with habitat relationships that were at least as consistent with focal species' habitat descriptions as the focal species themselves (see Tables 6–8). For all figures here, lines and ribbons are posterior median and 95% credible bands for predicted occupancy. For grid cell occupancy, thinner lines show occupancy for individual years of the study, and the thicker line shows mean occupancy across years (95% credible band is for mean occupancy). Figures are arranged presented in alphabetical order by species common name. Because panels depict covariate relationships for different parameters, relationships are not necessarily comparable across panels in a figure but are shown together to assist interpretation of supported relationships and evaluation of predictions for a given species.

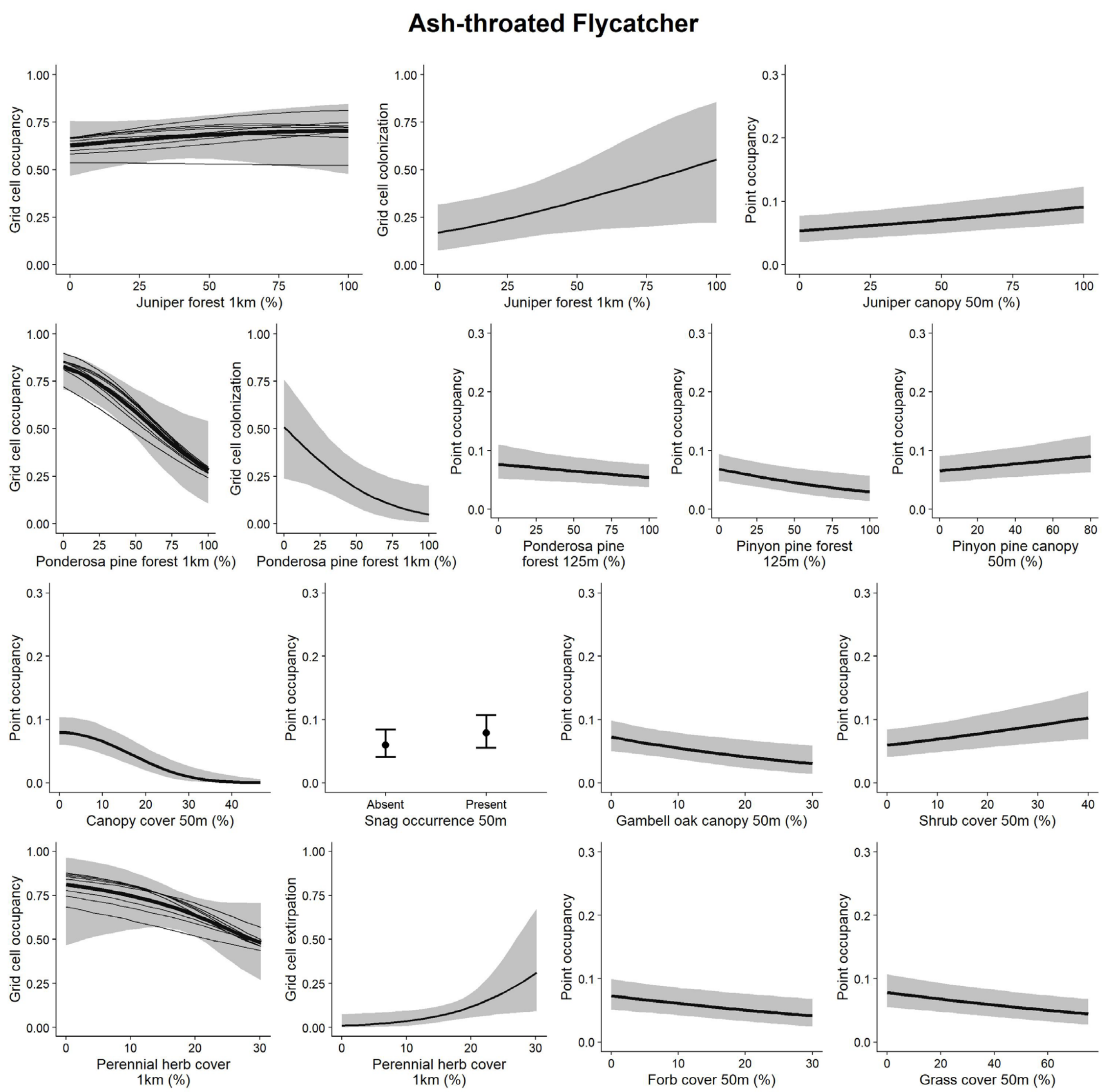

Figure E1. Supported occupancy relationships for Ash-throated Flycatcher.

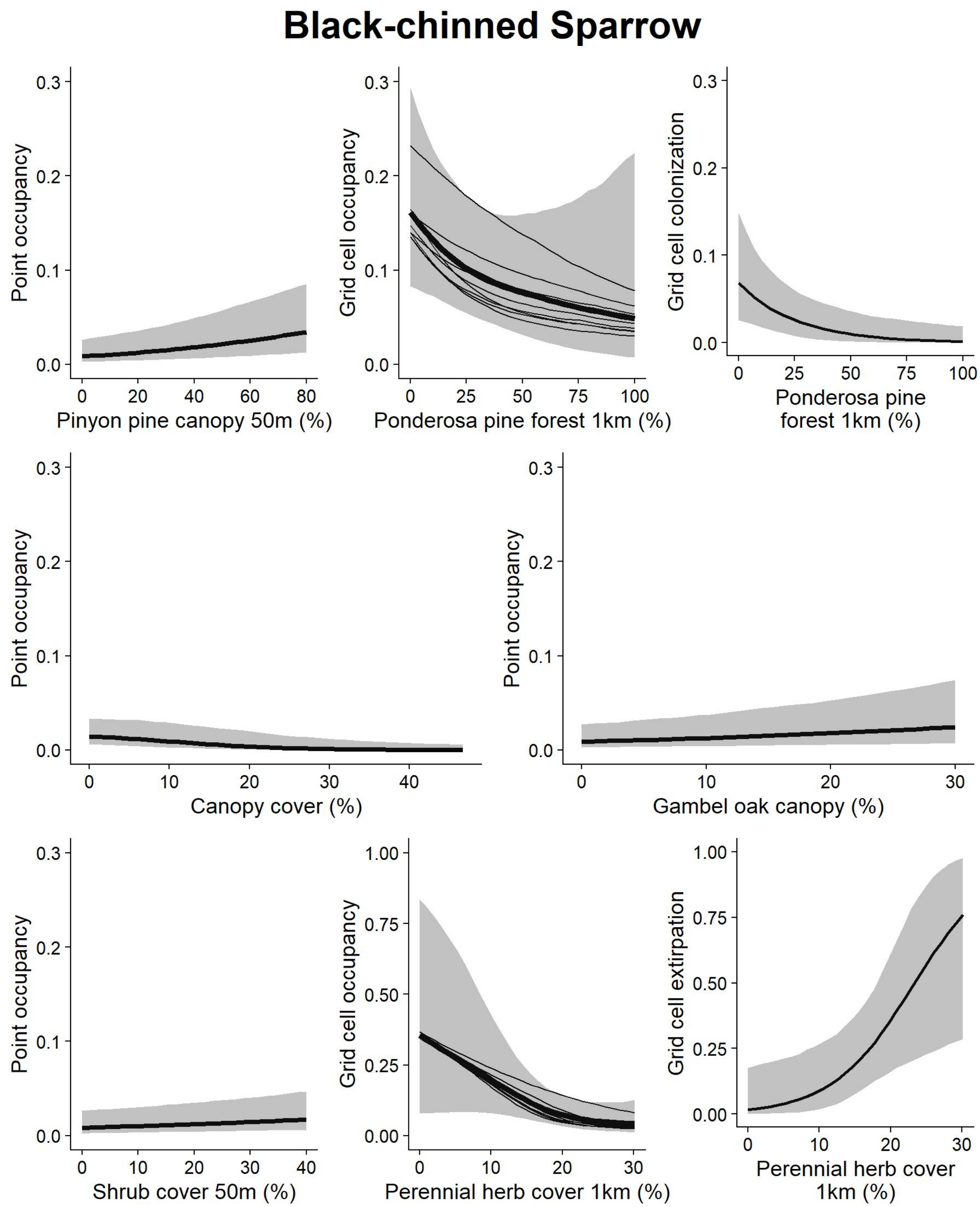

Figure E2. Supported occupancy relationships for Black-chinned Sparrow.

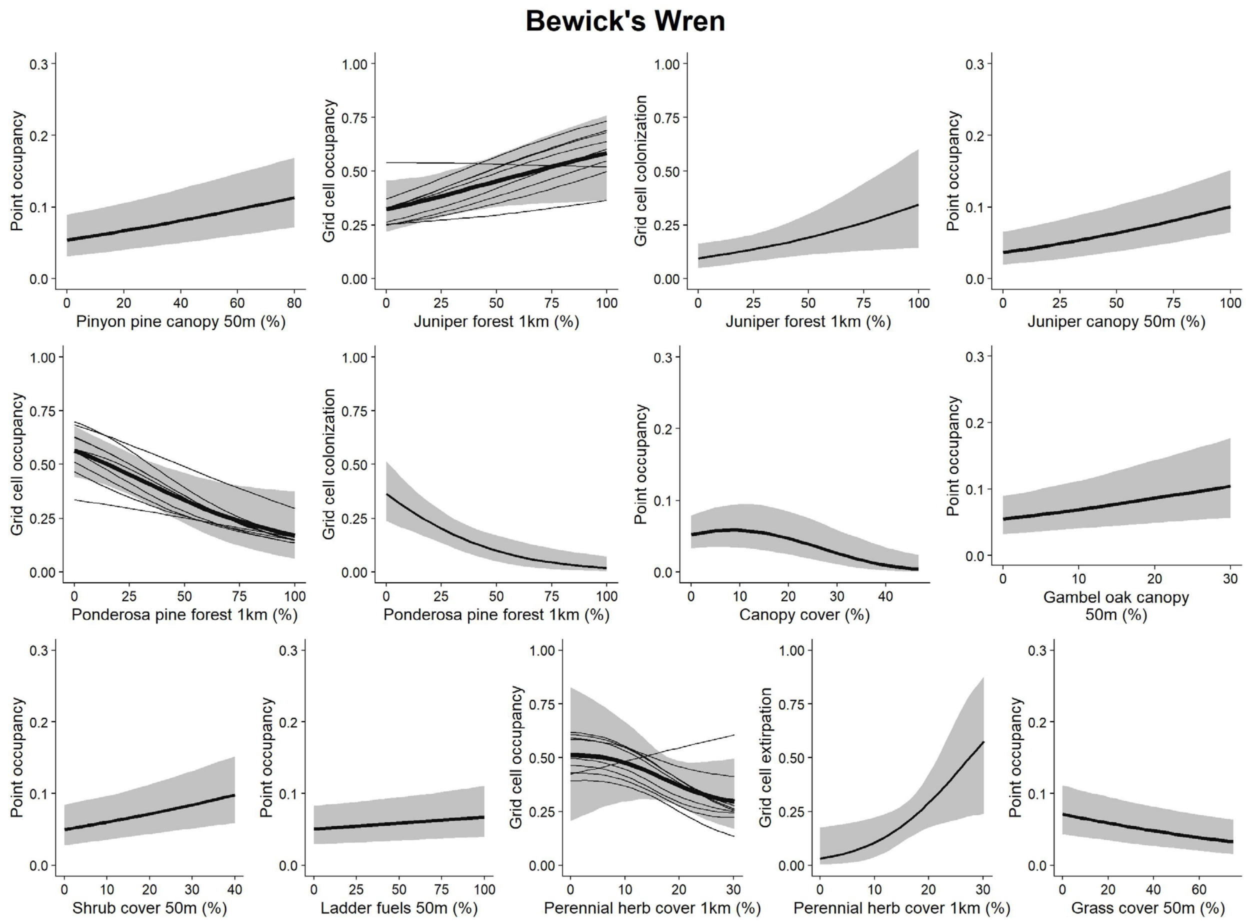

Figure E3. Supported occupancy relationships for Bewick's Wren.

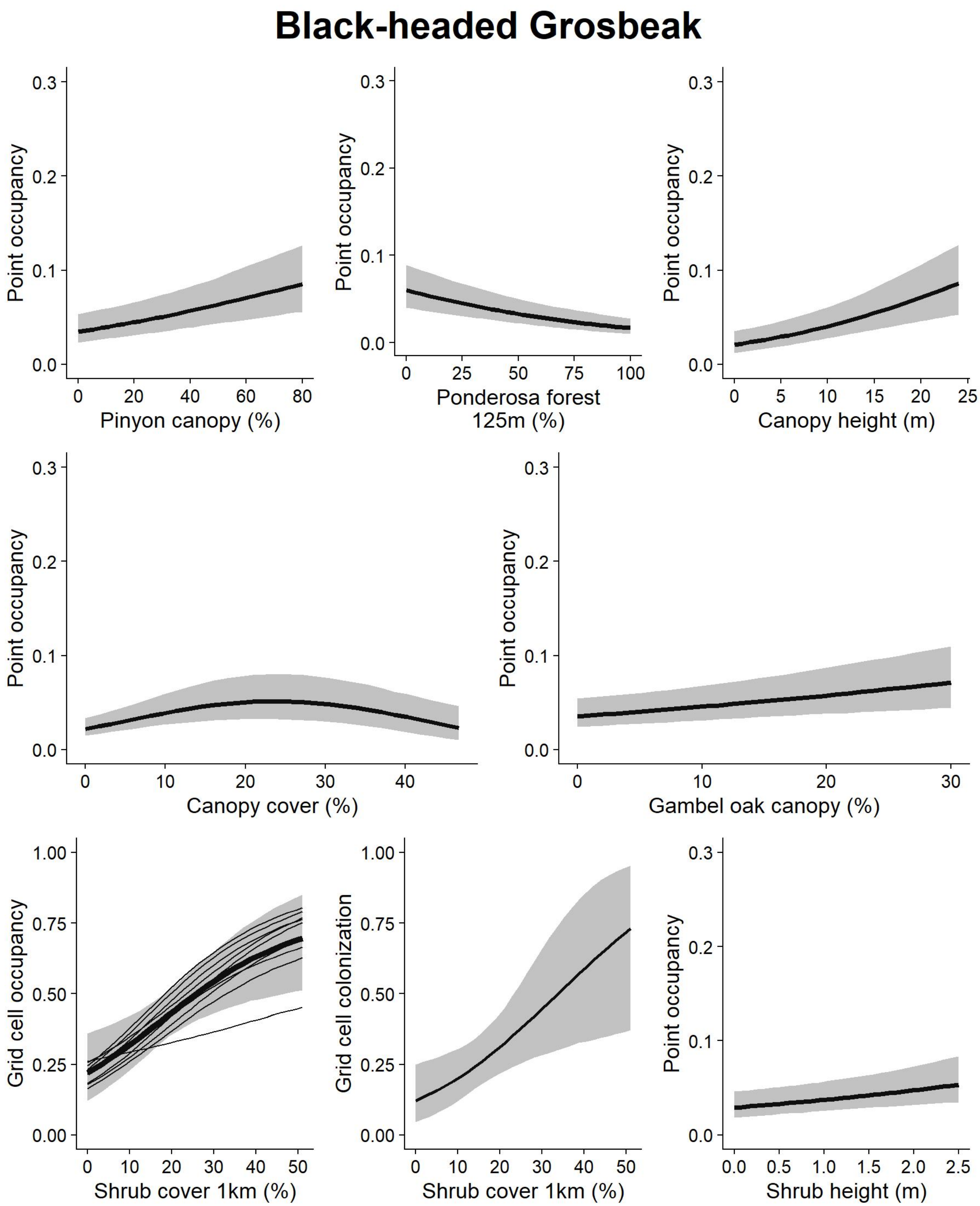

Figure E4. Supported occupancy relationships for Black-head Grosbeak.

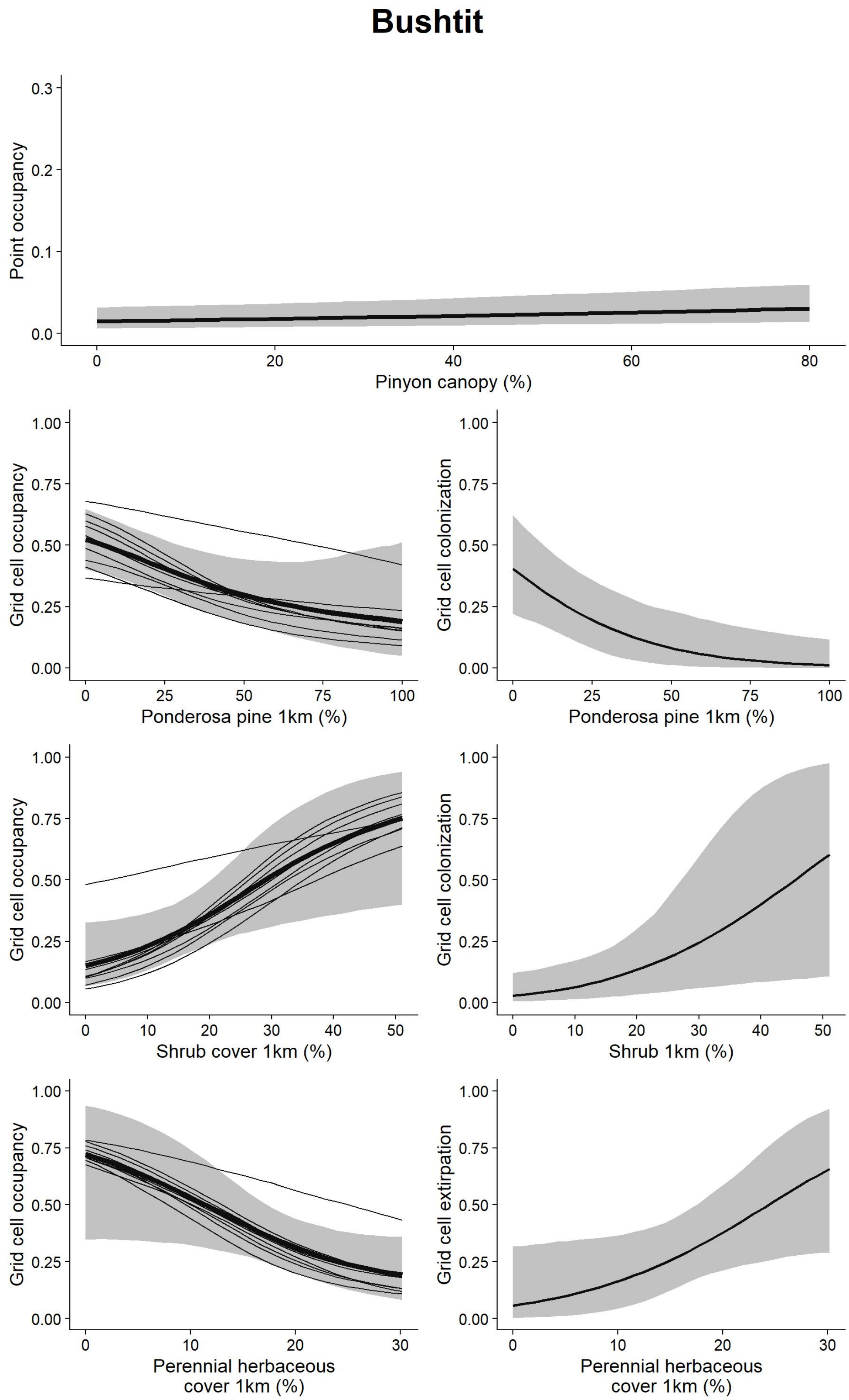

Figure E5. Supported occupancy relationships for Bushtit.

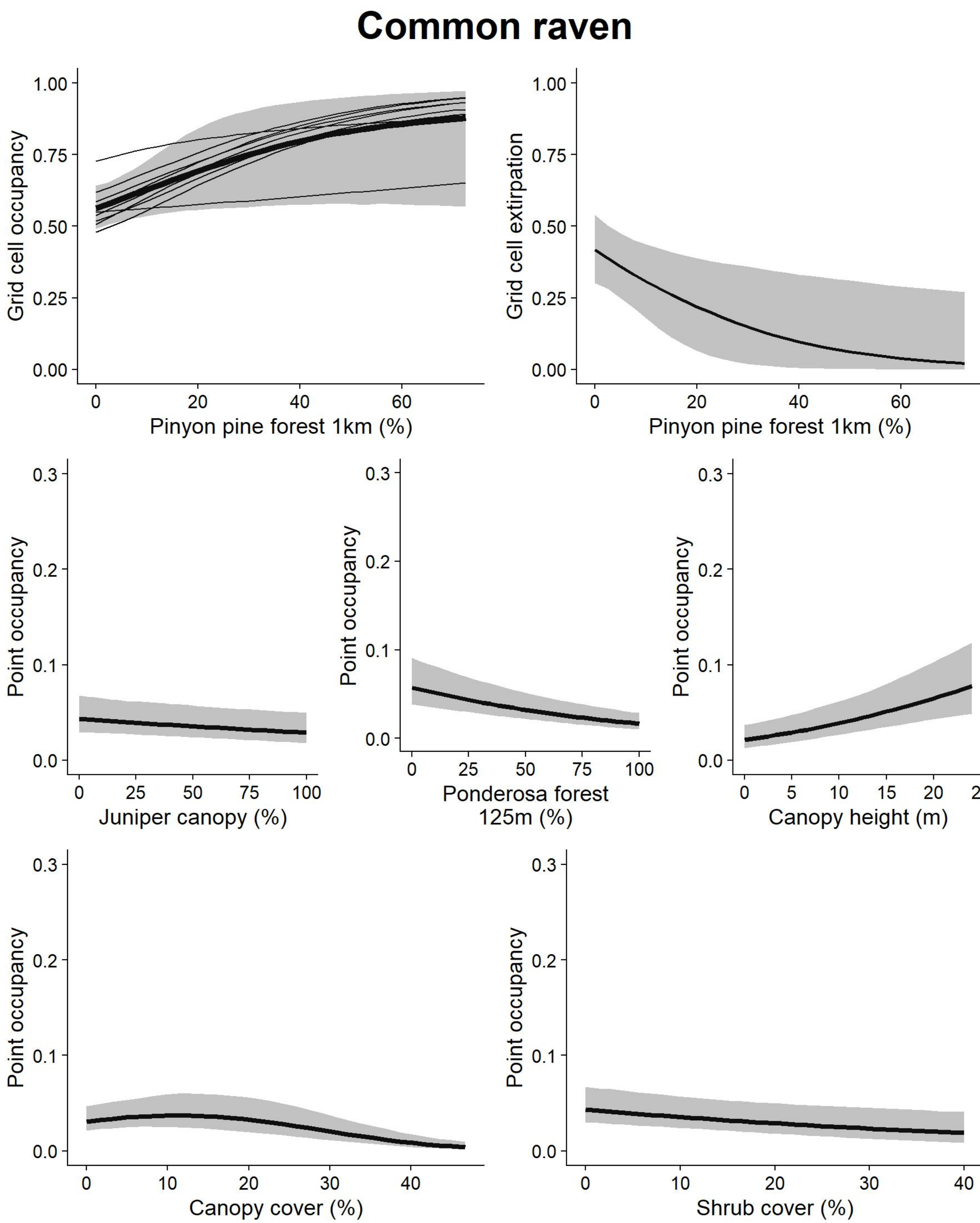

Figure E6. Supported occupancy relationships for Common Raven.

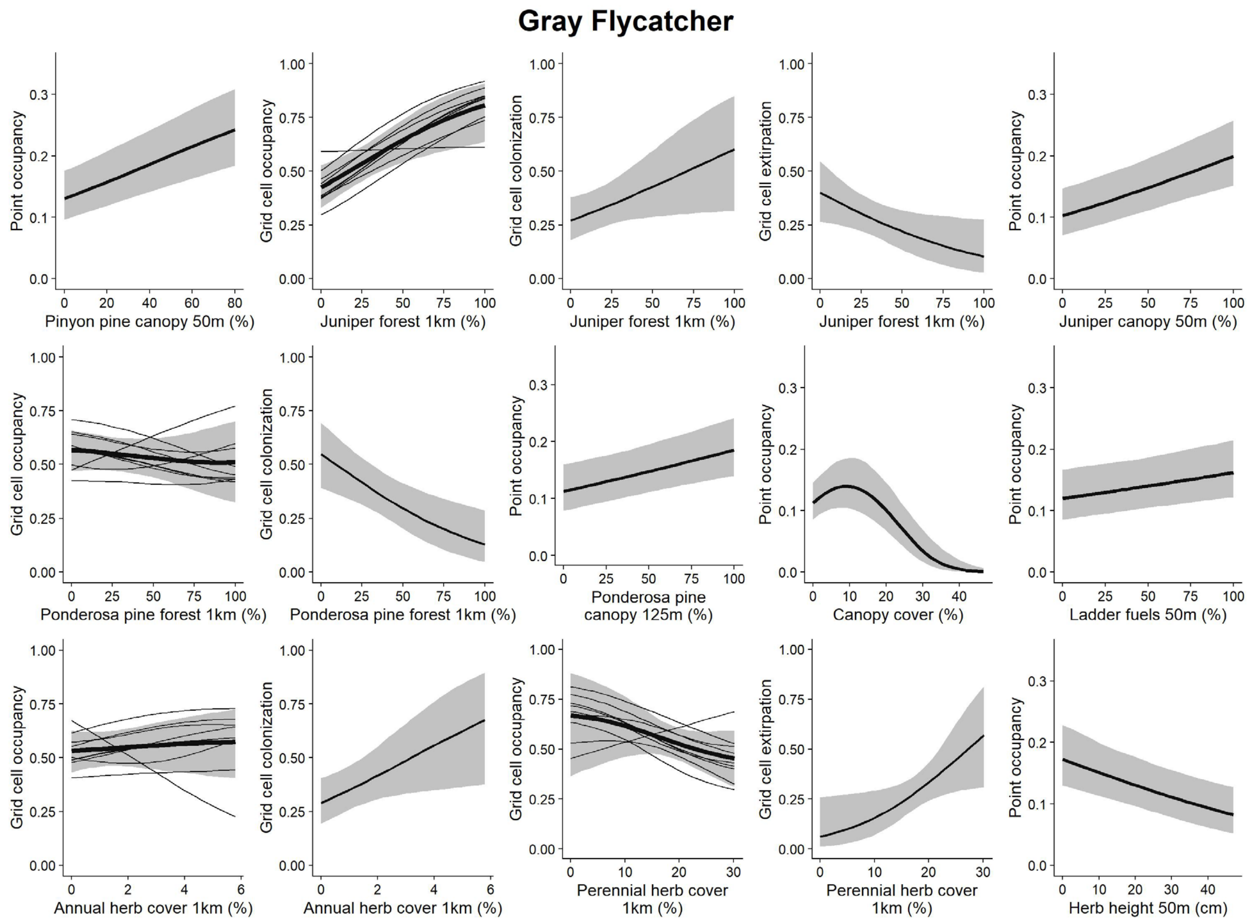

Figure E7. Supported occupancy relationships for Gray Flycatcher.

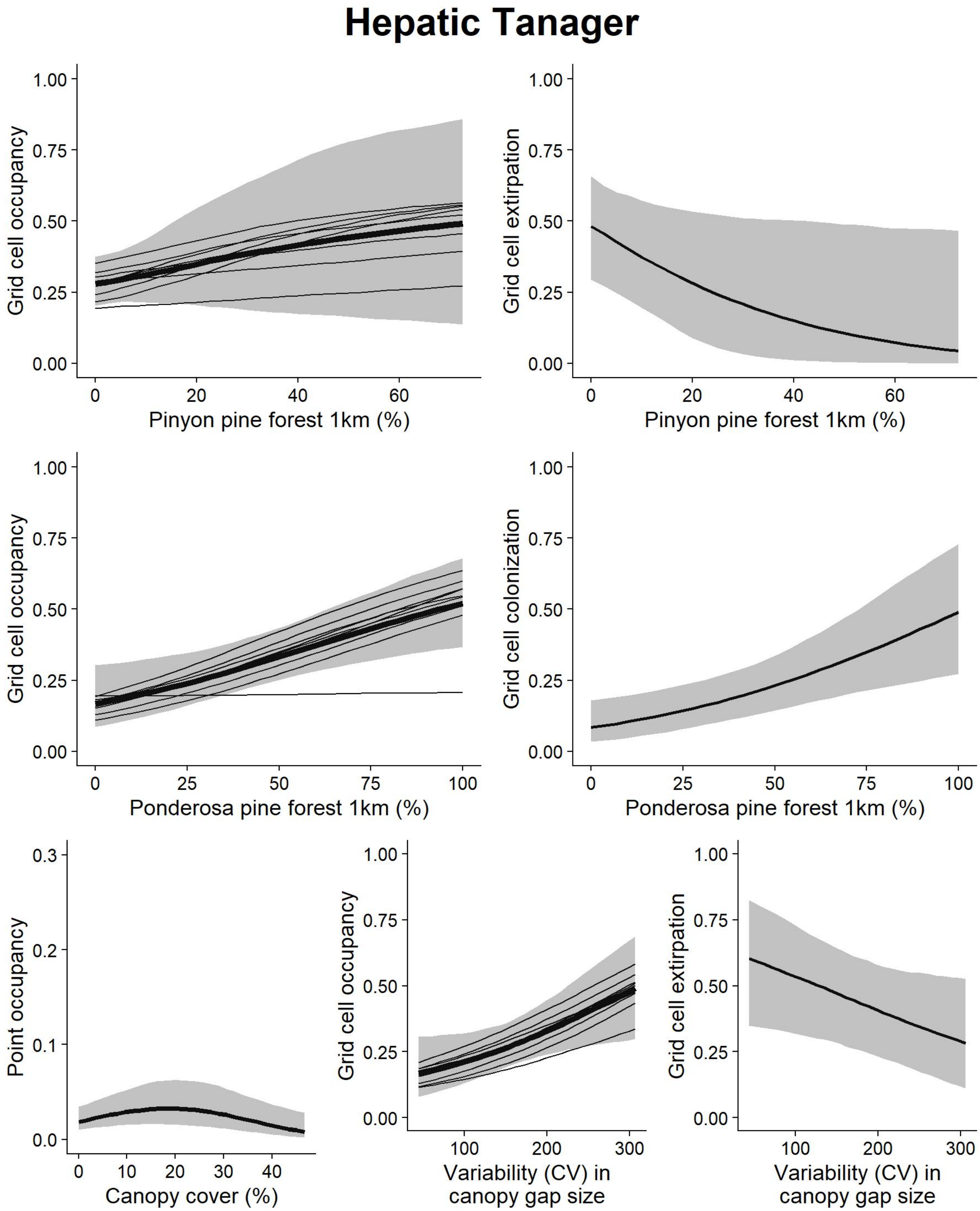

Figure E8. Supported occupancy relationships for Hepatic Tanager.

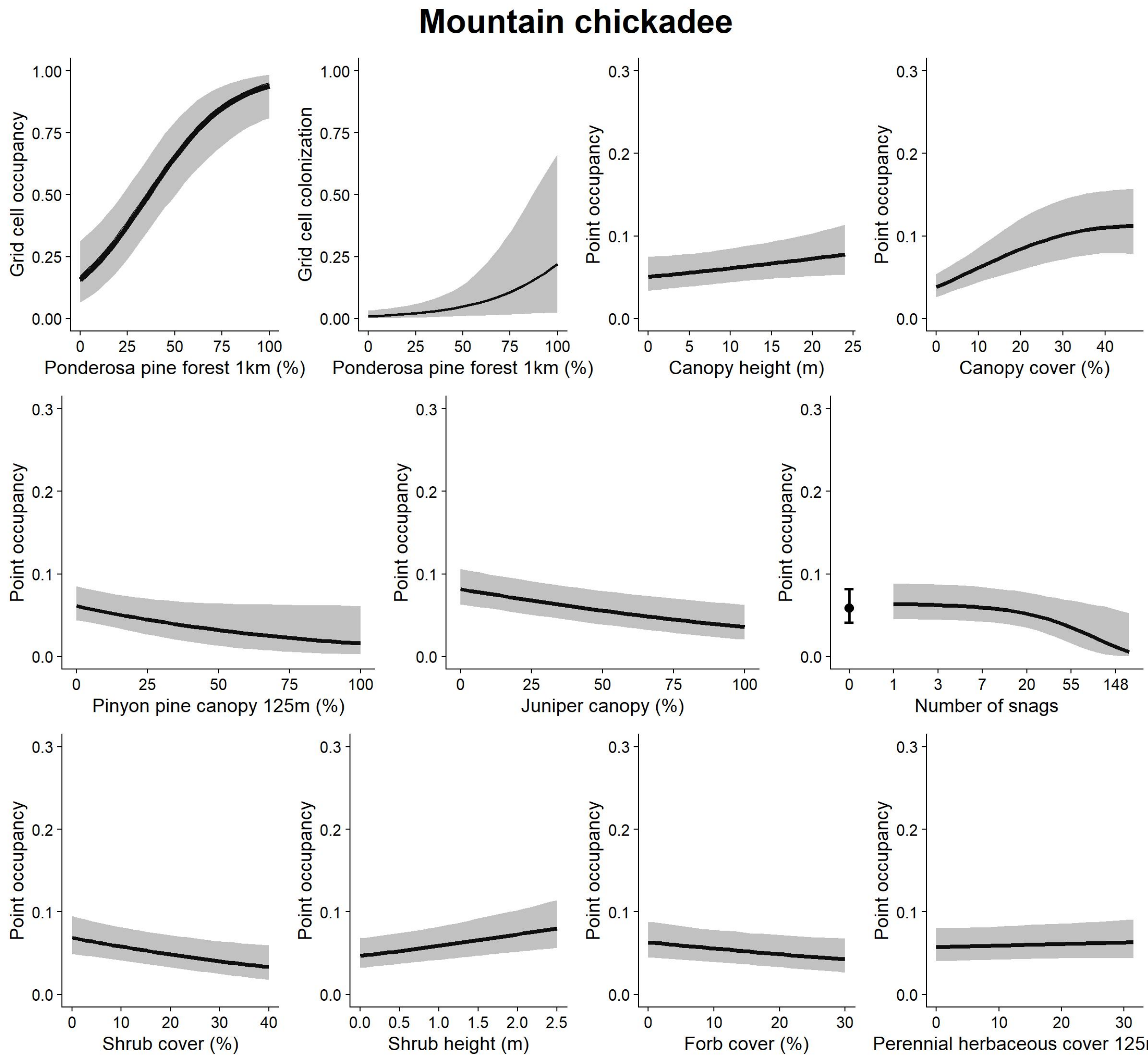

Figure E9. Supported occupancy relationships for Mountain Chickadee.

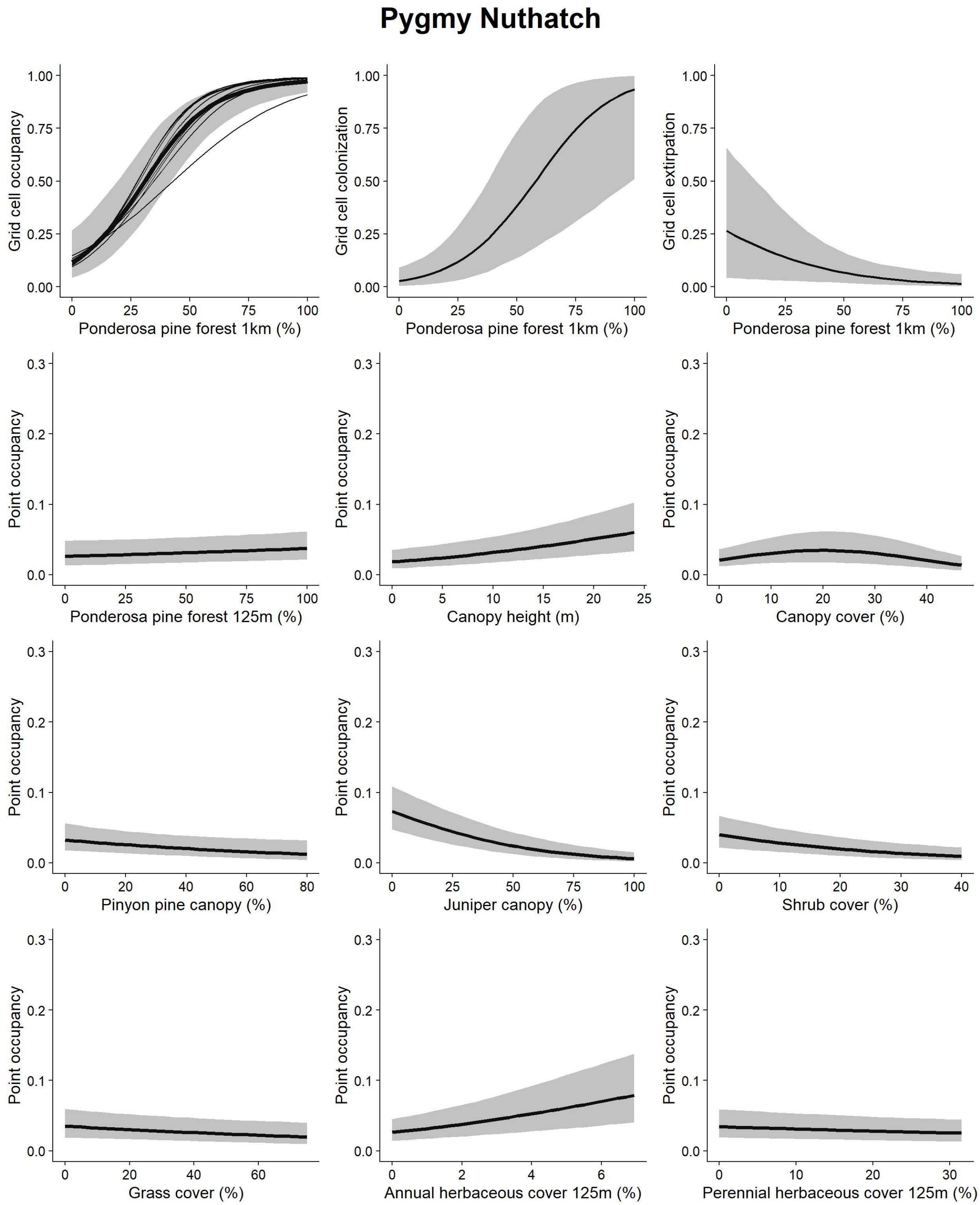

Figure E10. Supported occupancy relationships for Pygmy Nuthatch.

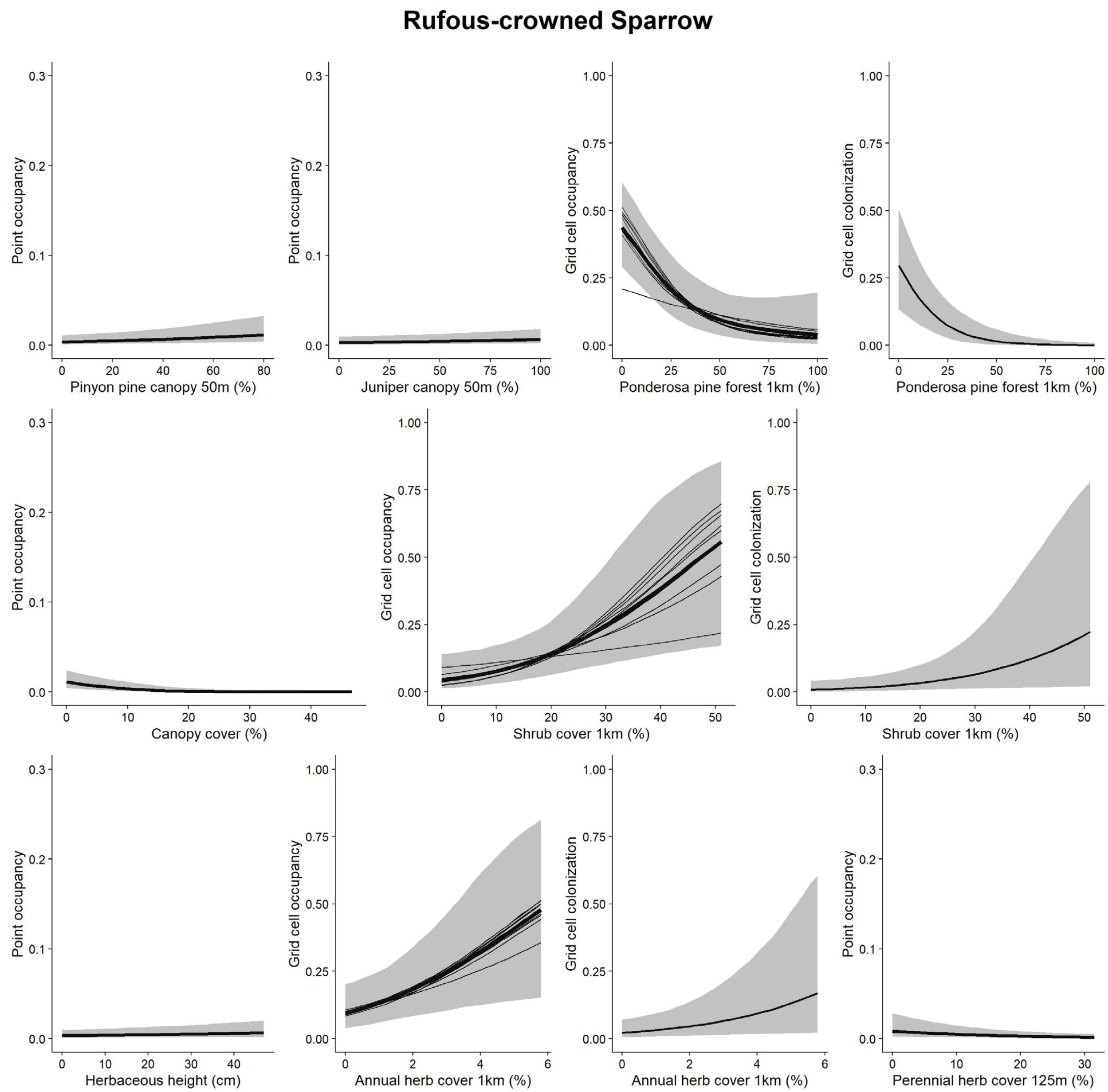

Figure E11. Supported occupancy relationships for Rufous-crowned Sparrow.

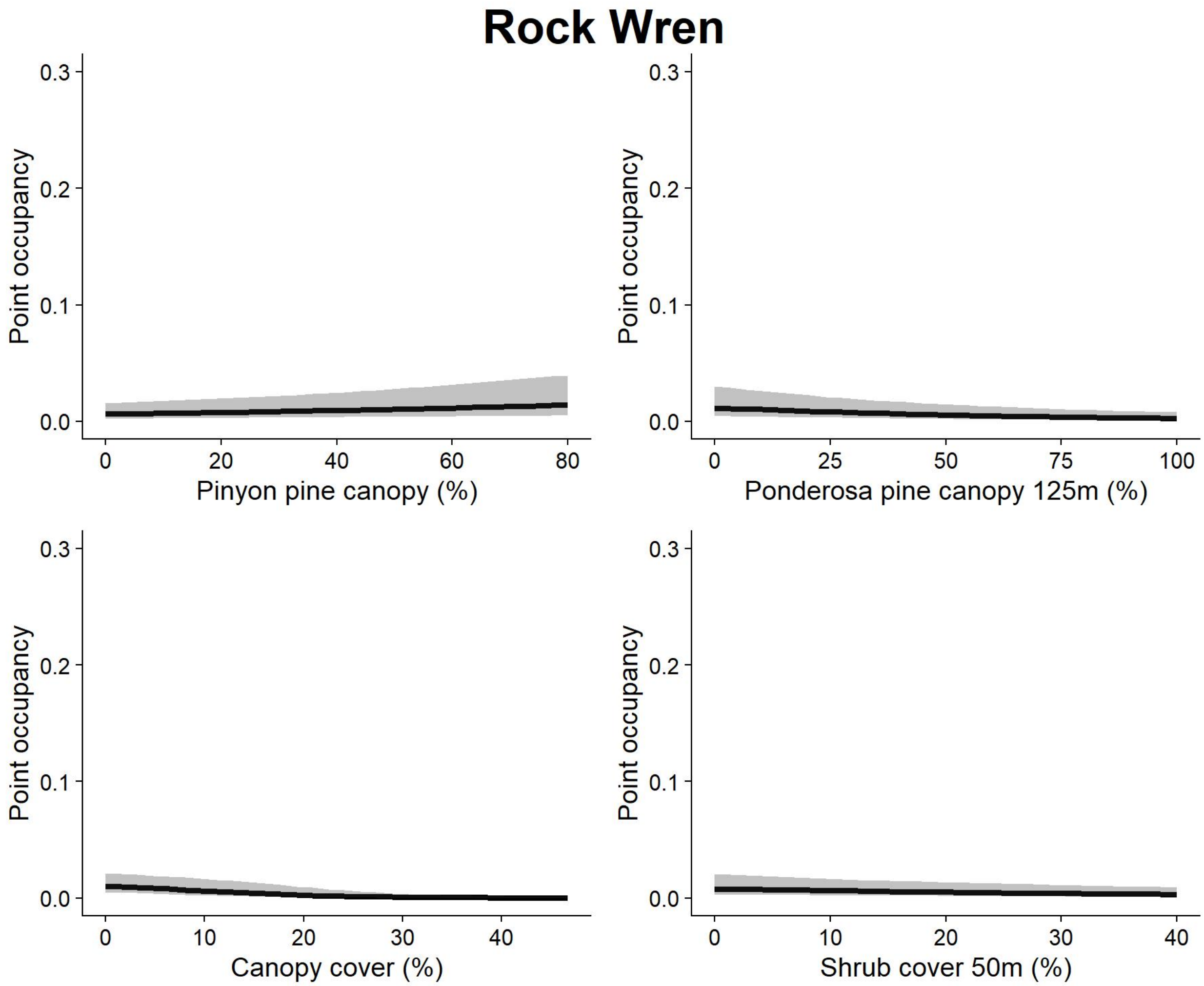

Figure E12. Supported occupancy relationships for Rock Wren.

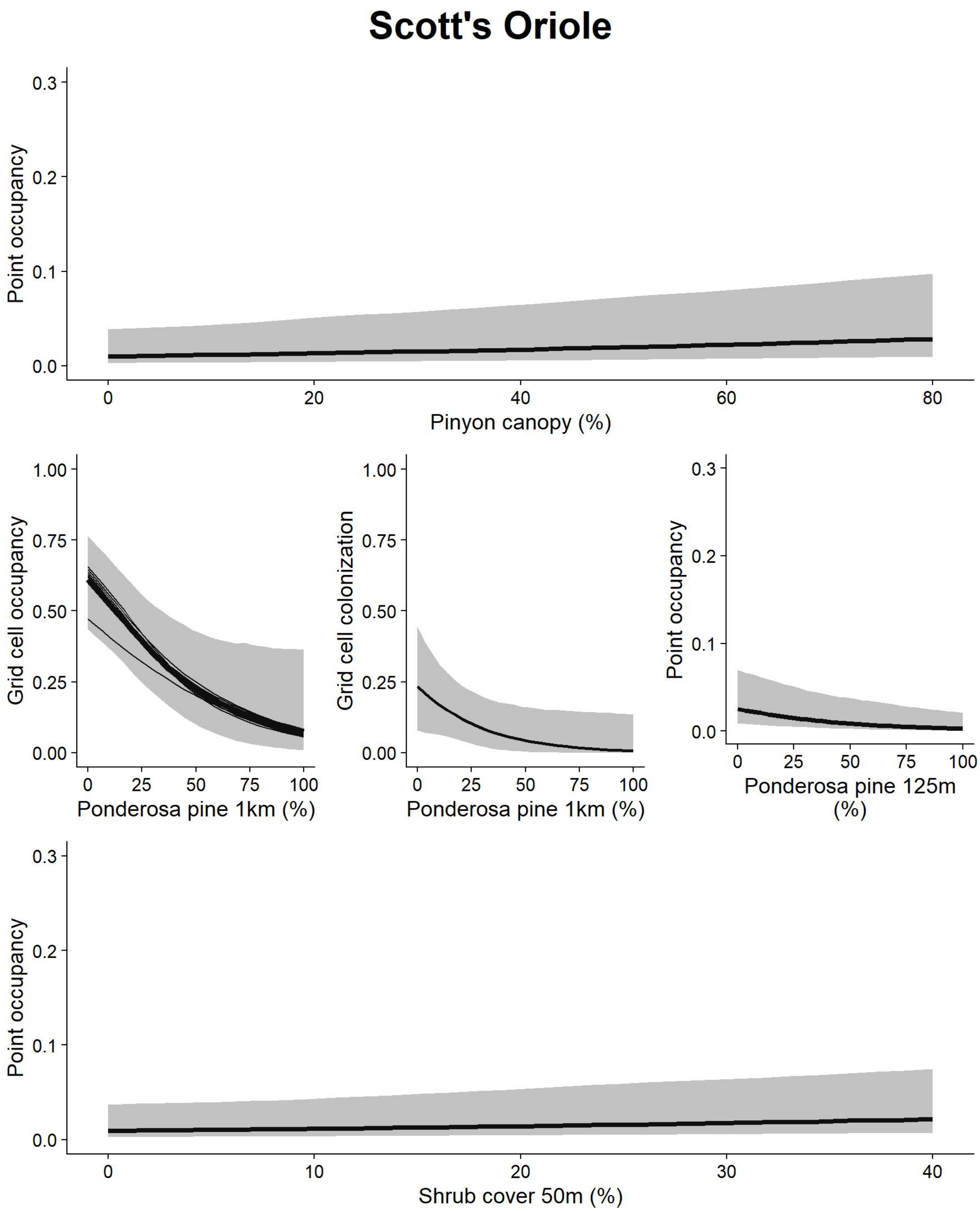

Figure E13. Supported occupancy relationships for Scott's Oriole.

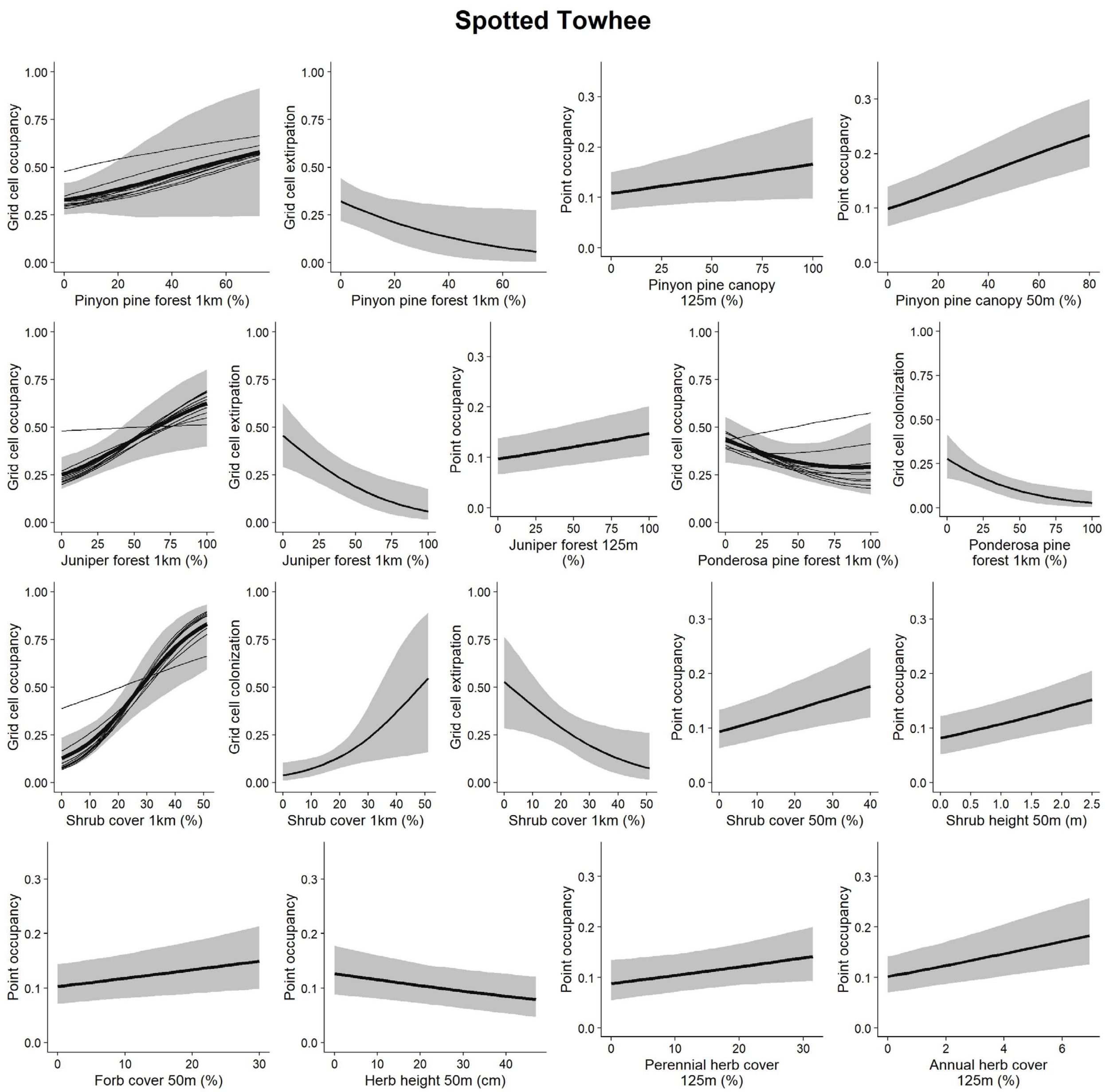

Figure E14. Supported occupancy relationships for Spotted Towhee.

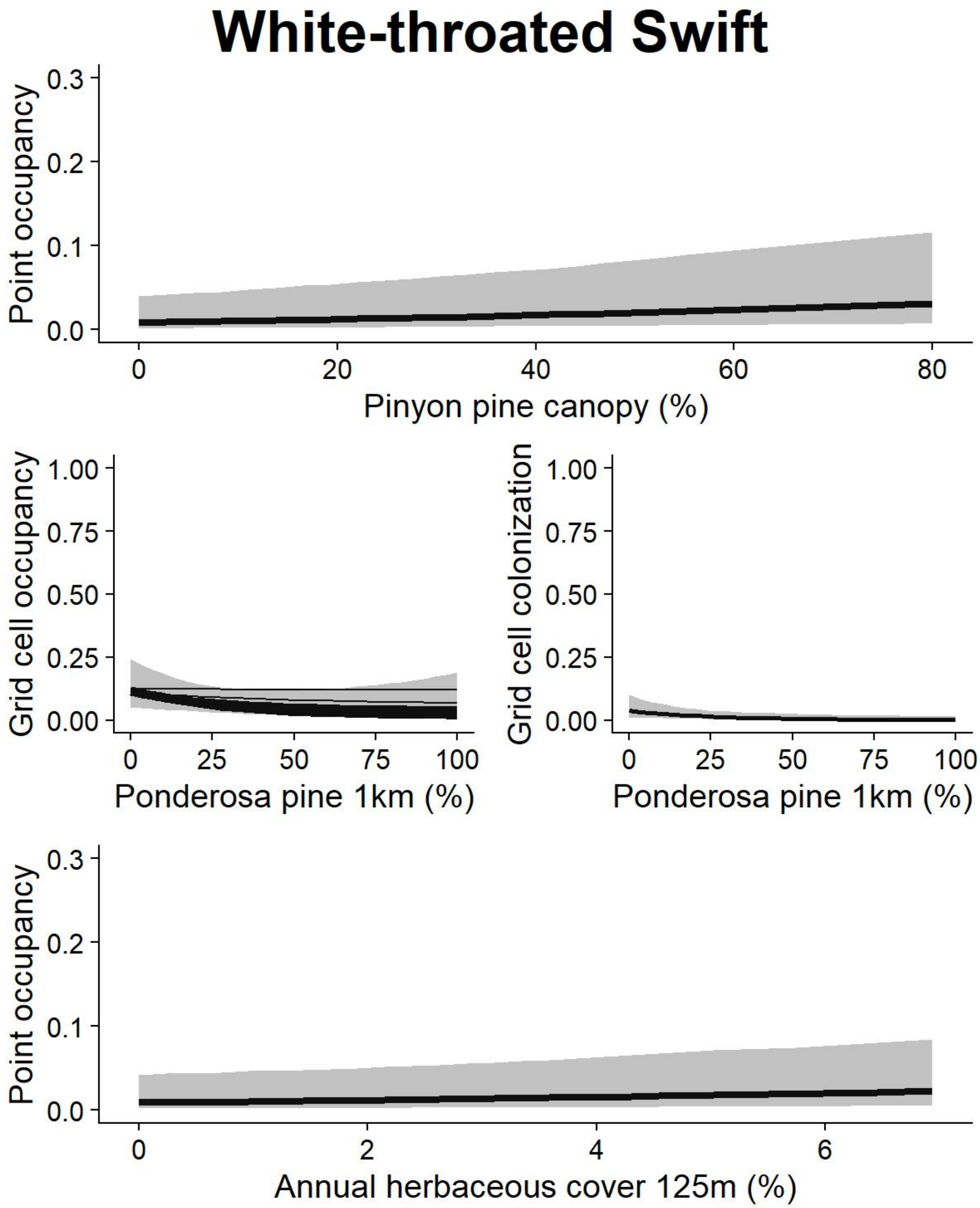

Figure E15. Supported occupancy relationships for White-throated Swift.

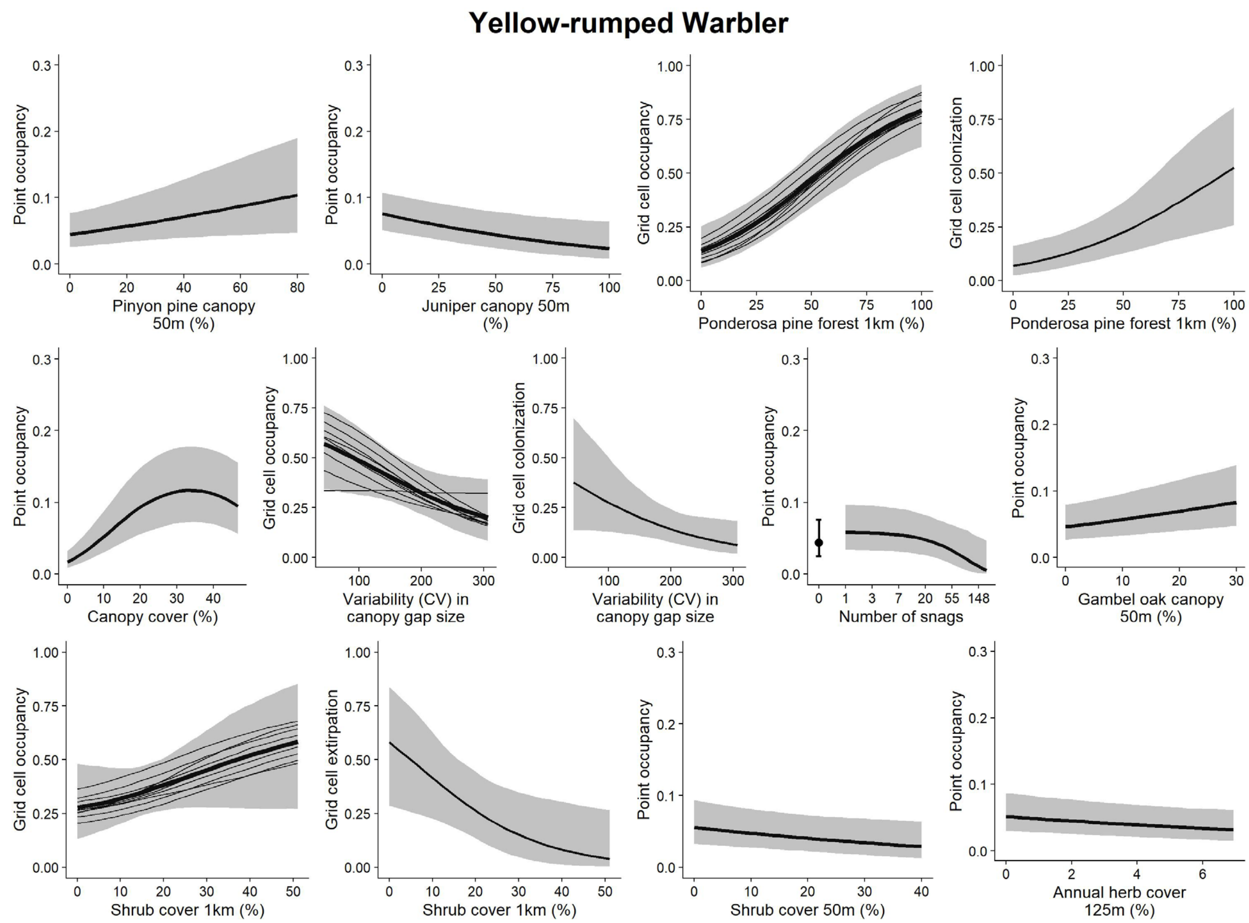

Figure E16. Supported occupancy relationships for Yellow-rumped Warbler.

Appendix F.

This appendix contains figures presenting statistically supported occupancy relationships with covariates for potential grassland focal species for the Coconino Forest Plan. Species represented here are those with habitat relationships that were consistent with expectations for species to represent grasslands and whose habitat described in the literature explicitly includes grasslands (see Tables 9). For all figures here, lines and ribbons are posterior median and 95% credible bands for predicted occupancy. For grid cell occupancy, thinner lines show occupancy for individual years of the study, and the thicker line shows mean occupancy across years (95% credible band is for mean occupancy). Figures are arranged presented in alphabetical order by species common name. Because panels depict covariate relationships for different parameters, relationships are not necessarily comparable across panels in a figure but are shown together to assist interpretation of supported relationships and evaluation of predictions for a given species.

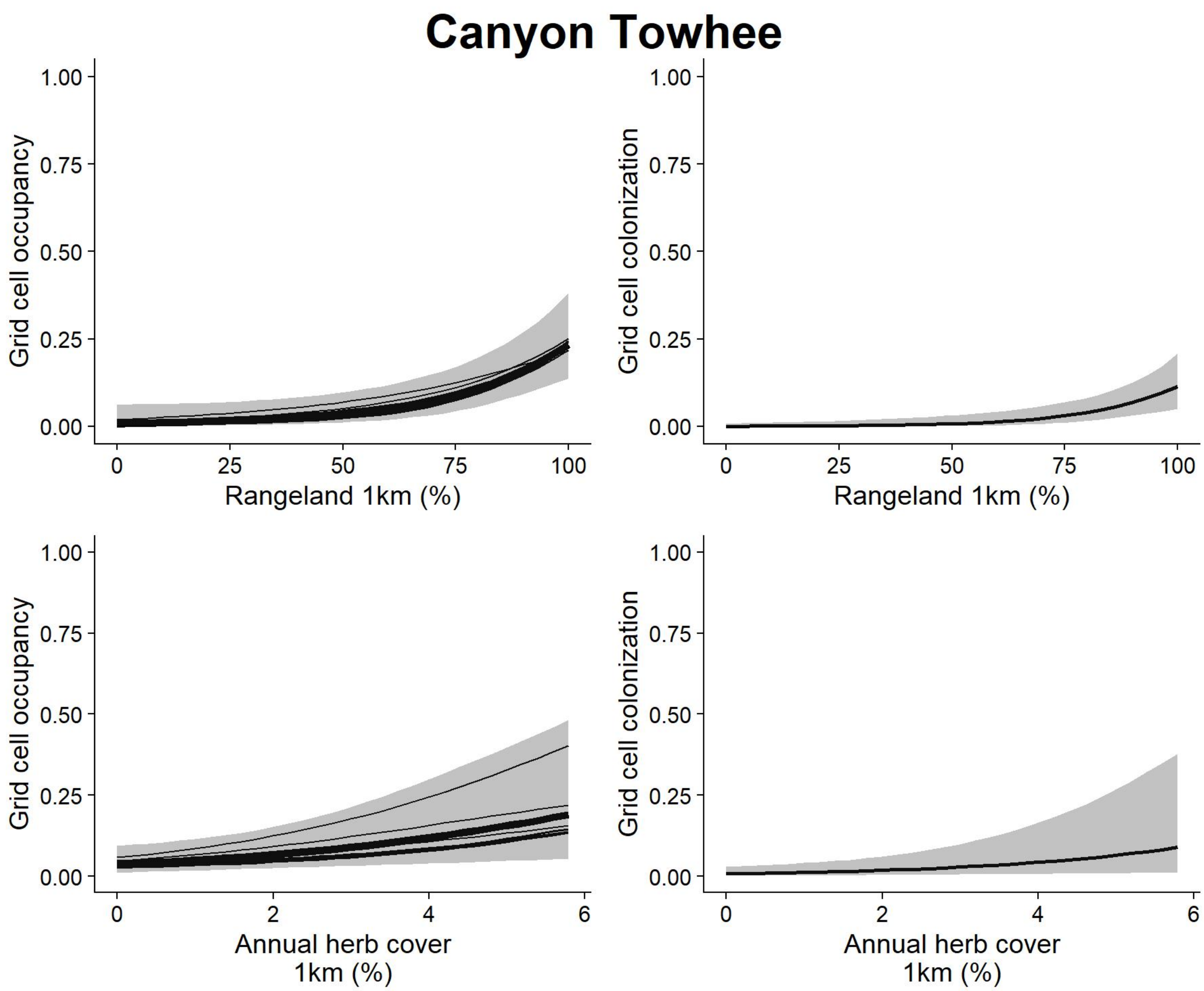

Figure F1. Supported occupancy relationships for Canyon Towhee.

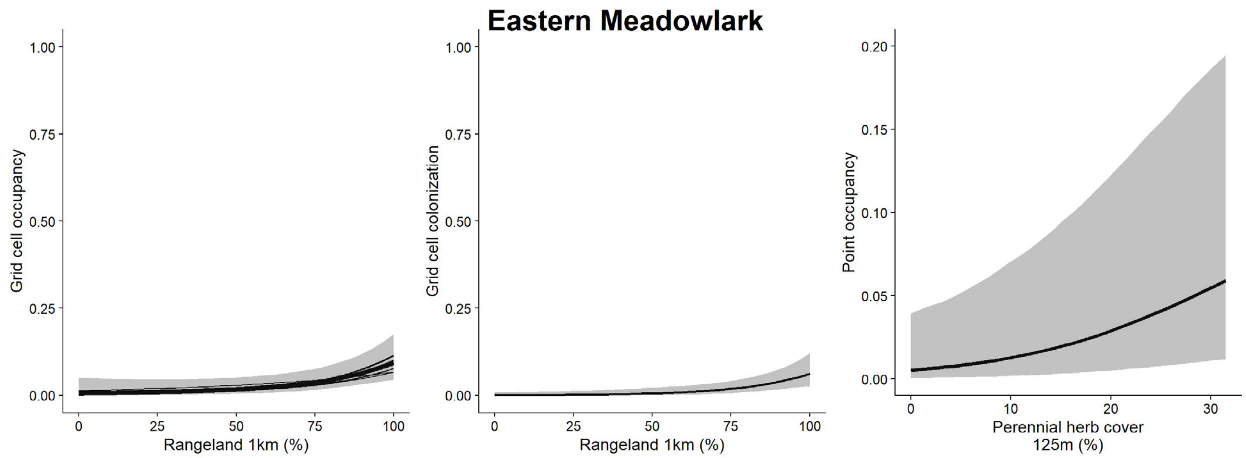

Figure F2. Supported occupancy relationships for Eastern Meadowlark.

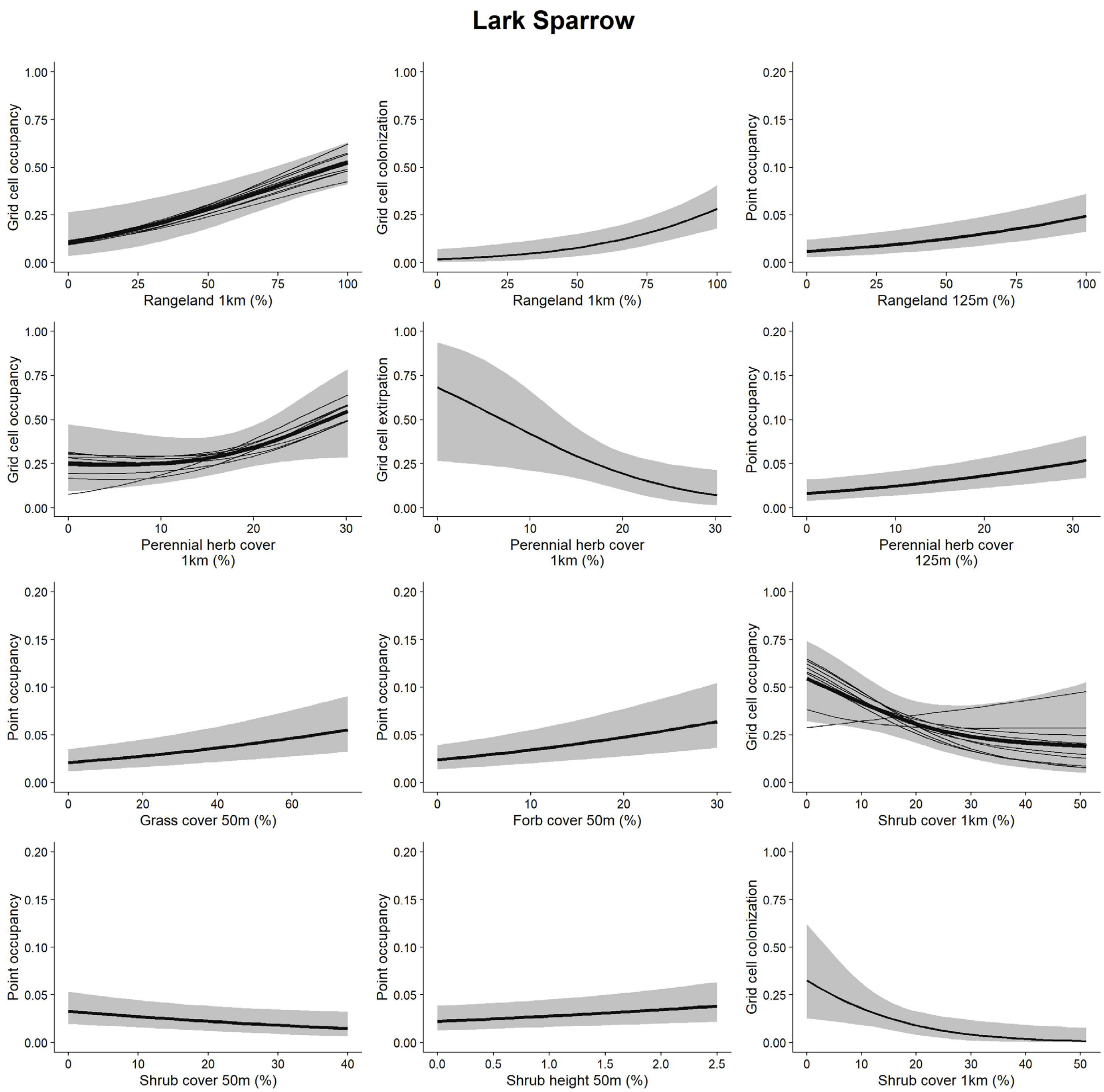

Figure F3. Supported occupancy relationships for Lark Sparrow.

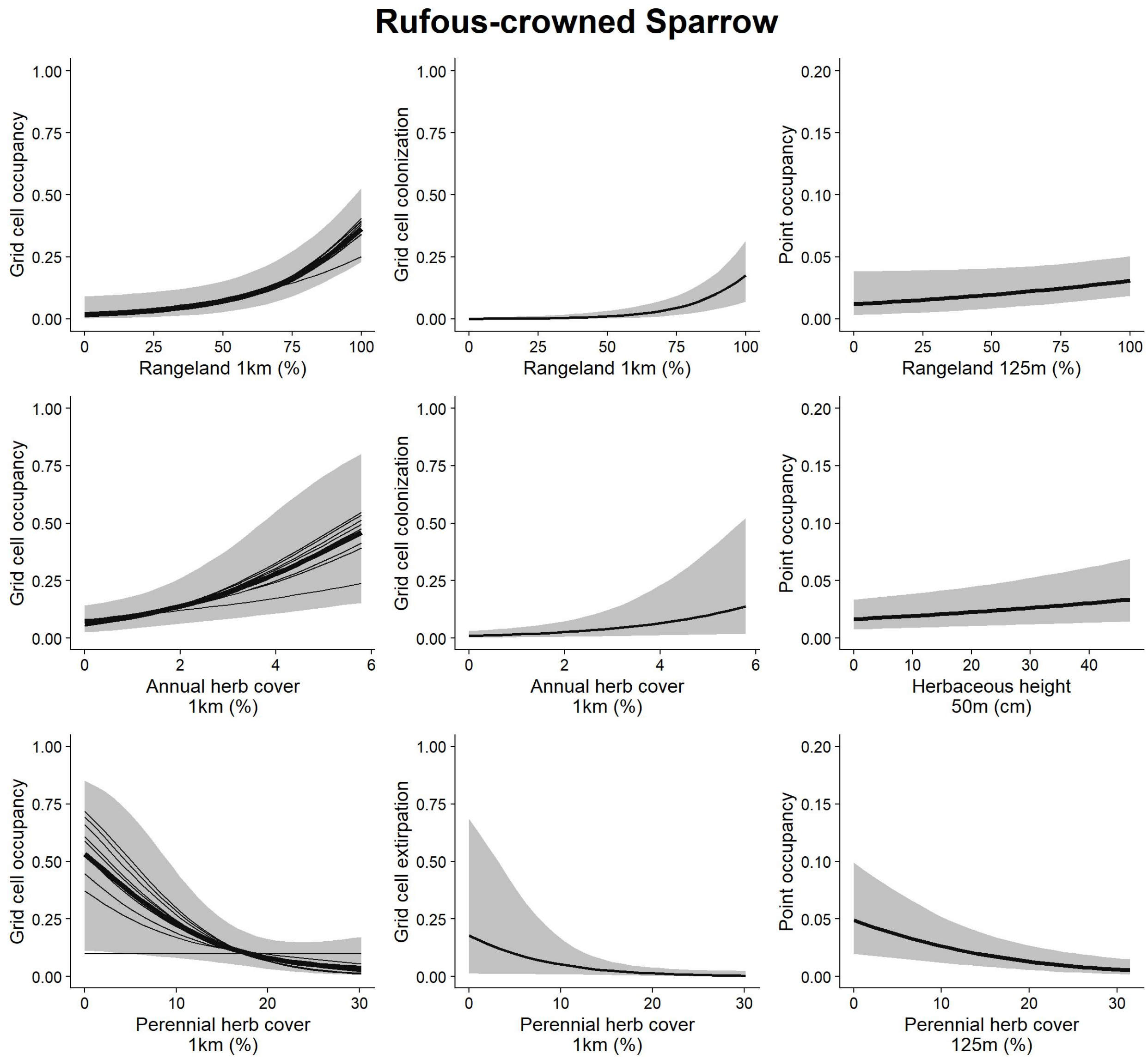

Figure F4. Supported occupancy relationships for Rufous-crowned Sparrow.

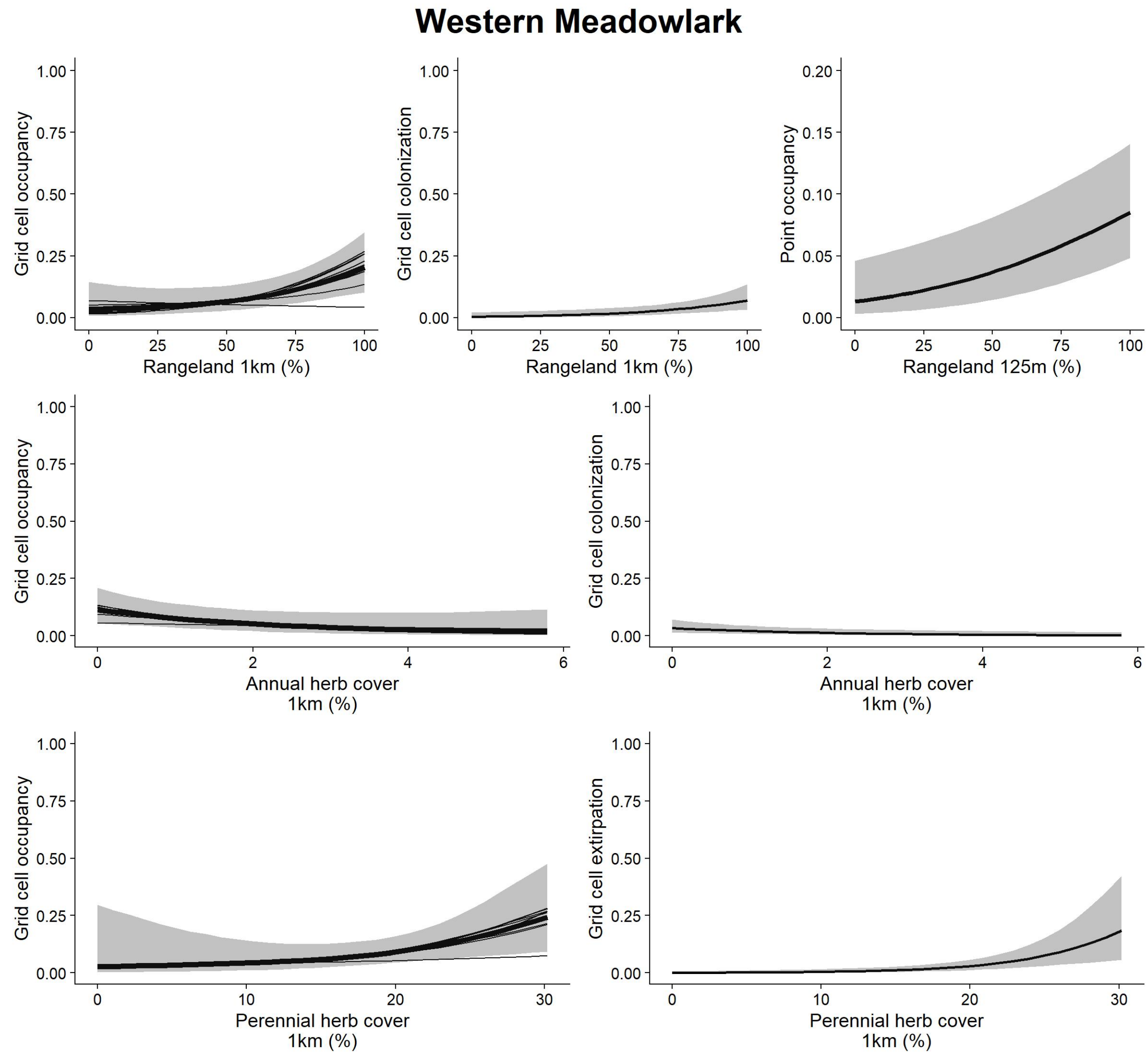

Figure F5. Supported occupancy relationships for Western Meadowlark.