Avian relationships with treatment of encroaching woody vegetation in Arizona grasslands:

Report

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Arizona Game and Fish Department

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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

Encroachment of woody vegetation is one of several major stressors to the ecological integrity of grasslands and the habitat grasslands provide for various wildlife species. Management aimed at grassland conservation often includes mechanical thinning, prescribed fire, or herbicide treatments to limit or remove woody vegetation. These treatments are expected to reduce competitive pressures exerted by woody plants and thereby restore grass and forb dominance that is central to various ecological functions, including providing habitat for wildlife.

The Arizona Game and Fish Department (hereafter Department) and partners implemented mechanical thinning treatments during 2017–2019 to reduce encroaching woody vegetation on historic grasslands of central and southeast Arizona. Along with these treatments, the Department leveraged ongoing long-term monitoring under the Integrated Monitoring in Bird Conservation Regions (IMBCR) program to implement effectiveness monitoring focusing on birds. We analyzed bird survey data collected alongside treatments to estimate avian species and community relationships with treatments and treatment relationships with vegetation and thus to evaluate treatment effects over a short timeframe. Our objectives were 1) to evaluate treatment relationships for grassland bird species occupancy, richness, and composition in central and southeastern Arizona and 2) to evaluate treatment relationships with vegetation structure to inform potential mechanisms underlying observed relationships. To meet objective 1, we applied a Bayesian hierarchical occupancy model to estimate treatment relationships with species occupancy and richness at two different spatial scales. For objective 2, we analyzed treatment relationships with six vegetation metrics expected to mediate treatment relationships with birds.

We found primarily negative treatment relationships with birds at both spatial scales considered in our analysis. We found 25 statistically supported treatment relationships for 19 species, of which only one (a coarse-scale relationship for Cactus Wren) was positive. We mainly observed negative treatment relationships in southeastern Arizona (18 species) whereas relationships in central Arizona were fewer and more muted (2 species). Accordingly, we estimated lower species richness following treatment, particularly in southeastern Arizona. We observed similar negative treatment relationships across grassland specialists, facultative grassland species, and non-grassland species. Treatment relationships with vegetation suggested treatments were effective at removing woody vegetation from grasslands, while also reducing grass cover, grass height, and forb cover. These relationships suggest possible short-term negative impacts to non-target herbaceous vegetation, and that the expected promotion of grasses and forbs had not yet materialized within the 2-year post-treatment period represented here. Reductions in both woody and non-woody vegetation provide a plausible mechanism for short-term negative avian treatment relationships. Published studies suggest strong potential for positive responses of both vegetation and birds to shrub removal treatments over a longer timeframe. Thus, if and when grasses and forbs do respond to the reduction in woody vegetation, we would expect a concomitant long-term positive response by grassland birds. Additionally, post-treatment years were extremely dry and approximately half of survey units were subject to cattle grazing. Thus, drought and cattle grazing represent factors that could have limited vegetation and thus avian response to treatment in this study. Considered in this broader context, our results highlight the need for continued effectiveness monitoring over a period that is long enough for herbaceous vegetative responses to treatments while bearing in mind factors potentially governing ecological response to treatment.

Acknowledgements

Funding for this project was provided by the Arizona Game and Fish Department (AGFD) Landowner Relations and Habitat Enhancement programs, Bureau of Land Management, and US Fish and Wildlife Service (Partners for Fish and Wildlife Program). We would especially like to thank the field crew of the Great Basin Bird Observatory that spent many hours in the field collecting data. Additionally, Edwin Juarez and Troy Corman, biologists with AGFD, contributed to this report.

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Introduction

North American grasslands have severely declined in extent and ecological integrity over the last century. Primary threats include overgrazing, fragmentation with conversion of grasslands to small ranchettes, and encroachment of woody vegetation (Bestelmeyer et al. 2018, Sayre et al 2012, VanAuken 2009). The loss and degradation of grasslands has precipitated losses of various ecosystem services, including reduced habitat for grassland wildlife (With et al. 2008). Various land management agencies implement grassland restoration and management programs to mitigate and reverse grassland loss.

Birds are particularly impacted by declining grasslands, making them a priority species for conservation efforts (Peterjohn and Sauer 1999). The Arizona Game and Fish Department (hereafter Department) manages wildlife populations and their habitats for their long-term persistence within the state of Arizona. The Department collaborates with Bird Conservancy of the Rockies (hereafter Bird Conservancy) to implement long-term and broad-scale monitoring of grassland bird distributions, abundance, and diversity via Integrated Monitoring in Bird Conservation Regions (IMBCR). Leveraging IMBCR monitoring, the Department implemented a three year study (2017–2019) of breeding grassland birds on working grasslands undergoing management actions. Treatments implemented during this period consisted primarily of mechanical thinning with limited prescribed fire to mitigate encroachment of woody vegetation and thereby improve habitat quality for grassland-associated wildlife. The Department surveyed breeding birds in relation to treatments using IMBCR sampling and survey protocols to evaluate treatment effects in the short term and evaluate response by grassland birds.

Effectiveness monitoring plays an important role in making state-dependent management decisions, evaluating the success of management objectives, and contributing to adaptive management cycles (Lyons et al. 2008). Effectiveness monitoring here aimed to evaluate treatment response by grassland birds in two distinct regions: 1) central Arizona where grassland birds breed relatively early (mid-May–June) and juniper (*Juniperus* spp.) represents the primary woody encroacher of grasslands (hereafter CTAZ), and 2) southeastern Arizona where birds breed later (July–mid-August) and mesquite (*Prosopis* spp.), creosote (*Larrea tridentata*), and acacia (*Acacia* spp.) represent primary encroachers (hereafter SEAZ). Many priority avian species of conservation concern only occur in SEAZ. Considering the differences in breeding ecology, species composition, and woody encroachers, monitoring of treatment effects on birds was implemented separately by region to best inform management of each system.

It is generally expected that mechanical thinning and prescribed fire treatments aimed at reducing coverage of woody encroachers (trees and shrubs) will benefit grassland birds by allowing proliferation of grasses and herbaceous vegetation upon which grassland species depend. Woody vegetation, grasses, and forbs are central to expected mechanisms for treatment effects on birds and therefore represent important foci for effectiveness monitoring. Additionally, it is expected that primarily grassland-associated species will benefit from treatments, whereas habitat generalists or species associated more with non-grassland habitats are expected to be unaffected or negatively affected. Species ecology, habitat associations, and the composition of bird communities therefore represent key system components for understanding treatment effects on birds.

In consultation with the Department and following consideration of the above issues, Bird Conservancy staff identified 2 primary objectives and hypotheses for the analysis described in this report:

1. Evaluate treatment relationships for grassland bird species occupancy, richness, and composition in CTAZ and SEAZ, paying particular attention how species association with grasslands modulates treatment effects.

Hypotheses. – We hypothesized that bird species occupancy and richness would increase with treatment implementation aimed at reducing encroaching woody vegetation on grassland habitats. Additionally, we hypothesized that these effects would be strongest for species strongly associated with grasslands.

2. Evaluate treatment relationships with vegetation structure to inform potential mechanisms underlying observed treatment effects on birds.

   Hypothesis. – Considering the intent of treatments, we expected coverage of woody vegetation (trees and shrubs) to decrease and coverage of grasses and herbaceous vegetation to increase with treatments.

Methods

Study Area

The central Arizona region of our study coincided with two vegetation communities within the Colorado Plateau Major Land Resource Area 35 (MLRAs) as designated by the National Resource Conservation Service (NRCS). CTAZ study units fell in the Colorado Plateau Mixed Grass Plains (35.1), a grassland dominated by cool season grasses with scattered shrubs, forbs, junipers (*Juniperus monosperma* and *Juniperus osteosperma)* and pinyon pine (*Pinus edulis*) at elevations ranging from 4800 to 6300 feet and precipitation averaging 10 to 14 inches per year. Vegetation included *Stipa* species, Indian ricegrass, galleta, blue grama, fourwing saltbush, winterfat, and cliffrose. The soil temperature regime was mesic and the soil moisture regime was ustic aridic. One-seed juniper is native to the site, but has the potential to increase and dominate after unmanaged grazing and/or fire exclusion. Remaining study units fell in a second vegetation community designated as Land Resource Unit 35.3, Colorado Plateau Woodland-Grassland, wherein junipers (*Juniperus monosperma* and *Juniperus osteosperma)* and pinyon pine (*Pinus edulis*) were mixed with cliffrose, Apache plume, four-wing saltbush, and Mormon tea. Grasses included needle and thread, sideoats grama, blue grama, black grama, galleta, bottlebrush squirreltail, and muttongrass. Elevations ranged from 5000 to 7000 feet and precipitation averaged 14 to 18 inches per year. The soil temperature regime was mesic and the soil moisture regime was aridic ustic.

The CTAZ study sites in Yavapai County were in MLRA 38, Mogollon Transition, wherein vegetation included junipers (*Juniperus monosperma* and *Juniperus osteosperma)* and pinyon pine (*Pinus edulis*) mixed with interior chaparral species: turbinella oak, Wright silktassel, hollyleaf buckthorn, desert buckbrush, algerita, and sugar sumac. Grasses included tobosa, prairie junegrass, blue grama, curly mesquite, bottlebrush squirreltail, muttongrass, cane beardgrass, plains lovegrass, and bullgrass. Elevations ranged from 4000 to 5500 feet and precipitation averaged 16 to 20 inches per year. The soil temperature regime ranged from thermic to mesic and the soil moisture regime was aridic ustic. This unit occurred within the Transition Zone Physiographic Province and was characterized by canyons and structural troughs or valleys. Igneous, metamorphic and sedimentary rock classes occurred on rough mountainous terrain in association with less extensive sediment-filled valleys exhibiting little integrated drainage.

The southeastern Arizona study region coincided with Major Land Resource Area 41 designated as southeastern Arizona Basin and Range. SEAZ study sites were located in two Land Resource Units. MLRA 41.3, Chihuahuan-Sonoran Semi-desert Grasslands, where elevations ranged from 3200 to 5000 feet and precipitation ranged from 12 to 16 inches per year. Vegetation included mesquite, catclaw acacia, netleaf hackberry, palo verde, false mesquite, range ratany, fourwing saltbush, tarbush, littleleaf sumac, sideoats grama, black grama, plains lovegrass, cane beardgrass, tobosa, vine mesquite, threeawns, Arizona cottontop, and bush muhly. The soil temperature regime was thermic and the soil moisture regime was ustic aridic. Remaining sites were in MLRA 41.2, Chihuahuan-Sonoran Desert Shrubs. Elevations ranged from 2600 to 4000 feet and precipitation ranged from 8 to 12 inches per year. Vegetation included mesquite, palo verde, catclaw acacia, soaptree yucca, creosotebush, whitethorn, staghorn cholla, desert saltbush, Mormon tea, burroweed, snakeweed, tobosa, black grama, threeawns, bush muhly, dropseed, and burrograss. The soil temperature regime was thermic and the soil moisture regime was typic aridic.

Avian monitoring

Bird survey units were established in CTAZ and SEAZ between 2017 and 2019 on public land or on participating ranches that had granted access for bird surveys (Figure 1). Sampling units were 1-km^2 grid cells consisting of 16 survey points separated by 250 m and located ≥125 m from the grid cell boundary (Pavlacky et al. 2017). Surveyors visited a spatially balanced sample (*sensu* Stevens and Olsen 2004) of grid cells within strata defined by ranch boundaries during each year of monitoring within the breeding season (May 9 – August 12). At each point within each grid cell, surveyors recorded all bird species seen or heard during a six minute survey period (Hanni et al. 2016). Herbicide treatments, prescribed fire, and mechanical thinning were initially planned, but we only analyzed data following mechanical thinning, because it was the only treatment implemented across a substantial extent during the study period. We also excluded data collected following prescribed fire at one ranch in SEAZ. Thus, the data analyzed in this report represented 913 grid cell surveys and 1857 point surveys of 161 points within 63 grid cells across both regions (Table 1). Following the initial plan, most treatments were implemented following 2017 and before 2018 surveys, although a substantial minority were implemented either before 2017 or after 2018 surveys (Table 2). Thus, 501 point surveys (27%) occurred at treated points and 67 grid cell surveys (42%) included at least one survey of a treated point (Table 1).

Table 1. Sampling effort for effectiveness monitoring of management treatments on working grasslands of central and southeastern Arizona. Primary sampling units are 1-km^2 grid cells and secondary units are 150-m radius circular point-centered plots, with 6–16 points (mean [SD] = 14.5 [1.9]) spaced evenly 250 m apart nested within grid cells. Treatment points were those that occurred within a treatment unit and treated grid cells are those that included at least one treated point.

Region	**Unit**	**Control**	**Treatment**	**Total**
Central Arizona	Grid cells	7	29	36
	Grid cell × years	48	48	96
	Points	213	290	503
	Point × years	641	398	1039
Southeast Arizona	Grid cells	19	8	27
	Grid cell × years	46	19	65
	Points	307	103	410
	Point × years	643	175	818

Table 2. Sampling effort in each year of effectiveness monitoring of management treatments on working grasslands of central and southeastern Arizona. Primary sampling units are 1-km^2 grid cells and secondary units are 150-m radius circular point-centered plots, with 6–16 points (mean [SD] = 14.5 [1.9]) spaced evenly 250 m apart nested within grid cells. In any year, treated points (T) were those that occurred within a treatment unit, treated grid cells are those that include at least one treated point, and control units (C) are those that had not yet been treated.

Region	**Unit**	**2017**		**2018**		**2019**	
		C	**T**	**C**	**T**	**C**	**T**
Central Arizona	Grid cells	34	2	11	21	3	25
	Points	386	9	181	171	74	218
Southeast Arizona	Grid cells	24	3	14	8	8	8
	Points	368	15	184	90	91	70

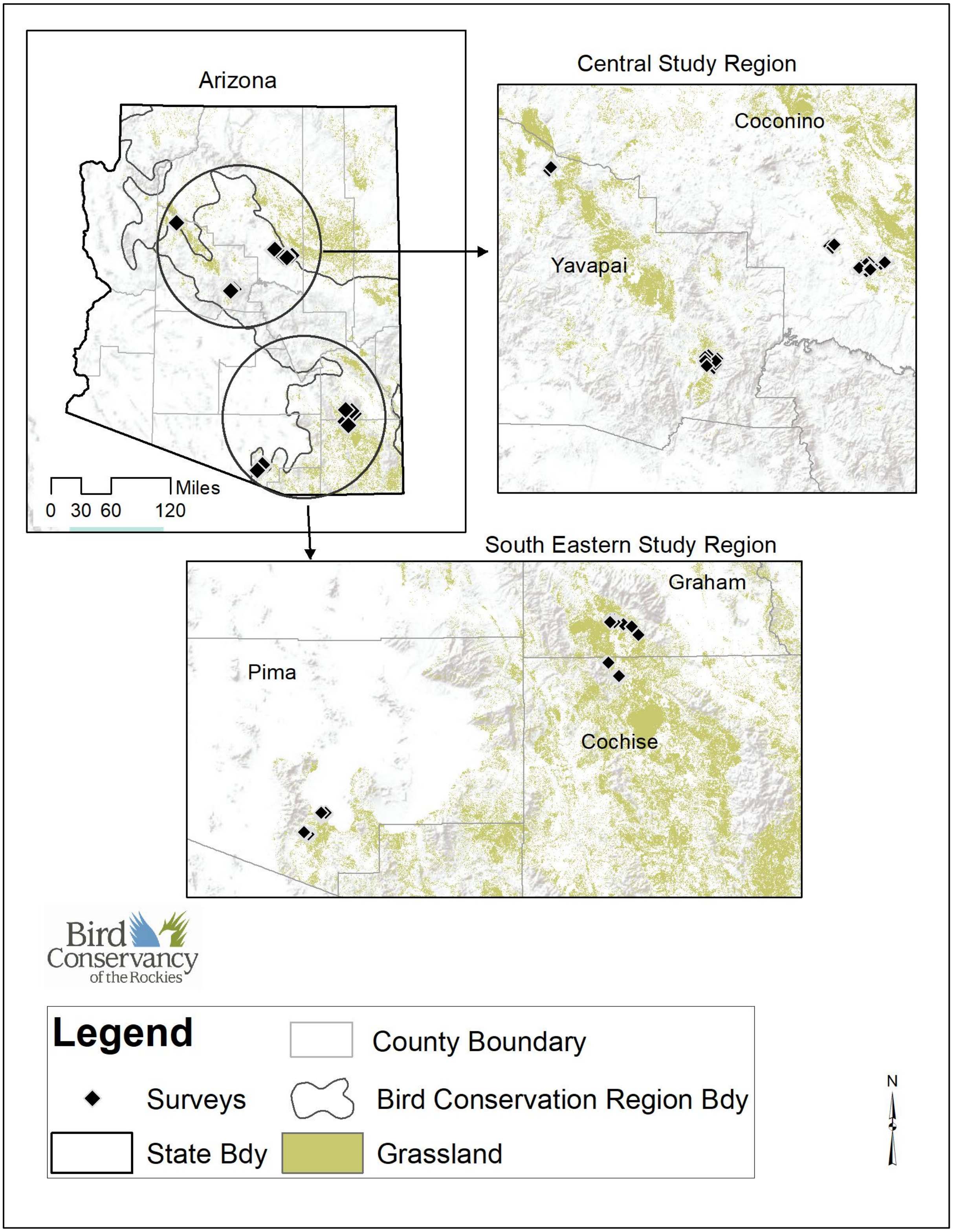

Figure 1. Distribution of sampling units and ranches encompassing the study area.

Treatment and vegetation metrics

To inform objective 1, we quantified the extent to which sampling units (points and grid cells) intersected treatment units (Table 3). We categorized survey points as either treated (1) or untreated (0) based on whether they were centered within an area that had been treated prior to being surveyed. We then calculated the percent of points treated for each grid cell prior to being surveyed.

To inform objective 2, we used attributes of vegetation structure measured for 50-m radius circular plots centered on survey points following the IMBCR field protocol (Hanni et al. 2016; Table 4). These measurements quantified structure of the tree canopy, shrubs, and ground vegetation.

Table 3. Covariates used in models analyzing treatment effects on grassland birds of central and southeastern Arizona.

Variable (abbrev.)	Scale	Description
Treated (Trt)	point	Binary category indicating whether a point was treated (1) or not treated (0) prior to the survey.
Percent treated (percTrt)	grid cell	Percentage of points treated within the grid cell prior to the survey.
Day of year (DOY)[a]	survey	Number of days elapsed since January 1
Time since sunrise (Time)[a]	survey	Number of minutes elapsed since sunrise

[a]These metrics served as covariates of detection probability.

Table 4. Vegetation measurements recorded at survey points for monitoring management effects on grassland birds of central and southeastern Arizona.

Measurement (abbrev.)	Description
Canopy cover (CanCov)	Percent canopy cover
Shrub cover (Shrub)	Percent coverage of shrubs (defined as woody vegetation 0.25 to 3 m high)
Shrub height (ShrubHt)	Ocularly estimated average height (m), with shrubs (defined as woody vegetation between 0.25 and 3 m high)
Herbaceous cover (Herb)	Ocularly estimated percent cover of non-grass herbaceous ground cover
Grass cover (Grass)	Percent coverage of live and dead grass
Grass height (GrassHt)	Ocularly estimated average height (cm)

Data Analysis

We estimated treatment relationships with species occupancy and richness using a multi-species, multi-scale occupancy model (Latif et al. 2020; model structure detailed in Appendix A). 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). The resulting model included individual occupancy models for each species, while sharing information across species to inform estimates for sparsely detected species and thus to better inform species richness. We estimated treatment relationships at two scales (grid cell occupancy with percent of survey points treated within the cell and point occupancy with point treatment status) to inform decisions concerning the spatial extent and distribution of management treatments at different scales (see also Latif et al. 2020).

To support region-specific evaluations, we analyzed data separately for CTAZ and SEAZ regions. For species that occurred in only one region (e.g., Botteri's Sparrow and Rufous-winged Sparrow), the model leveraged community-wide information to generate estimates for species in the region where they did not occur. We did not draw species-specific inferences in regions where a species was absent.

We estimated offsets in treatment relationships for three species groups representing varying levels of habitat specialization: 1) obligate grassland associates, 2) facultative grassland associates, and 3) non-grassland species. We assigned each species represented in our analysis to one of these groups based on published lists and available literature on species ecology (Johnsgard 2009, Vickery and Herkert 1999) and compiled binary indicator variables representing membership in obligate and facultative grassland associates for analysis (reference = non-grassland species).

We examined 95% Bayesian credible intervals (BCIs) to infer statistical support for treatment relationships and species-group offsets to treatment relationships. We considered an effect statistically supported if the corresponding BCI excluded zero.

IMBCR also supports estimation of species-specific population densities. Nevertheless, we opted to analyze occupancy because we expected point-level occupancy to largely index local densities considering the typical home range sizes for most species of interest, and because analysis frameworks for multi-species occupancy analyses have been developed more extensively.

For objective 2, we summarized relationships between treatment and the six vegetation metrics using Pearson's correlation coefficients and visualized relationships with scatter plots. We evaluated hypothesized treatment effects on vegetation in light of observed relationships.

Results

During the study period, we recorded detections of 86 species, including 69 species in CTAZ and 57 in SEAZ. Across both regions, the five most commonly detected species were Black-throated Sparrow, Cassin's Sparrow, Northern Mockingbird, Cactus Wren, and Ash-throated Flycatcher (Appendix B). Of the 86 species detected, we classified 45 as facultative grassland associates and five as obligate grassland associates. These included 36 and three facultative and obligate associates in CTAZ, respectively, and 38 and three in SEAZ, respectively. Obligate grassland species detected in CTAZ were Vesper Sparrow, Eastern Meadowlark, and Western Meadowlark. Grassland obligates detected in SEAZ were Botteri's Sparrow, Cassin's Sparrow, and Eastern Meadowlark.

We found primarily negative occupancy relationships with treatment metrics across regions, but particularly in SEAZ (Figure 2). We found statistically supported treatment relationships for 19 species, including two species in CTAZ and 18 species in SEAZ (Figure 2). In SEAZ, we found 14 statistically supported relationships with percTrt at the grid cell level, of which thirteen were negative and one positive (Figure 2). Additionally, we found nine relationships in SEAZ with Trt at the point level, all negative (Figure 2). In CTAZ, we found only two supported treatment relationships, both negative with Trt at the point level (Figure 2). Posterior median detectability estimates for a 6-min survey ranged 0.01–0.6 across species in CTAZ and 0.02–0.63 in SEAZ, with 24 species exhibiting statistically supported covariate relationships with detectability across regions (Appendix C).

We found little evidence that strength of association with grasslands modulated species treatment relationships. Mean treatment relationships at both grid cell and point scales were centered near zero for all three levels of grassland association in CTAZ and were more negative in SEAZ (Figure 3). None of group level offsets for treatment relationships (differences for obligates and facultative species relative to other species) were statistically supported (95% credible intervals all included zero; Table 4). Species exhibiting (primarily negative) treatment relationships observed here included all three species groups. Most of these species exhibited substantially lower occupancy rates in treated compared to untreated units (Figures 4, 5). Only cactus wren in SEAZ exhibited a positive treatment relationship, but this relationship was not consistent across scales. Cactus wren occupancy of SEAZ grid cells increased with increasing extent of treatment, but they occupied treated points at lower rates than untreated points within occupied grid cells (Figures 2, 5).

Consistent with species treatment relationships, species richness related negatively with treatment in SEAZ (Figure 6). Posterior median predicted richness for treated grid cells in SEAZ was lower than untreated grid cells by 10 species, and lower at treated compared to untreated points by 3 species. Richness was also lower at treated compared to untreated sampling units in CTAZ, but differences were smaller and not statistically clear.

Vegetation metrics measuring canopy, shrubs, and ground cover all related negatively with treatment metrics (Table 5, Figures 7, 8). Negative treatment correlations for woody vegetation were consistent with our *a priori* hypotheses whereas relationships for ground vegetation (grasses and forbs) contradicted our hypotheses (Table 5). Pearson's correlation coefficients in SEAZ were all statistically significant and greater in magnitude than those in CTAZ where some relationships were not as statistically clear but still negative in direction (see canopy cover, forb cover, and grass cover).

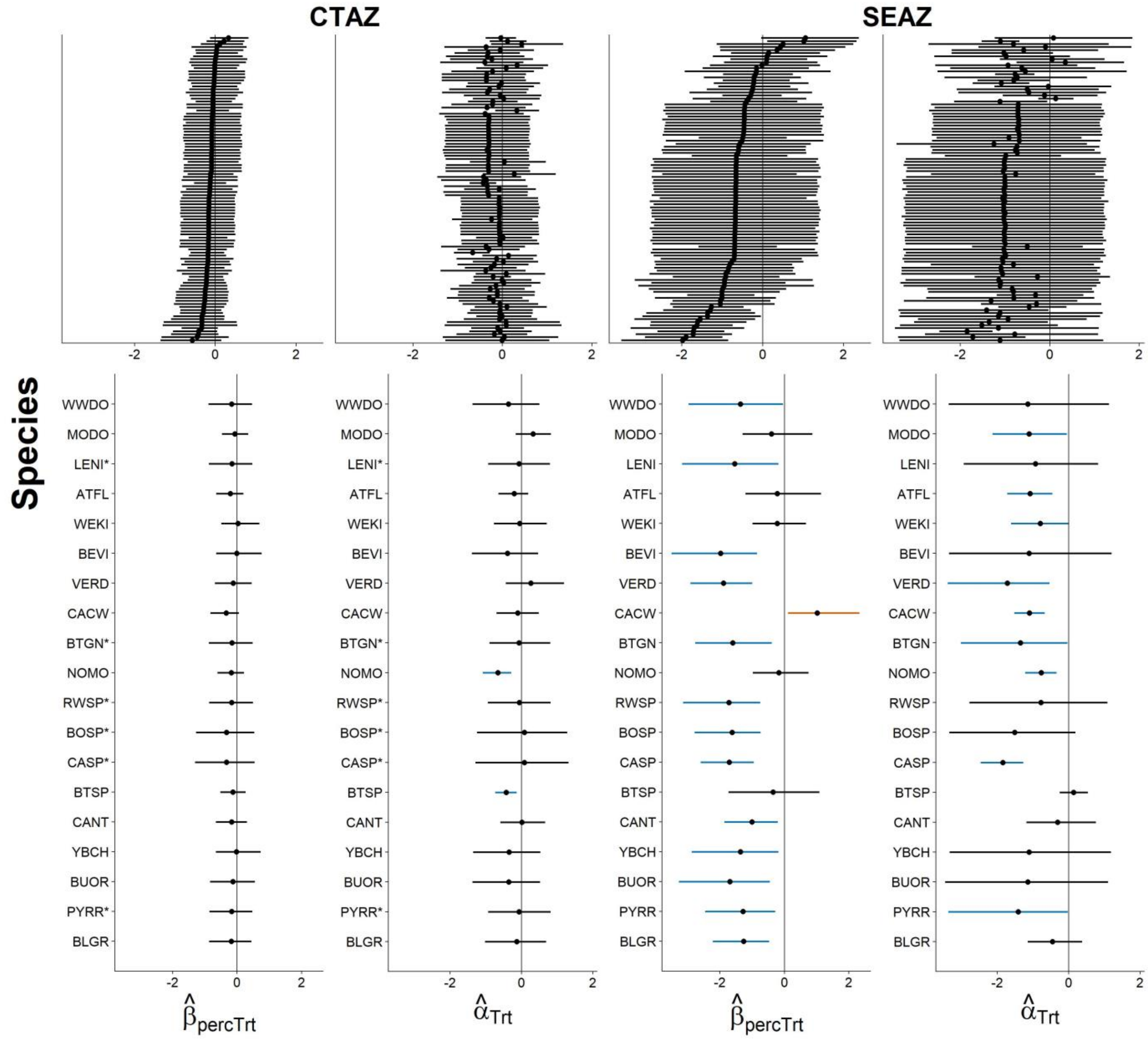

Figure 2. Estimated occupancy relationships (posterior medians and 95% BCIs) with treatment metrics in central Arizona (CTAZ) and southeastern Arizona (SEAZ). Top panels show all species (unlabeled), and bottom panels show relationships for the 19 species with at least one supported relationship (for full species names, see Appendix B). In top panels, relationships are sorted by the relationship with grid-level percent area treated from negative to positive within each region. In bottom panels, species are listed in taxonomic order and error bar colors indicate supported positive (orange) and negative (blue) relationships. Asterisks indicate species never detected in the region whose estimates therefore represent the mean treatment relationship for the community.

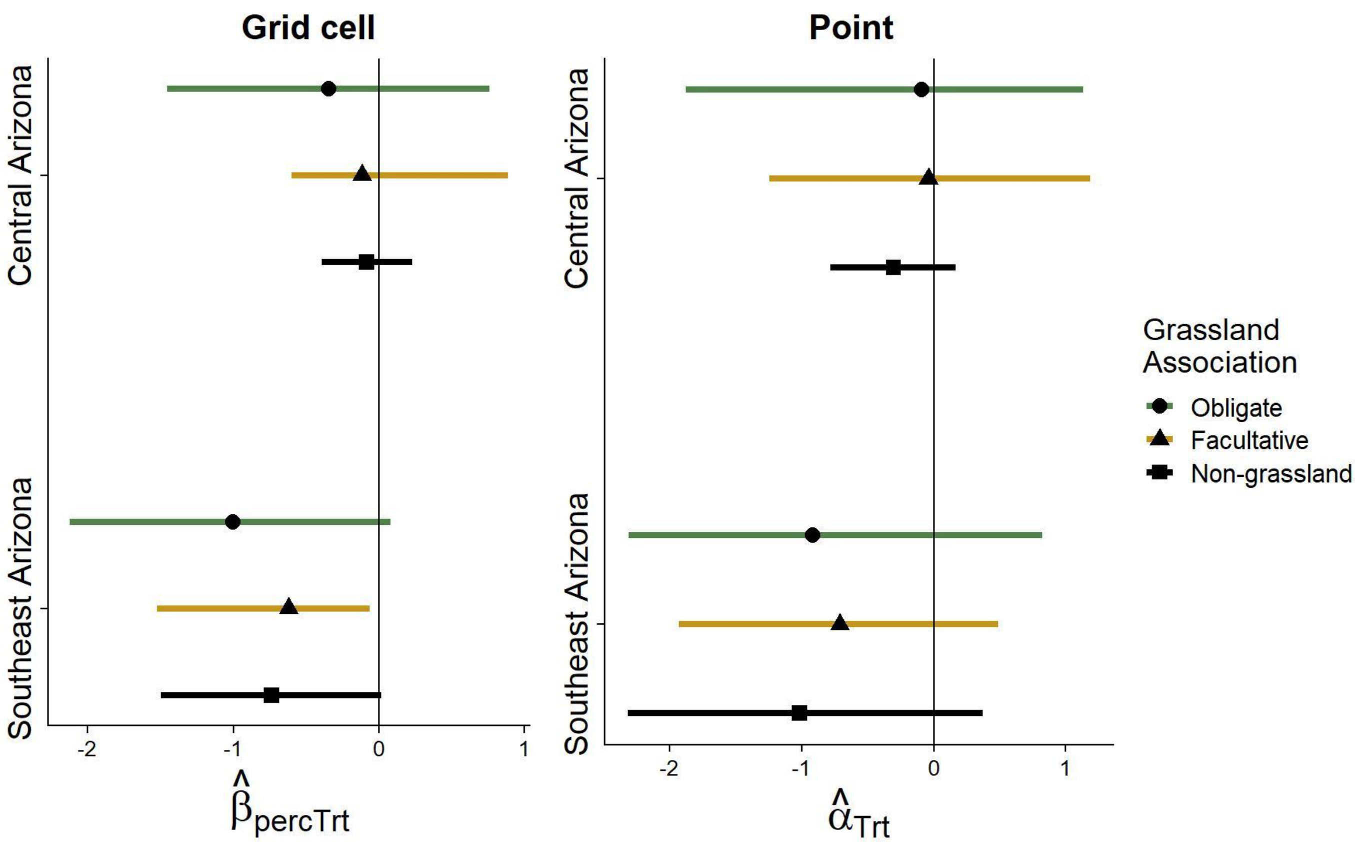

Figure 3. Posterior median estimates (and 95% Bayesian credible intervals) for mean treatment relationships for species groups distinguishing levels of association with grasslands (obligate, facultative, and other). Treatment relationships are grid cell occupancy relationships with percent of the grid cell treated ($\beta_{percTrt}$) and species point occupancy relationships with treatment statuses of points (α_{Trt}) within occupied grid cells.

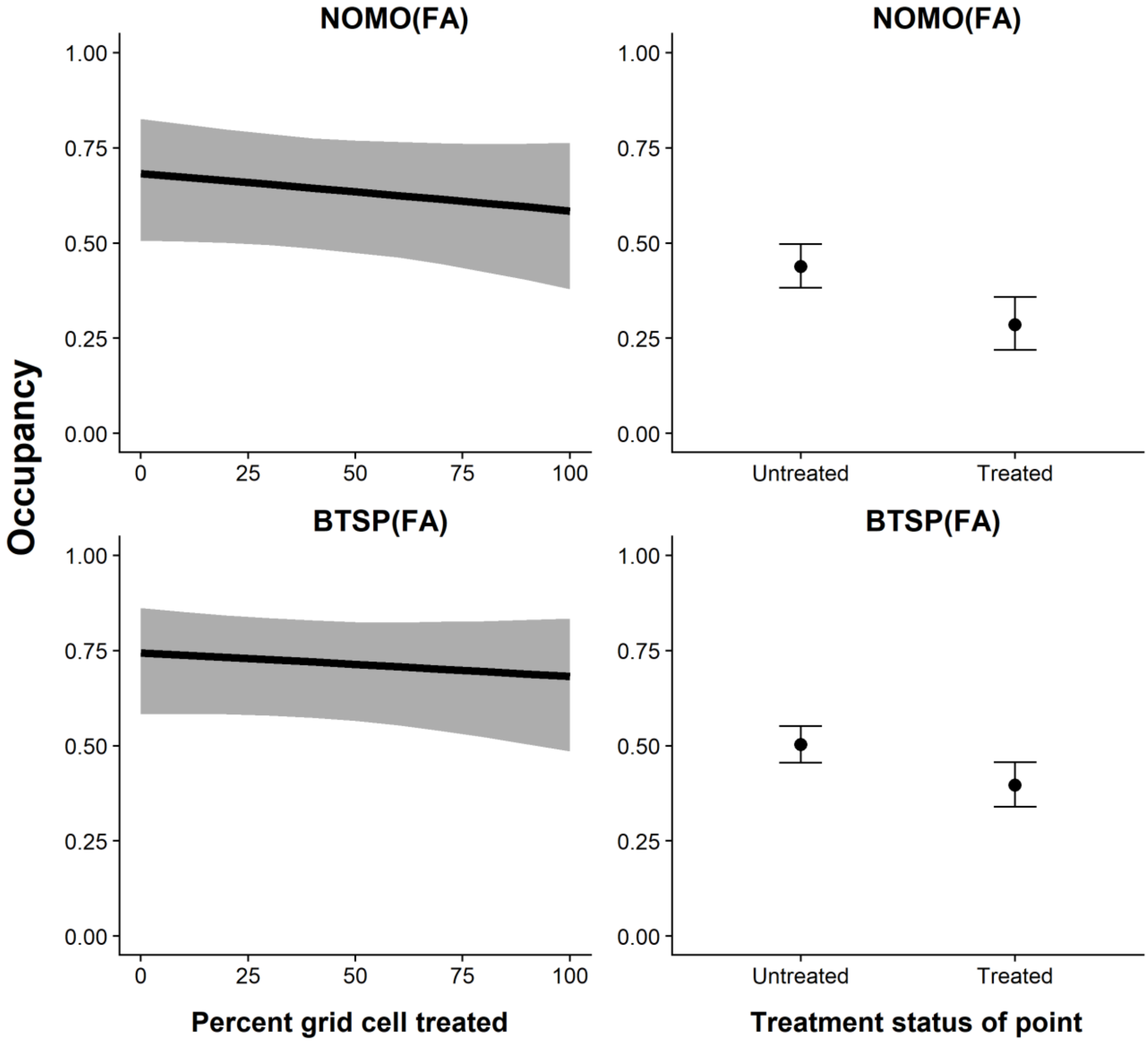

Figure 4. Posterior median predicted occupancy probabilities (and 95% credible intervals) for two species (Northern Mockingbird [NOMO] and Black-throated Sparrow [BTSP]) with statistically supported treatment relationships in Central Arizona. Both species are facultative grassland associates (FA), and both exhibited statistically supported negative treatment relationships at the point level.

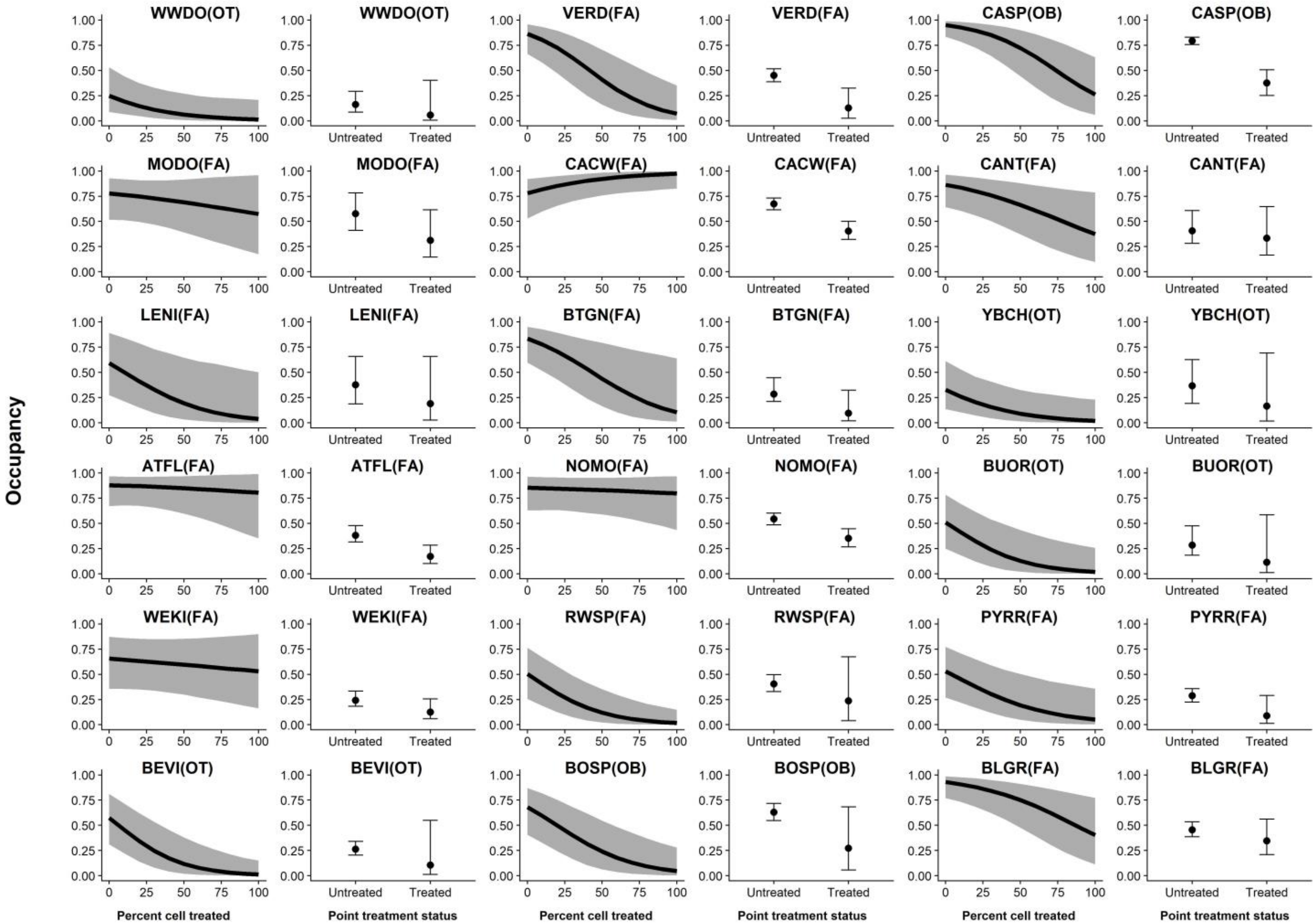

Figure 5. Posterior median predicted occupancy probabilities (and 95% credible intervals) for 18 species (for full species names, see Appendix B) with statistically supported treatment relationships in Central Arizona. Membership in species groups distinguishing levels of grassland association are noted in parentheses: obligate (OB), facultative (FA), and other (OT).

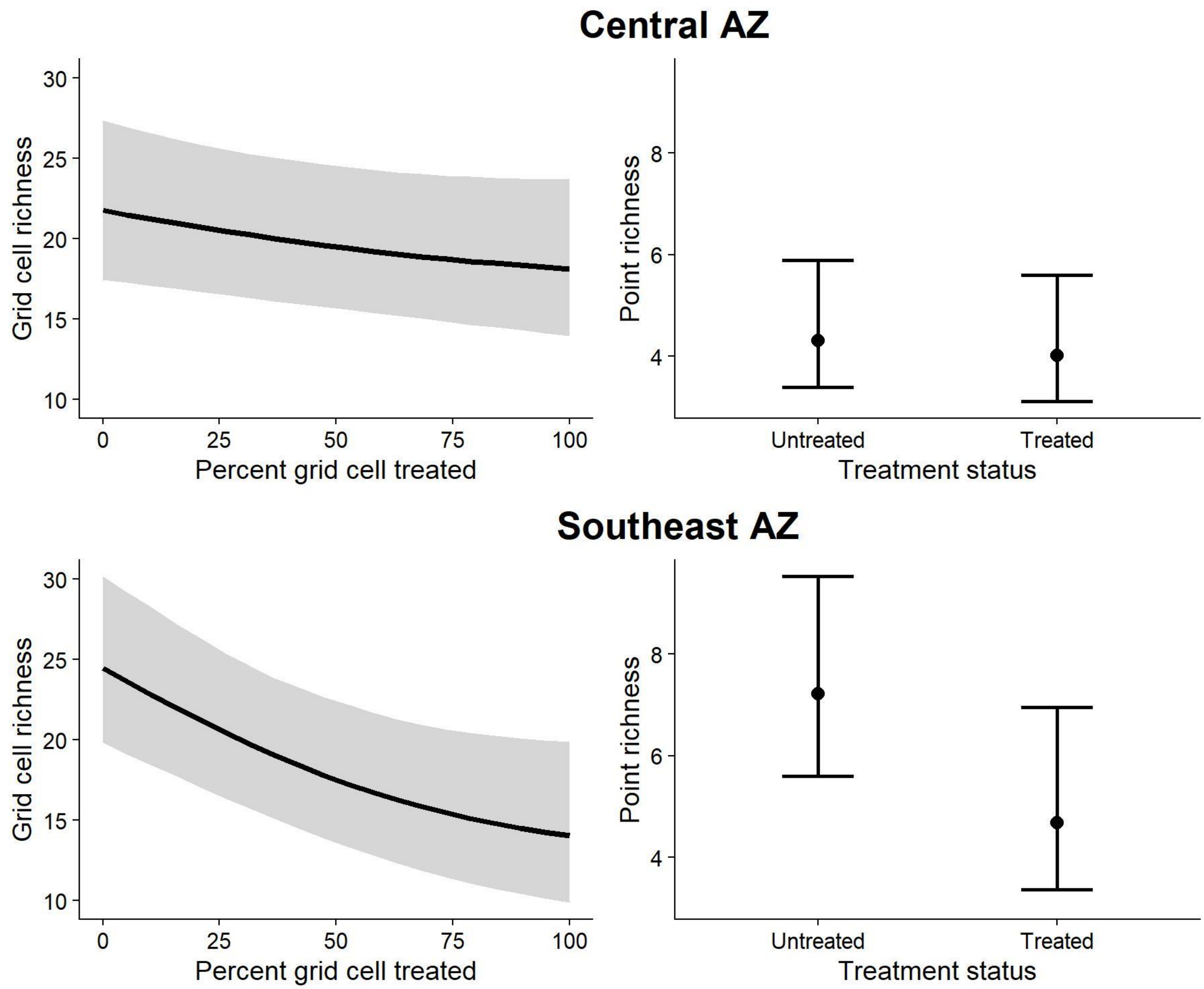

Figure 6. Predicted species richness in relation to treatment metrics for grid cells and survey points. Estimates are posterior median with 95% Bayesian credible intervals. Predicted richness represents the sum of predicted grid cell or point occupancy probabilities across species within the community.

Table 5. Relationships of vegetation with treatment metrics. Pearson's correlation coefficients quantify linear relationships of point-level vegetation with treatment status of survey points and grid-level vegetation with percent of the grid cell treated. Asterisks indicate statistically significant correlations.

Point-level vegetation	**CTAZ (*n* ≥ 1033)**	**SEAZ (*n* ≥ 812)**	**Hypothesis**	**Evidence**
Canopy cover	-0.12*	-0.3*	negative	supported
Shrub cover	-0.11*	-0.48*	negative	supported
Shrub height	-0.16*	-0.61*	negative	supported
Forb cover	-0.08*	-0.25*	positive	contradicted
Grass cover	-0.09*	-0.35*	positive	contradicted
Grass height	-0.14*	-0.27*	positive	contradicted
Grid-level vegetation	**(n = 96)**	**(n = 65)**		
Canopy cover	-0.16	-0.43*	negative	supported
Shrub cover	-0.22*	-0.54*	negative	supported
Shrub height	-0.29*	-0.74*	negative	supported
Forb cover	-0.11	-0.39*	positive	contradicted
Grass cover	-0.16	-0.53*	positive	contradicted
Grass height	-0.25*	-0.38*	positive	contradicted

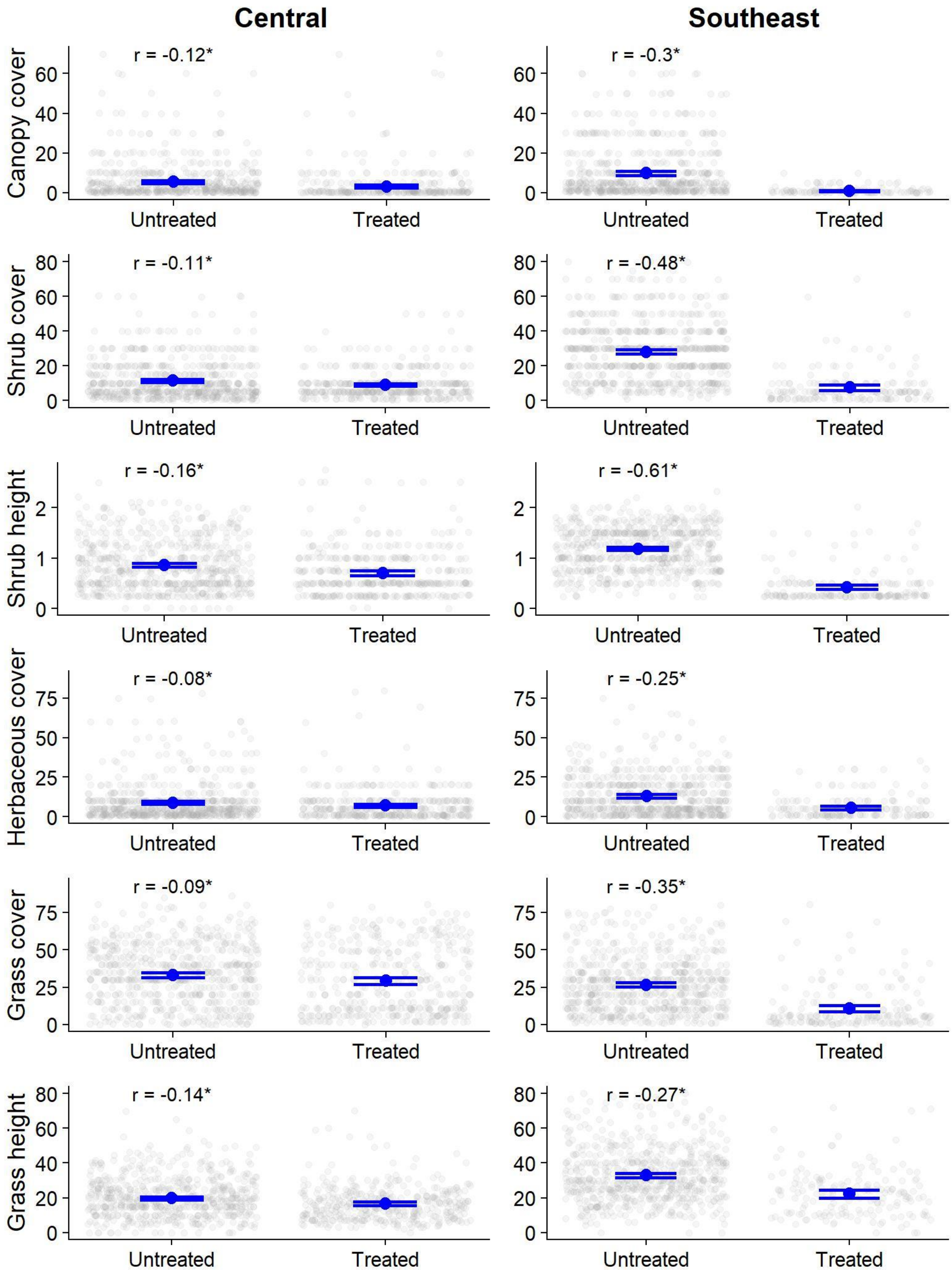

Figure 7. Scatter plots relating vegetation metrics with point-level treatment status. Means and standard errors are in blue. Pearson's correlation coefficients (r) are marked with an asterisk when statistically supported.

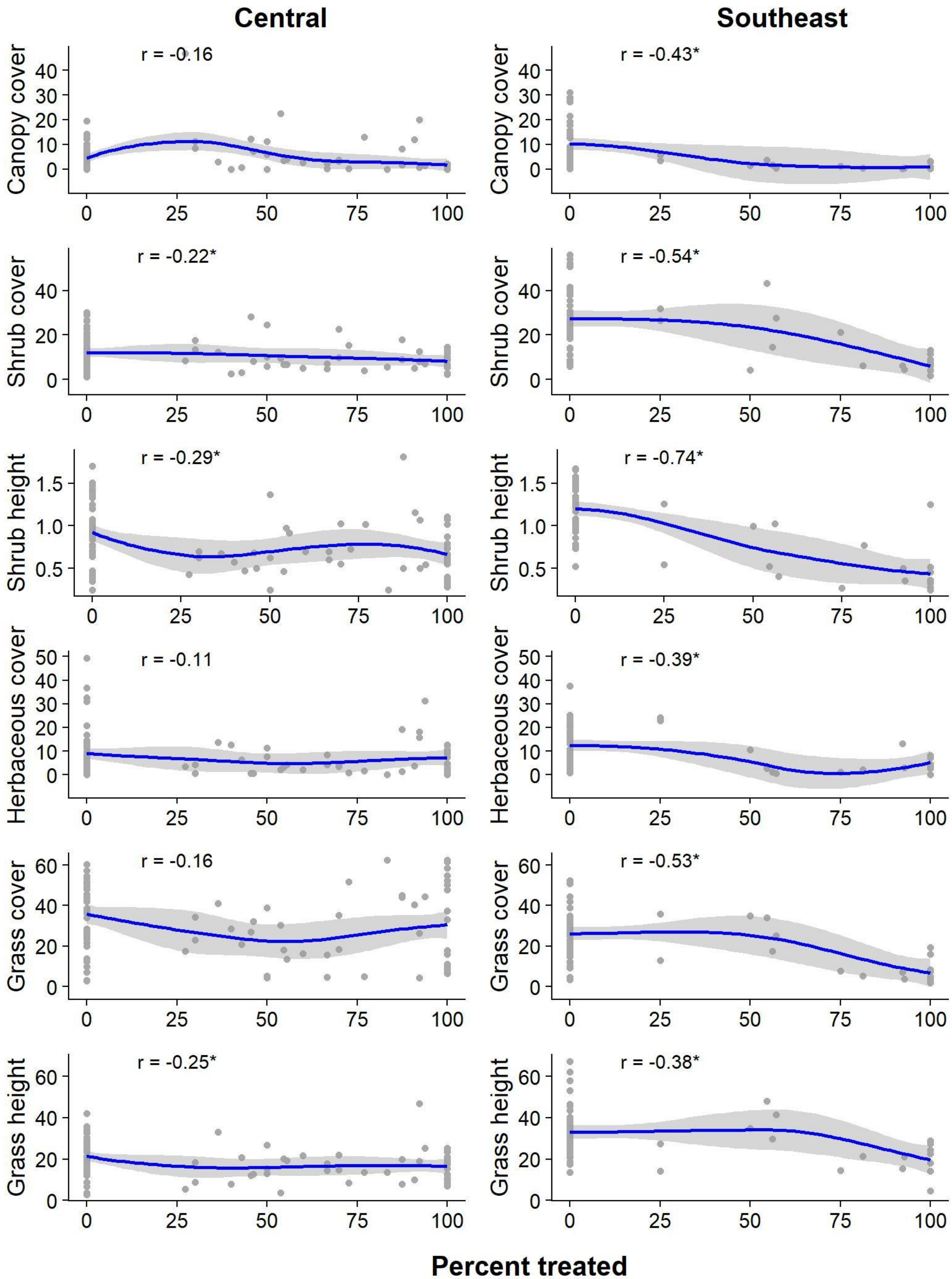

Figure 8. Scatter plots relating grid -level vegetation metrics with percent of the grid cell treated. Blue lines and ribbons show smoothed means and standard errors in relation to percent treated. Pearson's correlation coefficients (r) are marked with an asterisk when statistically supported.

Discussion

In the short term (two breeding seasons post-treatment), we found a primarily negative relationship with grassland management treatments aimed at mitigating encroaching woody vegetation for avian species occupancy and richness. A negative relationship for birds overall would not have necessarily contradicted our expectations had grassland associated species exhibited positive treatment relationships. The relationship observed, however, did not vary notably among obligate grassland species, facultative grassland species, and species associated with other habitats.

Treatment relationships with vegetation provide insight into potential underlying mechanisms and thus suggest implications of short-term avian treatment relationships for grassland management. Consistent with our expectations and the intended goal of mechanical thinning treatments, we measured less woody vegetation (canopy cover, shrub cover, and shrub height) at treated sampling units. We ultimately expect reduced woody vegetation to alleviate competitive pressures, leaving more resources and space for proliferation of grasses and forbs (Bestelmeyer et al. 2018, Lett and Knapp 2005). In the short-term, however, we measured lower cover of grasses and forbs at treated units. Given sufficient time and rainfall for grasses and forbs to respond as intended, grassland birds will likely exhibit concomitantly positive responses to treatment. Indeed, others have documented more positive responses of both grassland vegetation and birds to shrub removal over a longer timeframe (Coffman et al. 2014). Thus, we suggest our results primarily indicate the need for continued monitoring to fully evaluate how mechanical thinning of encroaching woody vegetation contributes to habitat restoration for grassland birds.

Although we had a limited time frame for realizing expected treatment benefits, we observed patterns consistent with expected mechanisms for positive treatment effects on grassland bird populations in the long term. Reduced occupancy and richness across obligate-, facultative-, and non-grassland species groups was ultimately understandable after considering the apparent loss in both woody and herbaceous vegetation with treatment. Concomitantly stronger negative treatment relationships for both birds and vegetation in SEAZ compared to CTAZ additionally suggest a strong role of vegetation in mediating avian-treatment relationships. Thus, there remains potential for longer term positive avian responses with expected competitive release of grasses and forbs and consequent habitat improvements.

The timing and pace needed for continued effectiveness monitoring to fully evaluate treatment effects on birds depends on the timing of ecological response to treatments. Studies documenting the pace of grassland response to treatments or other disturbance could help inform how long to continue effectiveness monitoring (Lett and Knapp 2005). Climate modulates the pace of vegetative response, which in turn governs the response by birds to environmental change. The initial year of monitoring (2017) was relatively wet whereas the year when most treatments were implemented (2018) was drier (NOAA 2021), limiting the response of grasses and forbs to treatment. Monitoring vegetation response will inform when and for how long to continue bird surveys. Additionally, herbivory can modulate vegetative growth (Valone et al. 2002) and surveyors recorded presence of cattle grazing at 47% of our survey points. Finally, our results suggest potential short-term negative impacts of mechanical thinning on non-target ground vegetation, which if minimized could conversely accelerate intended benefits of treatments. Treatment effects analyses that explicitly account for climate, herbivory, and treatment effects on non-target vegetation will better inform grassland management.

Study limitations

Our estimates of treatment effects are potentially confounded by spatial heterogeneity. By surveying treated and untreated sampling units before and after treatment, effectiveness monitoring was intended to allow before-after-control-impact (BACI) analysis (Morrison et al. 2001, Popescu et al. 2012). Inference with BACI is strongest when estimating additive and interactive spatial and temporal effects (i.e., before-after + control-impact + before-after × control-impact), wherein additive effects control for confounding spatial and temporal variation, allowing relatively strong inference of treatment effects from the interaction (Popescu et al. 2012). Unfortunately, treatments were not all implemented in 2018 as initially intended, complicating assignment of sampling units to before-after and control-impact blocks. We therefore omitted the additive spatial block, limiting our ability to control for confounding variation and, consequently, our strength of inference. For example, treatment units happened to occur outside the range of Rufous-winged Sparrow, so negative treatment effects for this species may represent the distribution of treatments rather than their effect. Similarly, treatment relationships for Yellow-breasted Chat and Bullock's Oriole may reflect adjacency (or lack thereof) of treatments with riparian habitat. Thus, we need to improve how we account for likely confounding sources of variation. It is unlikely that unrelated sources of variation have confounded all of the treatment effects estimated here, however, especially given the rigorous spatially balanced sampling protocol used to select survey units. We therefore expect our overall conclusions of primarily negative treatment effects or at least no meaningful positive effects within 2 years of treatment would hold even with a more rigorous full BACI analysis. Nevertheless, identifying control blocks for treatments implemented in each year could strengthen inference for future effects monitoring. Estimating species habitat relationships could also strengthen inference by informing evaluation of potential mechanisms underlying observed treatment effects (Latif et al. 2020).

Future directions

To best inform grassland management practices aimed at mitigating encroaching woody vegetation, mechanical thinning treatments examined here would ideally be compared with alternative management strategies. Mechanical thinning represents one of several management tools and approaches proposed for mitigating woody vegetation encroachment on grasslands (Anderson and Steidl 2019). Different management approaches can have different implications on the pace of grassland recovery (Brockway et al. 2002). Initial plans for Arizona ranchlands included application of herbicide and prescribed fire to control woody encroachers, but these alternative treatments were not realized at the time of this study, so we report exclusively on mechanical thinning. Comparing mechanical thinning with alternative approaches to shrub removal could inform treatment designs that minimize short-term negative impacts while facilitating longer term management objectives.

We leveraged long-term monitoring under the IMBCR program to implement effectiveness monitoring of grassland management treatments. IMBCR data therefore provide a means to explicitly place our results into a broader landscape context. Comparing population abundance estimates for species of management concern from effectiveness monitoring with estimates from background monitoring can inform how management contributes to maintaining populations across a broader landscape (Appendix D). Additionally, background monitoring could help identify where to target and evaluate management to meet objectives for particular species or communities of management concern.

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Appendix A

We analyzed bird occupancy using a hierarchical multispecies (Dorazio et al. 2010) and multiscale (Mordecai et al. 2011, Pavlacky et al. 2012) model. We considered detection data, **y**, to represent 5 dimensions; y_{ijkrt} = 1 indicates species i (i = 1, …, M; M = 101) was detected at point j (j = 1, …, J; J = 16) within grid cell k (k = 1, …, K; K = 36 or 27 grid cells in the region) within region r ($r \in \{1, 2\}$) in year t (t = 1, …, T; T = 3). To inform detectability estimation following removal sampling (Rota et al. 2009), we compiled a parallel array, **R**, whose elements indicated time to detection ($r_{ijkrt} \in \{1,2, …, 6\}$ when y_{ijkrt} = 1, or r_{ijkrt} = 6 when y_{ijkrt} = 0). We modeled data generation as

$$y_{ijkrt}|u_{ijkrt} \sim Binomial(r_{ijkrt}, p_{ijkrt} \times u_{ijkrt}),$$

where p_{ijkt} is the probability of detecting species i during a one-minute interval given occupancy of point j in grid cell k in region r and year t. We modeled point occupancy as

$$u_{ijkrt}|z_{ikrt} \sim Bernoulli(\theta_{ijkrt} \times z_{ikrt}),$$

where θ_{ijkrt} is the point occupancy probability for species i given grid cell k in region r was occupied in year t. We modeled grid cell occupancy as

$$z_{ikrt}|w_{ir} \sim Bernoulli(\psi_{ikrt} \times w_{ir}),$$

where ψ_{ikrt} is the grid cell occupancy probability in year t for species i given that species i belonged to the super community in region r. Finally, we modeled whether species i belonged to the super community in region r as $w_{ir} \sim Bernoulli(\Omega_r)$.

We modeled occupancy probabilities at each spatial scale as logit-linear functions of treatment covariates modulated by species membership in three groups defined by their level of habitat specialization towards grasslands (HSG: non-grassland, facultative, or obligate). We modeled point occupancy probability as

$$logit(\theta_{ijkrt}) = \alpha_{0,ir} + (\alpha_{Trt,ir} + \alpha_{HSG} \times HSG_i) \times \mathrm{Trt}_{jkrt},$$

where $\alpha_{0,ir}$ is the logit-linear species- and region-specific intercept, $\alpha_{Trt,ir}$ is the logit difference in occupancy between treated (Trt = 1) and untreated (Trt = 0) points, and α_{HSG} modulates the treatment effect depending on level of habitat specialization (HSG) for species i (α_{HSG} = 0 where HSG = non-grassland). Similarly, we modeled grid cell occupancy probability as

$$logit(\psi_{ikrt}) = \beta_{0,ir} + \beta_{dev,irt} + (\beta_{percTrt,ir} + \beta_{HSG} \times HSG_i) \times \mathrm{percTrt}_{krt},$$

where $\beta_{0,ir}$ is the logit-linear species- and region-specific intercept, $\beta_{dev,irt}$ is the year-specific deviation in mean occupancy ($\beta_{0,ir}$), $\beta_{percTrt,ir}$ is the logit-linear relationship with percent of the grid cell treated, and β_{HSG} modulates the relationship with percent treated depending on level of habitat specialization (HSG) for species i (β_{HSG} = 0 where HSG = non-grassland). We estimated the intercept term ($\beta_{0,ir}$) for grid cell occupancy as a species-specific normal random effect within each region, with yearly deviations ($\beta_{dev,irt}$) governed by an additional normal random effect with mean = 0. We estimated point occupancy intercepts and baseline treatment effects as species-specific normal random effects. We estimated parameters quantifying offsets for grassland specialization as fixed effects of group membership.

We modeled detectability as

$$logit(p_{ijkrt}) = \zeta_{0,ir} + \zeta_{DOY,i} \times DOY_{jkrt} + \zeta_{DOY^2,i} \times DOY_{jkrt}^{\ 2} + \zeta_{Time,i} \times Time_{jkrt} + \zeta_{Time^2,i} \times Time_{jkrt}^{\ 2} + \zeta_{Trt,i} \times Trt_{jkrt},$$

where $\zeta_{0,ir}$ is the logit-linear region- and species-specific intercept for detectability and remaining parameters described relationships with covariates: day of year (DOY, quadratic) time since sunrise (Time, quadratic), and treatment status of the point (Trt, linear). We modeled the detectability intercept parameter as a species-specific normal random effect within each region, and all detectability covariate effects as species-specific normal random effects pooled across regions.

We inferred treatment relationships with species richness by plotting predicted richness (posterior median and 95% credible intervals) in relation to treatment metrics. We predicted species richness by summing unconditional occupancy probabilities for points and grid cells:

$$\widehat{N}_{\psi,krt} = \sum_{i=1}^{M} \Omega_r \times \psi_{ikrt} \text{ and}$$

$$\widehat{N}_{\theta,jkrt} = \sum_{i=1}^{M} \Omega_r \times \psi_{ikrt} \times \theta_{ijkrt}.$$

We implemented data augmentation to fully correct for imperfect detection when predicting species richness. Thus, we set M = 101 to represent the entire list of species comprising the potential super-community for the study area. This species list includes the 86 species detected at survey units and an additional 15 species (XX with HSG facultative and XX HSG other) detected during background IMBCR monitoring within primary habitats in Bird Conservation Region 34 that represented the study area (grassland, shrubland, desert shrubland, mesquite bosque, and pinyon-juniper). We excluded from this list species not readily detected with passive point count surveys (i.e., raptors, owls, grouse, cranes, and water birds) and species only detected as migrants that do not breed in the study area.

We sampled posterior parameter distributions for this model using JAGS v.4 (Plummer 2003) programmed from R (Meredith 2020). We used independent noninformative priors for all parameters (for model code and data, see Appendix C). We ran three parallel MCMC chains of length 511,000, burn in = 31,100, and thinning = 100 to sample posterior distributions, after which we verified $\hat{R} \leq 1.1$ for all parameters (Gelman and Hill 2007).

Appendix B.

Bird species detected during effectiveness monitoring for mechanical thinning of encroaching woody vegetation in central and southeastern Arizona grasslands. Detections = number of point surveys during which the species was recorded. Each species is categorized by their level of association with grasslands (Habitat group).

Species (taxonomic name)	Code	Central AZ (max = 1039)	Southeast AZ (max = 818)	Habitat group
White-winged Dove (*Zenaida asiatica*)	WWDO	3	17	Other
Mourning Dove (*Zenaida macroura*)	MODO	131	106	Facultative

Greater Roadrunner (*Geococcyx californianus*)	GRRO	5	25	Facultative
Yellow-billed Cuckoo (*Coccyzus americanus*)	YBCU	0	5	Other
Lesser Nighthawk (*Chordeiles acutipennis*)	LENI	0	18	Facultative
Common Nighthawk (*Chordeiles minor*)	CONI	42	0	Facultative
Common Poorwill (*Phalaenoptilus nuttallii*)	COPO	3	2	Facultative
Black-chinned Hummingbird (*Archilochus alexandri*)	BCHU	8	3	Facultative
Costa's Hummingbird (*Calypte costae*)	COHU	1	3	Other
Broad-tailed Hummingbird (*Selasphorus platycercus*)	BTHU	3	0	Facultative
Gila Woodpecker (*Melanerpes uropygialis*)	GIWO	0	2	Other
Ladder-backed Woodpecker (*Dryobates scalaris*)	LBWO	4	42	Facultative
Northern Flicker (*Colaptes auratus*)	NOFL	3	0	Other
Gilded Flicker (*Colaptes chrysoides*)	GIFL	0	3	Other
Ash-throated Flycatcher (*Myiarchus cinerascens*)	ATFL	127	170	Facultative
Cassin's Kingbird (*Tyrannus vociferans*)	CAKI	13	24	Facultative
Western Kingbird (*Tyrannus verticalis*)	WEKI	12	90	Facultative
Western Wood-Pewee (*Contopus sordidulus*)	WEWP	4	0	Other
Gray Flycatcher (*Empidonax wrightii*)	GRFL	12	0	Facultative
Cordilleran Flycatcher (*Empidonax occidentalis*)	COFL	1	0	Other
Black Phoebe (*Sayornis nigricans*)	BLPH	0	2	Other
Say's Phoebe (*Sayornis saya*)	SAPH	20	5	Facultative
Vermilion Flycatcher (*Pyrocephalus rubinus*)	VEFL	0	25	Facultative

Loggerhead Shrike (*Lanius ludovicianus*)	LOSH	16	90	Facultative
Bell's Vireo (*Vireo bellii*)	BEVI	2	77	Other
Gray Vireo (*Vireo vicinior*)	GRVI	17	0	Other
Hutton's Vireo (*Vireo huttoni*)	HUVI	1	0	Other
Pinyon Jay (*Gymnorhinus cyanocephalus*)	PIJA	23	0	Other
Woodhouse's Scrub-Jay (*Aphelocoma woodhouseii*)	WOSJ	23	0	Facultative
Chihuahuan Raven (*Corvus cryptoleucus*)	CHRA	0	7	Facultative
Common Raven (*Corvus corax*)	CORA	29	7	Facultative
Horned Lark (*Eremophila alpestris*)	HOLA	250	6	Facultative
Violet-green Swallow (*Tachycineta thalassina*)	VGSW	6	1	Other
Purple Martin (*Progne subis*)	PUMA	0	1	Facultative
Cliff Swallow (*Petrochelidon pyrrhonota*)	CLSW	3	20	Facultative
Juniper Titmouse (*Baeolophus ridgwayi*)	JUTI	50	0	Other
Verdin (*Auriparus flaviceps*)	VERD	11	187	Facultative
Bushtit (*Psaltriparus minimus*)	BUSH	7	0	Other
White-breasted Nuthatch (*Sitta carolinensis*)	WBNU	1	0	Other
Rock Wren (*Salpinctes obsoletus*)	ROWR	28	0	Facultative
Canyon Wren (*Catherpes mexicanus*)	CANW	5	0	Other
Bewick's Wren (*Thryomanes bewickii*)	BEWR	33	42	Facultative
Cactus Wren (*Campylorhynchus brunneicapillus*)	CACW	73	370	Facultative
Blue-gray Gnatcatcher (*Polioptila caerulea*)	BGGN	4	1	Other
Black-tailed Gnatcatcher (*Polioptila melanura*)	BTGN	0	93	Facultative
Mountain Bluebird (*Sialia currucoides*)	MOBL	12	0	Facultative
Townsend's Solitaire (*Myadestes townsendi*)	TOSO	1	0	Other

Curve-billed Thrasher (*Toxostoma curvirostre*)	CBTH	4	19	Other
Bendire's Thrasher (Toxostoma bendirei)	BETH	8	2	Facultative
Crissal Thrasher (*Toxostoma crissale*)	CRTH	18	53	Facultative
Northern Mockingbird (*Mimus polyglottos*)	NOMO	217	267	Facultative
Phainopepla (*Phainopepla nitens*)	PHAI	19	6	Other
House Finch (*Haemorhous mexicanus*)	HOFI	92	33	Facultative
Lesser Goldfinch (*Spinus psaltria*)	LEGO	11	1	Facultative
Rufous-winged Sparrow (*Peucaea carpalis*)	RWSP	0	96	Facultative
Botteri's Sparrow (*Peucaea botterii*)	BOSP	0	196	Obligate
Cassin's Sparrow (*Peucaea cassinii*)	CASP	0	490	Obligate
Black-throated Sparrow (*Amphispiza bilineata*)	BTSP	338	578	Facultative
Lark Sparrow (*Chondestes grammacus*)	LASP	130	4	Facultative
Chipping Sparrow (*Spizella passerina*)	CHSP	83	0	Other
Black-chinned Sparrow (*Spizella atrogularis*)	BCSP	2	0	Facultative
Dark-eyed Junco (*Junco hyemalis*)	DEJU	1	0	Other
Vesper Sparrow (*Pooecetes gramineus*)	VESP	5	0	Obligate
Canyon Towhee (*Melozone fusca*)	CANT	55	124	Facultative
Rufous-crowned Sparrow (*Aimophila ruficeps*)	RCSP	63	3	Facultative
Green-tailed Towhee (*Pipilo chlorurus*)	GTTO	1	0	Other
Spotted Towhee (*Pipilo maculatus*)	SPTO	47	0	Other
Yellow-breasted Chat (*Icteria virens*)	YBCH	1	31	Other

Eastern Meadowlark (*Sturnella magna*)	EAME	44	26	Obligate
Western Meadowlark (*Sturnella neglecta*)	WEME	20	0	Obligate
Hooded Oriole (*Icterus cucullatus*)	HOOR	0	2	Other
Bullock's Oriole (*Icterus bullockii*)	BUOR	2	46	Other
Scott's Oriole (*Icterus parisorum*)	SCOR	27	10	Facultative
Bronzed Cowbird (*Molothrus aeneus*)	BROC	2	0	Other
Brown-headed Cowbird (*Molothrus ater*)	BHCO	15	47	Facultative
Great-tailed Grackle (*Quiscalus mexicanus*)	GTGR	0	1	Other
Lucy's Warbler (*Leiothlypis luciae*)	LUWA	1	43	Other
Common Yellowthroat (*Geothlypis trichas*)	COYE	0	1	Facultative
Yellow Warbler (*Setophaga petechia*)	YEWA	1	0	Other
Black-throated Gray Warbler (*Setophaga nigrescens*)	BTYW	7	0	Other
Western Tanager (*Piranga ludoviciana*)	WETA	1	0	Other
Northern Cardinal (*Cardinalis cardinalis*)	NOCA	6	5	Facultative
Pyrrhuloxia (*Cardinalis sinuatus*)	PYRR	0	75	Facultative
Black-headed Grosbeak (*Pheucticus melanocephalus*)	BHGR	5	0	Other
Blue Grosbeak (*Passerina caerulea*)	BLGR	2	220	Facultative
Varied Bunting (*Passerina versicolor*)	VABU	0	8	Facultative

Appendix C.

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 R workspaces needed to run scripts, 3) an R object containing model output referenced in scripts (“mod_trt_RegionSppGroups”), and 4) an Excel file (“Occupancy_model_estimates.xlsx”) containing all model parameter estimates.

Appendix D.

Estimated bird population sizes in Arizona grasslands of BCR 34 (Superstrata AZ BCR34 Grasslands), and Central Southeast Arizona overlays. *N* is the abundance estimate, and LCL and UCL are lower and upper 95% credible intervals, respectively. These estimates can inform assessments of the contribution of treatments to the overall population for a given species. For example, having found a large negative effect of treatments on Verdin (VERD) grid cell and point occupancy, we can then look at the population size estimates in this table to see the proportion of the regional VERD population treatments impacted by comparing population size estimates for Central and Southeast AZ overlays to those for AZ BCR 34 grasslands.

Species/Year	AZ BCR34 Grasslands			Central AZ						Southeast AZ					
	Regional			Control			Treatment			Control			Treatment		
	N	LCL	UCL	*N*	LCL	UCL	*N*	LCL	UCL	*N*	LCL	UCL	*N*	LCL	UCL
BEWR															
2016	103,404	73,111	145,731												
2017				25	15	45	53	35	80	38	25	58	27	17	42
2018				34	20	54	33	19	55	74	56	97	17	8	31
2019	190,007	154,902	239,756	39	25	64	126	89	180	121	92	161			
BLGR															
2016	269,441	221,082	331,822												
2017										225	197	262	178	150	211
2018										267	237	309	152	130	184
2019	235,519	203,198	278,959							255	216	304	81	61	111
BOSP															
2016	1,182,398	977,775	1,416,366												
2017										830	719	957	90	70	118
2018										575	500	677			
2019	396,780	323,883	484,843							664	560	789			
BTSP															
2016	2,040,847	1,863,849	2,487,723												
2017				850	750	1,030	858	749	1,057	1,107	1,008	1,337	1,594	1,475	1,881
2018				787	710	954	551	479	678	957	884	1,124	1,335	1,222	1,564
2019	962,346	856,740	1,156,819	650	565	814	597	512	739	765	677	912	1,028	905	1,263

CACW															
2016	645,415	560,376	764,663												
2017				170	136	216	73	54	100	433	385	499	435	391	497
2018				180	155	215	84	62	112	412	368	469	341	293	398
2019	617,674	546,998	706,595	128	99	162				465	412	539	421	356	499
CASP															
2016	741,499	663,466	825,453												
2017										2,216	2,106	2,337	1,135	1,065	1,218
2018										1,594	1,509	1,676	209	179	246
2019	396,902	358,683	441,307							1,322	1,246	1,422	81	64	100
CBTH															
2016	161,527	118,890	236,391												
2017										14	8	25	34	23	51
2019	101,424	76,340	142,019												
CRTH															
2016	15,577	9,519	25,608												
2017				22	14	34	33	23	46	43	32	58	61	48	79
2018				17	11	26	7	4	16	31	21	42	21	14	30
2019	46,348	34,998	61,683							46	34	63			
EAME															
2016	290,595	245,926	351,090												
2017				34	24	49	130	108	161	15	10	23	19	13	28
2018				10	6	17	108	93	127	22	16	31	33	25	45
2019	65,145	57,021	76,345	15	10	24	112	95	136	19	13	28	44	33	57
GAQU															
2016	191,691	155,794	258,720												
2017				34	24	51	78	60	106	95	79	119	72	58	93
2018							46	34	63	63	49	80	122	104	150
2019	117,193	98,771	149,363	29	19	46							110	85	144
GRSP															
2016	17,055	13,691	22,755												
2019	25,540	21,997	35,539												
LOSH															
2016	44,495	32,682	63,840												
2017				18	12	32	36	24	58	69	53	92	62	48	85
2018				12	7	21	42	30	63	76	59	98	67	52	91
2019	70,370	54,798	94,226	11	5	20	20	10	35	105	84	141	101	77	139
NOMO															
2016	200,296	171,064	238,379												
2017				166	145	193	441	401	483	117	102	134	316	284	350
2018				130	111	150	178	151	210	195	177	218	204	183	230

2019	329,262	299,168	364,557	183	159	211	292	265	334	246	223	279	73	60	92
RCSP															
2016	371,556	280,141	498,797												
2017				154	118	208	64	41	95						
2018				173	132	217	80	52	117						
2019	235,264	191,108	295,106	290	228	371									
RWSP															
2016	135,285	96,253	195,091												
2017										384	323	470			
2018										420	346	515			
2019	184,445	141,754	241,983							700	580	860			
SAPH															
2016	21,430	13,897	33,603												
2017				9	6	17	15	9	23	5	2	9			
2018				6	3	11	42	31	57						
2019	9,603	5,502	16,788				12	6	24						
SCOR															
2016	13,388	6,601	27,399												
2017				34	20	55	69	47	95	7	3	14			
2018				45	32	65	24	15	36	14	9	23			
2019	18,614	10,212	32,116	25	14	46				12	7	24			
SCQU															
2016	18,750	13,479	28,735												
2017										106	91	130	52	41	69
2018										72	60	90	39	29	54
2019	26,723	19,645	37,981							37	27	50	59	44	81
2019	73,111	44,684	113,754							58	36	94			
VEFL															
2017										63	42	100	41	23	72
2018										43	25	74			
2019	54,072	30,156	91,295							74	47	127			
VERD															
2016	1,237,856	939,632	1,594,038												
2017							26	11	56	493	413	588	153	117	200
2018				77	44	131				688	590	807	43	16	81
2019	806,713	669,446	959,533							886	738	1,047	95	56	171
VESP															
2016	43,043	28,860	64,405												
2017							43	33	64						
2019	10,507	7,421	16,933												
WEKI															

2017										191	152	405	46	31	96
2018										169	139	351			
2019	143,160	111,500	291,740	48	31	99				178	137	353			
WEME															
2017				41	32	55	47	37	61						
2018				9	5	14	11	8	19						
2019	39,875	31,560	49,978	19	13	26	16	9	24						