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Abstract

Piñon (*Pinus* spp.) and juniper (*Juniperus* spp.) removal is a common management approach to restore sagebrush (*Artemisia* spp.) vegetation in areas experiencing woodland expansion. Because many management treatments are conducted to benefit sagebrush-obligate birds, we surveyed bird communities to assess treatment effectiveness in establishing sagebrush bird communities at study sites in Utah, Nevada, Idaho, and Oregon. Our analyses included data from 1 or 2 yr prior to prescribed fire or mechanical treatment and 3 to 5 yr posttreatment. We used detrended correspondence analysis to 1) identify primary patterns of bird communities surveyed from 2006 to 2011 at point transects, 2) estimate ecological scale of change needed to achieve treatment objectives from the relative dissimilarity of survey points to the ordination region delineating sagebrush bird communities, and 3) measure changes in pre- and posttreatment bird communities. Birds associated with sagebrush, woodlands, and ecotones were detected on our surveys; increased dissimilarity of survey points to the sagebrush bird community was characterized by a gradient of increased juniper and decreased sagebrush cover. Prescribed fires burned between 30% and 97% of our bird survey points. However, from 6% to 24% cover of piñon-juniper still remained posttreatment on the four treatment plots. We measured only slight changes in bird communities, which responded primarily to current vegetation rather than relative amount of change from pretreatment vegetation structure. Bird communities at survey points located at greater ecological scales from the sagebrush bird community changed least and will require more significant impact to achieve changes. Sagebrush bird communities were established at only two survey points, which were adjacent to a larger sagebrush landscape and following almost complete juniper removal by mechanical treatment. Our results indicate that management treatments that leave residual woodland cover and are not adjacent to extensive sagebrush stands are unlikely to establish sagebrush birds.

Key Words: bird community, ecological scale, ordination, prescribed fire, sagebrush-obligate birds, woodland-sagebrush ecotone

INTRODUCTION

Piñon (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands have expanded since the mid-1800s into areas once occupied by sagebrush (*Artemisia* spp.) steppe across much of the intermountain western United States (Tausch et al. 1981; Miller et al. 2008). Consequently, habitat loss to woodland expansion in addition to stressors in other regions of the sagebrush steppe distribution has resulted in population declines by many of the > 350 species of vertebrates that depend on sagebrush (Dobkin and Sauder 2004; Wisdom et al. 2005). Greater sage-grouse (*Centrocercus urophasianus* Bonaparte; hereafter sage-grouse), a sagebrush obligate, currently is a candidate species for protection under the Endangered Species Act because of long-term population declines associated with fragmentation of both populations and habitat. In addition, existing regulatory mechanisms were considered inadequate to control development or address stressors either to sage-grouse or their sagebrush habitats (US Fish and Wildlife Service 2010).

Land managers currently are conducting numerous broad-scale treatments to reduce the area covered by piñon-juniper woodlands in an effort to restore sagebrush plant communities (Miller et al. 2005; Davies et al. 2011). In Oregon alone, over 41 000 ha of early conifer encroachment have been treated between 2010 and 2012 at a cost exceeding US$10 million (Baruch-Mordo et al. 2013). Prescribed fire or mechanical tree removal might achieve desired objectives for vegetation composition and structure for one or a few species. However, complete restoration encompasses more than creating a prescriptive vegetation configuration. Ecosystem processes, including the ability to support wildlife species, are an important component defining treatment success (Ruiz-Jaen and Aide 2005).

Many management actions to remove piñon and juniper are now focused explicitly on creating suitable habitat for sage-grouse. Assessing the effectiveness of management treatments (hereafter, treatments) to benefit sage-grouse is difficult because sage-grouse have low densities, large annual ranges, and low reproductive rates compared to other gallinaceous birds. Lag periods also preclude detecting measurable change in population response within the limited spatial or temporal extent of most studies (Knick and Connelly 2011). To our knowledge, no published studies have documented the effectiveness of piñon and juniper removal in restoring a functioning sagebrush
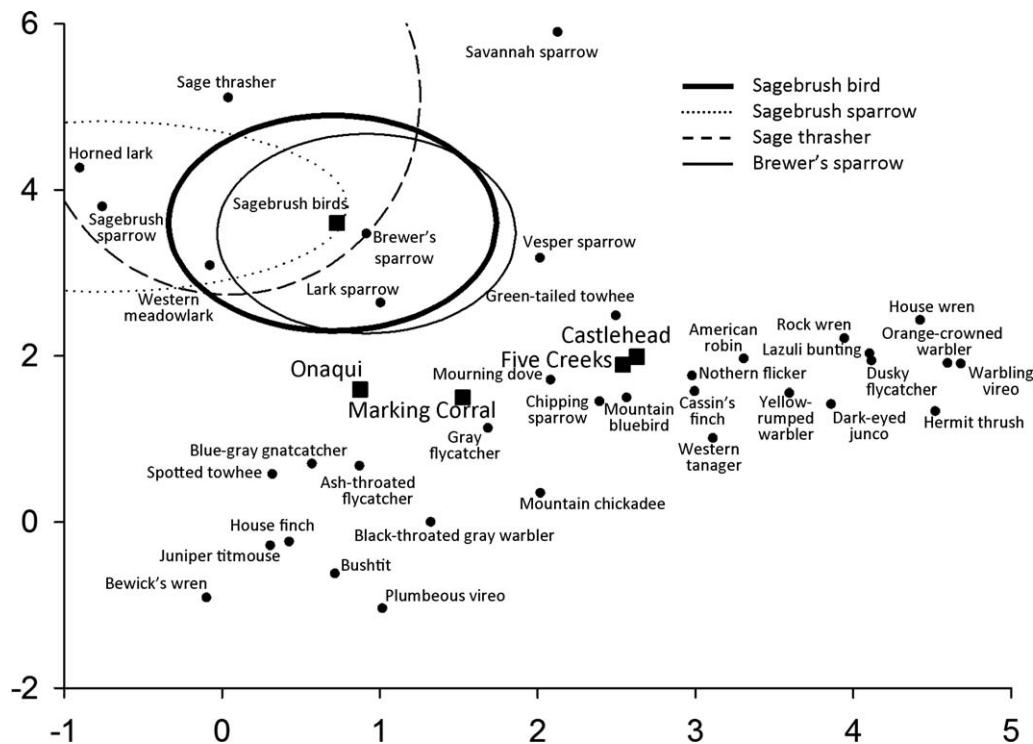
Figure 1. Ordination of bird species detected at survey points in control and treatment plots at Onaqui, Marking Corral, Castlehead, and Five Creeks study sites. Ellipses enclosing the guild of sagebrush birds and individual species were delineated from the mean score and tolerance (in units of standard deviation) on the first (bottom) and second (left) detrended correspondence analysis (DCA) axes.

ecosystem from the perspective of sage-grouse let alone the overall bird community that depends on sagebrush habitats.

Sage-grouse is an umbrella species: other sagebrush-obligate birds show similar responses to habitat change due to overlapping requirements (Hanser and Knick 2011). Populations of smaller passerines might be better suited than sage-grouse for studies of treatment effects. Passerines breeding in sagebrush steppe have small breeding ranges relative to size of treatments and high reproductive potential. Therefore, passerines might track habitat changes more closely and much sooner than sage-grouse. We used a guild of passerine bird species (Verner 1984; Mac Nally et al. 2008) to measure response to treatment and to identify factors influencing a treatment's outcome. Our findings might also be extrapolated to expected response by sage-grouse populations but occurring over longer periods.

Our primary objective was to identify factors important for restoring sagebrush bird communities where prescribed fire and mechanical treatments removed or reduced piñon-juniper woodlands to create sagebrush habitat at sites in Utah, Nevada, Idaho, and Oregon. To do this, we first delineated dominant patterns of bird communities from surveys of breeding birds conducted across a gradient of woodland and sagebrush vegetation. Using ordination techniques (ter Braak 1995), we arranged survey points in a multidimensional statistical space. The relative juxtaposition of two survey points or regions within the ordination represented both the magnitude of dissimilarity and the direction of an ecological gradient. We then delineated the region in ordination space that encompassed sites characterized by Brewer's sparrows (*Spizella breweri* Cassin), sagebrush sparrows (*Artemisiospiza nevaden-*

sis [formerly sage sparrow *Amphispiza belli* Cassin]), and sage thrashers (*Oreoscoptes montanus* Townsend), the three species in our guild of sagebrush birds. Thus, the relationship between each survey point to the sagebrush bird community provided a statistical metric for the ecological scale of change needed to convert a site from its existing state to one characterized by sagebrush bird communities. Finally, we used the change in ordination scores from pre- to posttreatment to relate bird community response to changes effected through treatment.

METHODS

Study Sites

We conducted our study at the Onaqui (Utah), Marking Corral (Nevada), Castlehead (Idaho), and Five Creeks (Oregon) study sites in the SageSTEP Project (Fig. 1 in McIver and Brunson, 2014). We selected these four locations from the 14 in the woodland network because their large size in both treatment and control plots, availability of both bird and vegetation data, and timing and extent of burns. These four sites spanned a broad portion of the environmental gradient occupied by sagebrush and woodland ecotones in the western United States and also included representative outcomes for prescribed fire in these systems. Each study site consisted of large (400–1 300-ha) paired control and treatment plots at which only prescribed fires were conducted. Distance between control and treatment plots ranged from 1.3 km at Castlehead to 5.7 km at Marking Corral. Prescribed fires were conducted at each treatment, although the extent and severity of fires varied within and among sites (table 1 in McIver and Brunson 2014). In addition,

mechanical tree removal was conducted within smaller (18–26-ha) core plots located adjacent to the larger burn treatment plots at Onaqui, Marking Corral, and Castlehead (table 1 in McIver and Brunson 2014). Each mechanical plot received only one treatment either by chainsaw cut and drop (n=3; Castlehead, Marking Corral, Onaqui) or tree mastication by Bull Hog (n=1; Onaqui). We use a nomenclature hierarchy where sites were locations within the SageStep network and plots were treatment or control areas within a site. We measured vegetation at subplots and conducted breeding bird surveys at points within a plot.

Treatments were implemented using a staggered start design dictated by planning and logistic constraints. Onaqui and Marking Corral were treated in 2006, Castlehead in 2007, and Five Creeks in 2008. Burn and mechanical treatments were conducted during late summer or autumn, after the nesting season and postfledging of young. Sagebrush birds would first experience the new vegetation structure the following spring on first arrival from wintering regions, although each species likely differs in the phenology of their response to new habitat configurations (Wiens and Rotenberry 1985; Wiens et al. 1986). Thus, the agent of disturbance likely was less important than the resulting change in the environment.

Bird Surveys

We sampled bird communities in both control and treatment plots every year at each site. Number of total years and posttreatment years varied among sites based on when the site was added to the network and year of prescribed burned. We conducted surveys using point transects to sample songbird communities (Rosenstock et al. 2002). Points were placed within a grid that maximized samples for each study site but maintained a 600-m separation among sampling points to minimize duplicate counts of individual birds. Number of points varied because control and treatment plots differed in size and among locations. We visited each point twice during the breeding season between the beginning of May and the end of June. Sequence of points and observers were rotated among sampling bouts to avoid consistent biases. Surveys were conducted during calm ($<$ 12 km·h) and nonrainy days between sunrise and 1100 h. Observers recorded all birds detected during a 10-min sampling period following a 3-min rest on arrival at a point to let birds adjust to an observer's presence.

We used distance sampling (Buckland et al. 2001; Rosenstock et al. 2002) to account for detection biases. Distance sampling requires accurate estimates of distances between observer and individual detections because area error propagation occurs quadratically on point transects (Bibby et al. 2000). To reduce distance estimation errors, we used laser range finders and attributed each distance estimate with behavioral data (visual vs. aural detection) to account for biases in density estimates associated with aural detections. All birds detected were mapped and tracked during the survey to avoid double counting.

We restricted the bird species in our analyses to those counted during both survey bouts in each year, thus excluding migrants or vagrants. We used the maximum count recorded during either survey in each year to estimate the number of individuals of a species at each survey point. Each survey point and year was considered a sample unit.

We used a global effective detection radius (EDR) of $<$ 130 m as the threshold for including detections based on preliminary analyses for plot, treatment period, and year using the program DISTANCE (Buckland et al. 2001). The EDR is the midpoint distance of the modeled detection probability at which as many individuals are detected outside as were undetected inside (Buckland et al. 2001).

Vegetation Measurements

We characterized vegetation by the composition, cover, and structure of shrubs and trees at two randomly located 33×30 m subplots within 200 m of each bird survey point. Vegetation subplots were not centered on bird survey points because detections of birds at point transects typically are away from the observer's central location (Buckland et al. 2001). We sampled subplots once during pretreatment and again in the first year posttreatment. Additional posttreatment measurements were conducted and averaged to obtain a final estimate when vegetation changes were observed at plots in subsequent years, based on visual comparisons with photos taken in previous years. Vegetation sampling began in July following completion of the bird surveys.

Percent composition and canopy cover of shrubs and trees were estimated along three permanent 30-m transects placed at 2, 15, and 28 m along the 30-m baseline of each subplot. We used line point-intercept (Herrick et al. 2005) to collect canopy cover at 0.5-m intervals along each transect (n=180); species were recorded when the sample point fell within the canopy perimeter. Although multiple species could be recorded, only one hit was recorded per species at a single sample point. We also recorded evidence of burn (burned/unburned) at each line intercept during the first posttreatment survey to estimate percent area burned. Tree and shrub structure was sampled at 2-m intervals (n=15) on the 30-m transect placed at 15 m on the baseline. The maximum height of the nearest shrub (cm) and tree (dm) within 1 m of the sample point was recorded. Individual shrubs and trees were measured only once; if other trees or shrubs were located within 1 m at subsequent sample points, the nearest alternative was measured. We combined values from the two subplots to obtain a single measure for each bird survey point by calculating the mean canopy cover and maximum height by species for pre- and posttreatment periods.

Statistical Analysis

Sagebrush Bird Response to Treatment. We tested for treatment effects on response by sagebrush-obligate birds at each study site using a generalized linear model to test for pre- and posttreatment differences in mean number of detections for each species. We specified a Poisson distribution to model count data and used a repeated-measures design to account for surveys conducted at multiple years at the same survey points (PROC GENMOD; SAS Institute 2008). Because our study was focused on the sagebrush bird community, we do not present results on woodland species.

Ordination. We used detrended correspondence analysis (DCA) to arrange all bird species and survey points along

dominant gradients or axes (CANOCO; ter Braak and Šmilauer 1998). Detrending standardizes among-point differences along ordination axes and preserves among-axis independence (Hill and Gauch 1980). We combined data collected on point transect surveys conducted in treatment and control plots at each study site to first develop the global pattern of gradients and species distributions. Only surveys conducted at treatment plots were used in subsequent analysis to assess treatment effects.

We delineated the ordination space occupied by the sagebrush bird guild from the mean and tolerance (species dispersion measured in units of standard deviation; ter Braak and Looman 1986) estimated for the combined counts of Brewer's sparrows, sagebrush sparrows, and sage thrashers at each survey point. When input as a supplementary variable, the grouped sagebrush birds did not contribute to DCA calculations but could be projected onto the ordination axes (ter Braak and Šmilauer 1998).

We used the Euclidian distance between survey points and the sagebrush bird centroid on the first two DCA axes to estimate the statistical dissimilarity between bird communities. As such, this distance represented an ecological scale across which a treatment point needed to move to support an "idealized" sagebrush bird community. Those points farther away from the centroid have bird community structures least similar to the sagebrush-obligate bird guild and require greater ecological change relative to points that are near or within the ellipse bounding the sagebrush birds. We used Euclidean distance between pre- and posttreatment DCA scores, averaged across treatment years for each point, to indicate how the bird community changed due to treatment relative to the sagebrush bird centroid. Euclidian distance may not accurately reflect the true separation in ordinations of community data because the underlying ecological distance between points may be nonlinear or even discontinuous (Legendre and Gallagher 2001). Nonetheless, the linear index provided a response metric for assessing relationships among bird communities.

Structural Equation Models. We developed a structural equation model (SEM) (AMOS; Arbuckle 2005) using observed variables to identify causal factors contributing to changes observed in the bird community following treatment. Structural equation models provide a platform for testing alternate hypotheses about system response to multiple factors that are expressed through direct and indirect pathways (Shipley 2000; Grace 2006). In our study, we considered that the posttreatment bird community at a survey point likely was shaped by combined influences of the previous vegetation and bird community that existed prior to treatment, the amount of habitat change caused by treatment disturbance, and the new posttreatment vegetation community. Therefore, we used SEM to 1) identify the primary habitat factors underlying the DCA gradient between pretreatment survey points and the sagebrush bird centroid, 2) quantify the relationship between pretreatment DCA location and the amount of posttreatment change observed in the bird community, and 3) test whether the posttreatment bird community responded to the current vegetation at a point or to the relative vegetation change due to treatment.

We first screened variables using bivariate correlations to identify vegetation components related to dissimilarity between a survey point and the sagebrush bird centroid. We further reduced the potential variables used in the SEM to those best describing pre- and posttreatment sagebrush and woodland cover and estimates of their change. We used χ^2 tests to evaluate the goodness of fit of the hypothesized SEM model to the data. We reduced model structure by eliminating pathways that represented nonsignificant relationships. Alternate models were assessed based on the Akaike information criterion as a comparative index (Grace 2006).

RESULTS

We surveyed birds at 87 points at Castlehead, 25 at Marking Corral, and 57 at Onaqui from 2006 through 2011 and 51 points at Five Creeks from 2008 through 2011. Of these 220 points, 126 surveys were conducted in treatment plots (Onaqui $n=36$, Marking Corral $n=16$, Castlehead $n=43$, Five Creeks $n=31$) to assess treatment effects. The four survey points conducted in mechanical treatments were included in the sample of treatment effects.

Sagebrush Bird Response to Treatment
Pre- and posttreatment detection probabilities were 0.37 (0.32–0.42; 95% confidence interval) and 0.32 (0.25–0.41) for Brewer's sparrows, 0.80 (0.35–1.00) and 0.57 (0.44–1.00) for sagebrush sparrows, and 0.47 (0.09–1.00) and 0.84 (0.44−1.00) for sage thrashers. For all three species combined, the detection probability was 0.38 (0.33–0.43) for pretreatment and 0.36 (0.33–0.39) for posttreatment surveys. Detection probability did not differ statistically between treatment periods.

Brewer's sparrows were the most common of the sagebrush-obligate species and were detected at all four sites (Table 1). Pre- and posttreatment detections of Brewer's sparrows were not statistically different. Sagebrush sparrows were detected at all plots except Five Creeks. We detected more sagebrush sparrows at Onaqui following treatment ($P < 0.1$); changes between treatment periods were not significant at the other three plots. Sage thrashers also were detected at all treatment plots, although few birds were observed, and none of the changes between pre- and posttreatment surveys were significant or consistent in trend (Table 1).

Ordination
Thirty-six bird species were included in the DCA ordination (Fig. 1). Our first two DCA axes each were approximately 6 standard deviations (SD; units are expressed as multiples of standard deviation); points separated by > 4 SD share few species in common (ter Braak 1995). The first four axes accounted for 25.5% of the cumulative variation in the species data. The first DCA axis represented the broad longitudinal gradient encompassed by our study sites; the DCA score averaged for all points within each treatment plot also reflected the restricted geographic ranges of some woodland bird species present in the assemblage (e.g., Bewick's wren [*Thryomanes bewickii* Audubon] and juniper titmouse [*Baeolophus ridgwayi*

Table 1. Average pre- and posttreatment distance in the detrended correspondence analysis (DCA) ordination to the centroid of the sagebrush bird guild, area burned (%), and number of bird survey points burned by prescribed fire. Pre- and posttreatment averages are shown for number of detections of each of the sagebrush bird species, big sagebrush percent cover and piñon-juniper percent cover, and height at Onaqui, Marking Corral, Castlehead, and Five Creeks treatment plots (n = bird survey points; treatment year, treatment area).

	Onaqui (n = 36; 2006, 393 ha)				Marking Corral (n = 16; 2006, 418 ha)				Castlehead (n = 43; 2007, 1 029 ha)				Five Creeks (n = 31; 2008, 959 ha)			
	Pretreatment mean (range)		Posttreatment mean (range)		Pretreatment mean (range)		Posttreatment mean (range)		Pretreatment mean (range)		Posttreatment mean (range)		Pretreatment mean (range)		Posttreatment mean (range)	
Number of survey years	1		5		1		5		2		4		1		3	
Burned (%)[1]			12	(0–78)			21	(0–87)			19	(0–100)			82	(0–100)
Burned points (n)			14				6				13				30	
Bird DCA distance (SD)	2.1	(0.3–3.5)	1.9	(0.1–3.2)	2.2	(1.3–2.9)	2.1	(1.3–2.6)	2.5	(1.3–3.4)	2.4	(1.5–3.2)	2.5	(1.2–3.1)	2.6	(1.9–3.1)
Sagebrush-obligate birds																
Brewer's sparrow	1.64	(0–8)	1.74	(0–11)	2.25	(0–5)	1.91	(0–10)	1.52	(0–6)	1.20	(0–6)	0.16	(0–2)	0.23	(0–3)
Sagebrush sparrow	0.19[2]	(0–2)	0.5[2]	(0–6)	0		0.04	(0–1)	0		0.12	(0–3)	0		0	
Sage thrasher	0		0.13	(0–2)	0.25	(0–1)	0.13	(0–1)	0		0.03	(0–1)	0		0.01	(0–1)
Vegetation																
Big sagebrush (%)	10.5	(0–41.4)	8.3	(0–41.4)	10.9	(2.2–35.0)	9.3	(0–32.8)	2.9	(0–15.3)	2.4	(0–14.9)	4.6	(0–36.7)	1.5	(0–35.8)
Piñon-juniper (%)	13.8	(0–38.3)	10.6	(0–38.3)	17.9	(2.1–32.1)	11.0	(0.0–30.3)	26.5	(1.0–60.8)	24.1	(0–60.8)	11.4	(0–25.6)	5.9	(0–28.3)
Piñon-juniper (m)	3.4	(1.4–4.5)	3.3	(0.3–5.0)	3.3	(1.4–4.4)	3.1	(0.9–4.4)	6.3	(2.6–10.2)	6.2	(2.5–10.2)	5.3	(0.6–7.6)	5.2	(0.6–9.7)

[1]Area burned was the percent of individual point intercepts with evidence of burn on line transects conducted in vegetation subplots associated with bird survey points.
[2]Type 3 treatment effects χ^2 = 3.1, 1 df, P < 0.1.

Table 2. Correlation of vegetation characteristics and ordination scores for bird survey points at Onaqui, Marking Corral, Castlehead, and Five Creeks treatment plots. Detrended correspondence analysis (DCA) distance is the Euclidian estimate (in units of standard deviation [SD]) from a survey point's $DCA_{1,2}$ location to the centroid for the guild of sagebrush birds.

Vegetation component		DCA 1	DCA 2	DCA distance (SD)
Shrub[1]	% Canopy cover	−0.27	0.36	−0.45
Dead shrub	% Canopy cover	−0.48	0.10	−0.33
Mountain big sagebrush	% Canopy cover	0.40	0.24	−0.01
	height (cm)	0.46	0.21	0.04
Wyoming big sagebrush	% Canopy cover	−0.66	0.14	−0.42
	height (cm)	−0.74	−0.09	−0.27
Big sagebrush[2]	% Canopy cover	−0.41	0.34	−0.47
Rabbitbrush	% Canopy cover	−0.21	0.38	−0.45
Yellow rabbitbrush[3]	% Canopy cover	−0.57	0.13	−0.33
Tree[1]	% Canopy cover	0.34	−0.56	0.63
Curl-leaf mountain mahogany[4]	% Canopy cover	0.42	−0.03	0.24
Western juniper	% Canopy cover	0.68	0.03	0.31
	height (dm)	0.73	0.11	0.26
Utah juniper	% Canopy cover	−0.50	−0.61	0.27
	height (dm)	−0.54	−0.53	0.17
Piñon-juniper	% Canopy cover	0.31	−0.58	0.62
	height (dm)	0.58	−0.25	0.47
Juniper	% Canopy cover	0.43	−0.64	0.74

[1]Table S1 (available online at http://dx.doi.org/10.2111/REM-D-13-00023.s1).
[2]Includes Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush.
[3]*Chrysothamnus viscidiforus* (Hook.) Nutt.
[4]*Cercocarpus ledifolius* Nutt.

Richmond]). Onaqui and Marking Corral were widely separated from Castlehead and Five Creeks; these two westernmost study sites also were the most similar in their bird communities, sharing 25 of the 29 species detected at both sites. Onaqui and Castlehead (intersite DCA distance = 1.8 SD) had 28 of 36 bird species in common; Onaqui and Five Creeks (intersite DCA distance = 1.7 SD) shared 22 of 36 species.

Descriptors of sagebrush or juniper were most strongly correlated (Pearson's r > 0.4) with either of the first two DCA axes or with distance to the sagebrush bird centroid (Table 2). Although both western juniper (*Juniperus occidentalis* Hook.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) were highly correlated with the first DCA axis, differences in sign reflected the geographic distribution of each species. Utah juniper is found at Onaqui and Marking Corral compared to western juniper at Castlehead and Five Creeks (singleleaf piñon [*Pinus monophylla* Torrey and Frémont] occurred only at Marking Corral and was combined with estimates of juniper for woodland cover). Similarly, mountain big sagebrush (*Artemisia tridentata* Nutt subsp. *vaseyana* [Rydb.] Beetle) was present at the higher-elevation study sites, Castlehead and Five Creeks, compared to Wyoming big sagebrush (*A. t.* Nutt subsp. *wyomingensis* Beetle and Young), which dominated the sagebrush communities at Marking Corral and Onaqui. Thus, we focused more on general vegetation categories than plant species or subspecies in subsequent analyses of treatment effects.

The ellipse that described the sagebrush bird community was defined primarily by Brewer's sparrows, the most numerous of the three sagebrush-obligate species (Table 1) and also the most generalized in selecting sagebrush habitats at the four treatment plots. Although ellipses for sagebrush sparrows and sage thrashers overlapped the centroid of the sagebrush bird community, their respective centroids were outside the sagebrush bird ellipse and represented even greater DCA distances
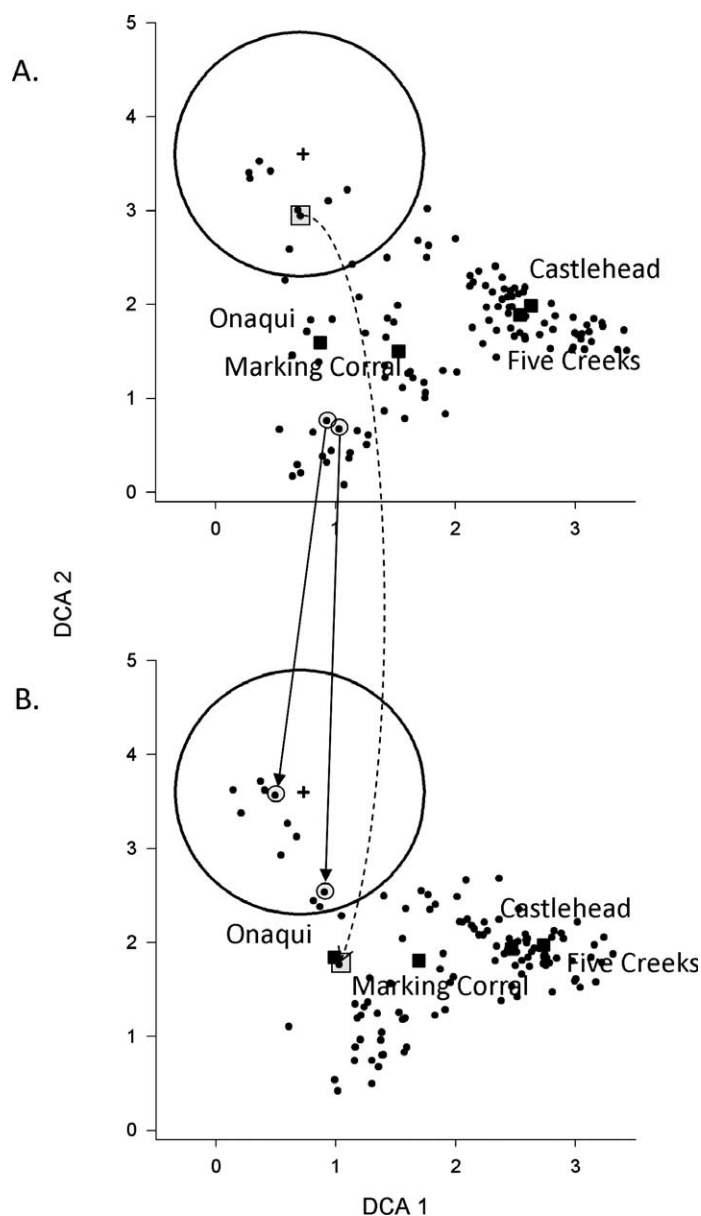
Figure 2. Point and study site scores in a detrended correspondence analysis of bird communities during **A,** pretreatment and **B,** posttreatment surveys (*n*=126). The ellipse enclosed the ordination space supporting sagebrush bird communities and the statistical centroid (+). Open circles designate two points that supported sagebrush birds following mechanical treatment to remove juniper. The open square identifies the single site that changed to a bird community outside of the sagebrush ellipse between pre- and posttreatment periods.

from the mean community scores for each treatment plot and for individual survey points in woodland habitats (Fig. 1).

Ten points surveyed in treatment plots, all located at Onaqui, were within the sagebrush bird ellipse during pretreatment surveys (Fig. 2a). Pretreatment vegetation for sagebrush bird points at Onaqui averaged 1.7% juniper cover (median=0; range 0–9.7%) that was 1.3 m in height (median 0; range 0–4.0 m) and 22.4% sagebrush cover (median=22.9; range 9.7–41.4%). One point in the juniper-sagebrush ecotone (Figs. 3a and 3b), characterized by 4% cover of 4.0-m junipers, moved outside the ellipse during posttreatment surveys (Fig. 2b).

Two points located outside the sagebrush bird ellipse prior to treatment, again both at Onaqui, moved inside the ellipse (Fig. 2b) following mechanical treatment that removed all junipers (average cover: pretreatment 18.7%, posttreatment 0.2%; average height: pretreatment 3.2 m, posttreatment 0.6 m). Sagebrush cover was preserved at these sites (average: pretreatment 4.3%, posttreatment 5.5%; Figs. 3a and 3b). At these two mechanically treated points (one by chainsaw cut-and-drop and one by tree mastication), Brewer's sparrows were absent during pretreatment surveys but were present in the year (2007) immediately following treatment and averaged 2.9 detections in posttreatment surveys. One sagebrush sparrow was first detected in the fifth posttreatment year; one sage thrasher was detected in the second year and two in the fifth year following treatment.

Pretreatment DCA distances to the sagebrush bird centroid, averaged among all bird survey points at a treatment plot, ranged from 2.1 SD at Onaqui to 2.5 SD at Castlehead and Five Creeks (Table 1). Plot DCA scores remained outside of the ellipse delineating sagebrush bird communities for both pre- and posttreatment surveys (Figs. 2a and 2b). Average post-treatment DCA distance from the sagebrush bird centroid decreased at all sites except Five Creeks, which increased by 0.1 SD (Table 2). The amount of change in DCA location for the bird community at individual survey points relative to the sagebrush bird centroid ranged from a decrease of –2.4 SD to an increase of 1.3 SD at Onaqui, –0.5 to +0.1 SD at Marking Corral, –0.6 to +0.5 SD at Castlehead, and –0.5 to +1.4 SD at Five Creeks.

Structural Equation Models

A survey point's initial environment, measured as the pretreatment DCA distance from the sagebrush bird centroid, was important in the amount of change that occurred in the bird community (Fig. 4a). Greater DCA distances to the sagebrush bird centroid prior to treatment were correlated with decreased sagebrush (–0.57) and increased juniper cover (0.26). The amount of change caused by treatment in either sagebrush (–0.02) or juniper (0.11) was not significantly related to the change in the bird community. Although this initial SEM identified some important relationships, the conceptual model did not fit the data (χ^2=17.3, 4 df, *P*=0.002).

We then constructed an SEM based on the existing vegetation structure that birds experienced rather than the amount of change in their environment (Fig. 4b). Again, the primary factor in the amount of change in the bird community was the pretreatment assemblage of birds; communities that were farthest from the sagebrush bird centroid had the least change compared to points that were closer to the sagebrush community ellipse (0.78). Sagebrush and juniper cover that made up the habitat following treatment also were significant factors in the amount of change in the bird community. The least amount of change in the bird community occurred at those points having the lowest sagebrush cover and greatest juniper cover.

DISCUSSION

Our study rests on a conceptual foundation that prescribed treatments can convert piñon-juniper woodlands to functioning
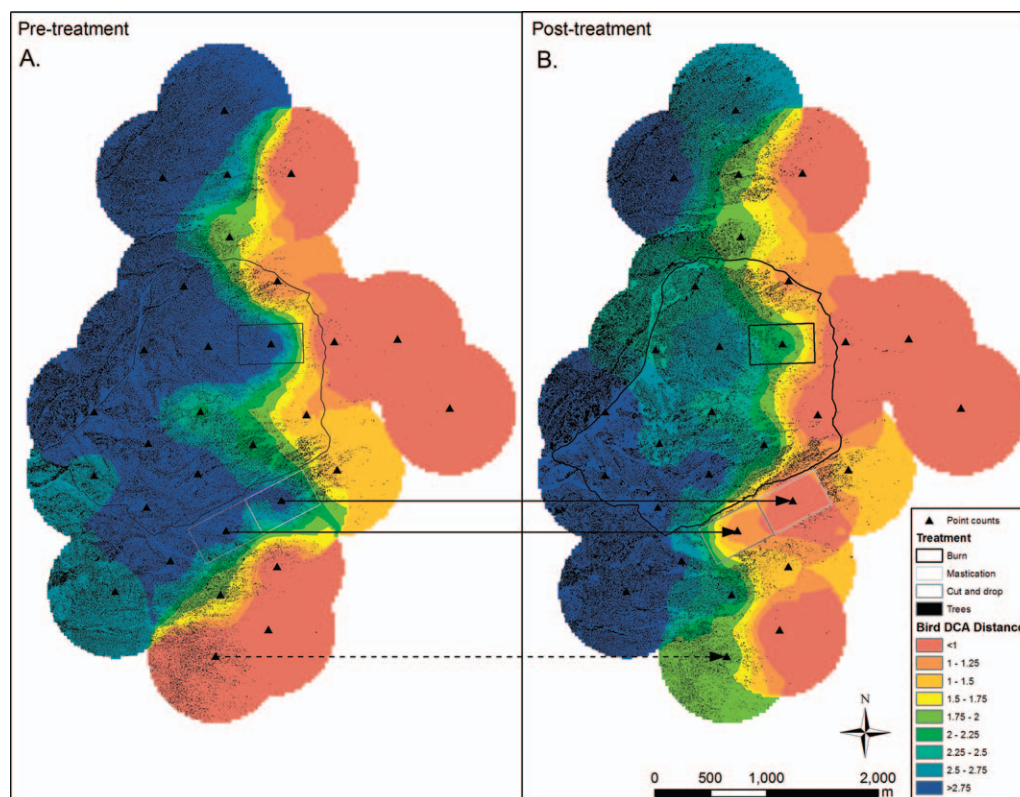
Figure 3. **A,** Pre- and **B,** posttreatment detrended correspondence analysis (DCA) ordination scores for bird survey points conducted at the Onaqui treatment plot. We surveyed 36 points in 2006 and 2007 but only 30 points in 2008 through 2012. DCA scores were interpolated using inverse distance weighting with a maximum radius of 600 m. Trees were mapped from aerial imagery. Two points (solid arrow) supported a sagebrush bird community following juniper removal. Community structure at one point (dashed arrow) changed from primarily sagebrush to woodland bird species from pre- to posttreatment surveys.

sagebrush plant communities that support bird assemblages obligate to these habitats. The dynamics of juniper woodland expansion include both an increase in area occupied and an increase in juniper dominance within expansion locations (Miller et al. 2005; Weisberg et al. 2007). Consequently, piñon-juniper woodlands and points within them differ in the ecological scale that any point must traverse to a new sagebrush plant and wildlife system relative to its geography, environment, and history. Our treatment plots spanned broad gradients of longitude, climate, elevation, and landscape context that were reflected in differing plant and bird species. Nonetheless, all four study sites were within the geographic distribution of the three species used to define the guild of sagebrush birds (sagebrush [sage] sparrow, Martin and Carlson 1998; Brewer's sparrow, Rotenberry et al. 1999; sage thrasher, Reynolds et al. 1999). Although geographic location was an important component of our first DCA axis, the average Euclidean distance for the four treatment plots was similar and ranged from 2.1 to 2.5 SD. Therefore, we assumed that a similar vegetation structure, if not the same (sub)species composition specific to a geographic location, would support the birds that depend on sagebrush for breeding habitat (Wiens and Rotenberry 1981).

We also assumed that each of the points in our treatment plots previously existed in a sagebrush-dominated state and could be returned by disturbance to a functioning sagebrush system (Davies et al. 2011). This assumption may be true for juniper phases I and II, characterized by early successional stages of woodland development, but may not hold for the phase III regions, which also were sampled by our point counts at each site (Miller et al. 2005; Bates et al. 2011; Davies et al. 2011). Sagebrush and herbaceous layers make up the dominant vegetation that influences system processes during phase I of woodland development. Trees codominate during phase II and share equal influence on system processes with shrub and herb layers. Phase III juniper sites are characterized by closed woodlands containing little or no shrub vegetation (Miller et al. 2005). More important, the ecological processes necessary to support shrub communities are altered by the dominant juniper component (Pierson et al. 2010). The likelihood of restoring sagebrush plant communities is further decreased at these points even after tree removal (Tausch et al. 2009; Miwa and Reuter 2010; Pierson et al. 2010).

We used statistical distance in an ordination as a metric for the ecological scale separating a bird community at a pretreatment point and the target community of sagebrush birds. Greater distances represented bird assemblages that were increasingly dissimilar to sagebrush bird communities and more representative of juniper woodlands (Balda and Masters 1980; Sedgwick 1987; Rosenstock and van Riper 2001; Reinkensmeyer et al. 2007). The underlying gradient separating treatment points from the sagebrush bird community was a function primarily of competing sagebrush and piñon-juniper cover; decreased sagebrush and increased piñon-juniper cover
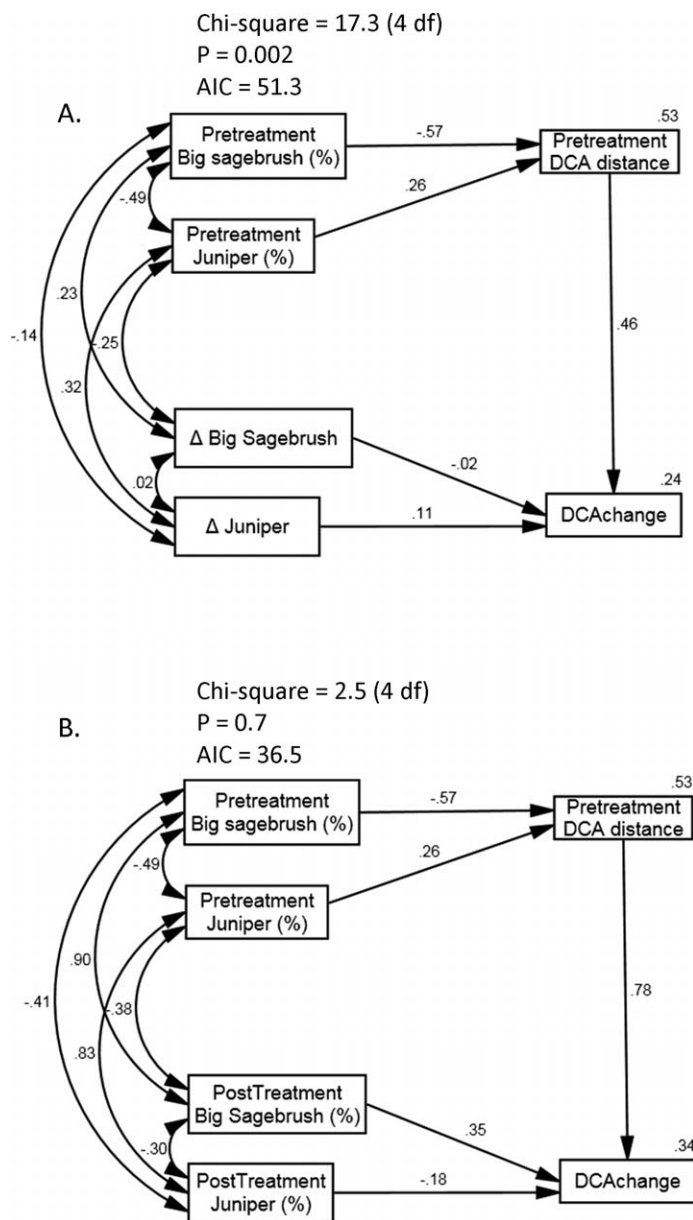
Figure 4. A, Initial structural equation model testing the influence of the bird community and vegetation prior to treatment and amount of change in sagebrush and piñon-juniper caused by treatment to move a site's bird community toward one characterized by sagebrush birds. **B,** Final structural equation model describing the contribution of the pretreatment bird assemblage and vegetation structure available to birds to changes in the bird community.

resulted in greater ecological distances to the sagebrush bird community. Birds responded more strongly to current plant community structure in the breeding season than to the amount of change in tree or sagebrush cover resulting from the treatment. Treatments needed to create a specific environment dominated by sagebrush without juniper trees before the sagebrush bird community would occupy the site. Piñon and juniper cover was reduced at many of our points and also when averaged across treatment plots. Nonetheless, average tree cover at plots still ranged from 5.9% (Five Creeks) to 24.1% (Castlehead) following treatment and did not provide the

sagebrush-dominated community required by obligate bird species. This lack of treatment effect also was supported by our analysis of count data for the sagebrush bird species.

Disturbance, usually by prescribed fire or mechanical means, is necessary to remove piñon and juniper and convert woodlands to a shrub-dominated ecosystem (Miller et al. 2005; Davies et al. 2011). Regardless of the specific agent of disturbance, the management objective is to restore both the form and the function of the sagebrush steppe communities that existed prior to woodland expansion. Sites that were farther from the sagebrush bird centroid in pretreatment surveys also moved the least distance toward the centroid compared to sites that were closer to the ellipse. Although we measured separation among sites by linear distance, our results indicate that the underlying ecological scale is clearly nonlinear. Treatments conducted at ecologically distant sites to the treatment objective would need to impose an increasingly larger impact to change the site's current vegetation structure to one that supported a sagebrush bird community.

The two points that moved from outside into the ellipse of sagebrush-obligate bird communities provided insights into the important factors driving change. First, juniper removal by mechanical treatment at these points was almost complete; average juniper cover was reduced from 19% to < 1% and average height from 3.2 to < 1 m, while sagebrush cover remained between 4% and 5%. Second, the location of these treatments was within an ecotone adjacent to an expansive sagebrush region covering > 14 000 ha. In effect, the treatment increased the amount of available habitat by expanding the area of the sagebrush landscape. Although we did not measure broad-scale landscape metrics, a similar response to an equally small but complete removal embedded deep within a juniper-dominated region likely would not be as successful. Composition and configuration of surrounding landscapes out to 5 km can influence selection of breeding ranges in sagebrush bird species (Knick and Rotenberry 1995; Vander Haegen et al. 2000; Knick et al. 2008).

Our expectation that birds would respond to changes in vegetation within 3–5 yr following treatment may be unrealistic. Time lags in individual and population response, coupled with larger regional dynamics, can be more significant drivers of sagebrush bird species abundance at a site than local vegetation characteristics (Rotenberry and Wiens 1980; Wiens et al. 1986). Treatments, both burn and mechanical, were conducted during late summer or autumn, after the nesting season and period, when young would fledge and disperse. The new vegetation structure would be first experienced the following year by returning adults or first-year birds hatched at the site in the previous year and by dispersing "floaters" in the population. Two sites that were converted to a vegetation community dominated by sagebrush were colonized by Brewer's sparrows in the first breeding season following treatment, although sagebrush sparrows and sage thrashers were not detected until at least the second year. Nonetheless, the entire community may require longer periods exceeding 5 yr posttreatment to develop or reestablish (Wiens et al. 1986; Petersen and Best 1999; Knick et al. 2005). Postdisturbance recovery times depend on site characteristics of precipitation, soils, prefire community, available seed sources, and size and intensity of burns. Postfire recovery periods range from 10 to

> 30 yr in mountain big sagebrush and can exceed 50–100 yr for Wyoming big sagebrush communities (Watts and Wambolt 1996; Lesica et al. 2007; Baker 2011). More than 100 yr may be required to recover entire sagebrush landscapes (Hemstrom et al. 2002). However, an environment suitable for sagebrush birds still will not result with longer time posttreatment than included in our study if trees remain in the landscape.

IMPLICATIONS

Each of the four sites in our study where treatments were conducted spanned a gradient of phase I through III juniper woodland development. The prescribed fires conducted at each site were patchy and highly variable in intensity; 97% of our vegetation subplots burned at Five Creeks, but only 30–40% of the points had some evidence of burn at the other three sites. The amount of juniper was reduced following prescribed burning but still averaged between 2% and 9% cover and 2.4–6.3 m in height. Juniper remained a dominant feature at these sites, and it is unlikely that sagebrush-obligate birds would colonize locations having this plant community structure. Although the general change in each site's average distance to the sagebrush bird centroid decreased following treatment (with the exception of Five Creeks), only two points moved from outside into the ellipse delineating the sagebrush bird community. Burn severity was one of the primary factors that effectively changed postfire vegetation and bird species abundance (Smucker et al. 2005; Kotliar et al. 2007). Prescribed fire in single applications at the intensities applied to juniper woodlands in our study sites did not result in functioning sagebrush communities from the perspective of birds obligate to these systems and during the time frame of our study.

Land managers currently are placing significant emphasis on creating habitat for sage-grouse in an effort to avert a listing under the Endangered Species Act (US Bureau of Land Management 2011; Barach-Mordo et al. 2013). Yet the effectiveness of these management actions in establishing sagebrush-dominated communities that support dependent wildlife, such as sage-grouse, remains unsupported by a critical evaluation and is thus unknown. We focused on the guild of sagebrush birds whose niche breadth broadly overlapped with sage-grouse (Hanser and Knick 2011) to define a functioning sagebrush ecosystem. Based on our results over the relatively short period following treatment, we suggest that few if any of the treatments conducted in these juniper woodlands are likely to increase available habitat for the sagebrush bird community, including sage-grouse.

ACKNOWLEDGMENTS

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