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Wintering bird responses to the presence of artificial surface water in a semi-arid rangeland

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Provision of artificial surface water has been suggested as a management practice that can benefit wildlife in arid and semi-arid regions. With unprecedented droughts predicted for many of these areas in North America in coming decades, understanding species response to the provision of artificial surface water should be evaluated. Moreover, a dearth of knowledge exists in the understanding of avian response to artificial surface water during the non-breeding season. To address this lack of knowledge, we sampled the avian community at varying distances from water sources in Beaver County, Oklahoma, USA from February–March 2013–2014. A total of 20 species were detected. We found no relationship to avian species richness and distance to water. Likewise, pooled data of detections across all species indicated no relationship in relation to artificial surface water. Analysis on individual species indicated that western meadowlarks *Sturnella neglecta* did not respond to water. However, American tree sparrows *Spizella arborea* (plateau model $\beta = 0.05$, SE $= 0.01$) were attracted to surface water sources up to a distance of 100 m (SE $= 40.19$ m). Furthermore, white-crowned sparrows *Zonotrichia leucophrys* (linear $\beta = -0.01$, SE $= 0.006$) were attracted to surface water sources up to distance of 250 m. Additionally, analysis indicated that used water sources by American tree sparrows had significantly more mixed shrub cover (%) when compared to unused water sources ($\beta = 6.04$, SE $= 2.64$; $p = 0.03$) and that use of water sources by white-crowned sparrows was influenced by the amount of mixed shrub cover within 50 m of the water source ($\beta = 0.36$, SE $= 0.16$; $p = 0.02$). Our results suggest that some overwintering sparrows will alter space use in response to the presence of artificial surface water, however, it is unknown whether provision of water influences overwinter survival of sparrows.

Although grassland birds have exhibited more rapid declines in population trends across North America than any other avian guild (Knopf 1994, Sauer et al. 2014), little data exist on non-breeding ecology of many grassland species (Ralph and Mewaldt 1975, Hovick et al. 2014, Marra et al. 2015). This is despite the fact that the non-breeding season has been suggested as perhaps the most limiting period for grassland birds (Rappole and McDonald 1994). Information on non-breeding season ecology of grassland birds is likely lacking because of difficulties associated with surveying grassland birds during the non-breeding season (Hovick et al. 2014). As most North American grassland birds spend more than one-half of their life on wintering grounds (Igl and Ballard 1999), a greater understanding and emphasis on the importance of wintering habitat for grassland birds may improve management and conservation efforts.

In arid and semi-arid landscapes, the importance of surface water has been emphasized for wildlife populations since the early 1900s (Leopold 1933). The construction of artificial structures to provide surface water for wildlife during times of limitation has been suggested as a management practice, though results from research have resulted in ambiguity of the overall effects of these structures (Rosenstock et al. 1999). Furthermore, there may be potential consequences associated with providing artificial surface water sources in arid and semi-arid landscapes. Researchers have suggested that these consequences can include facilitating the spread of invasive and exotic species (Letnic et al. 2014), creating potential ecological traps by influencing the space use of predators (DeStefano et al. 2000, Kluever et al. 2016), influencing the spread of diseases (Rosenstock et al. 2004), and facilitating novel biotic interactions and competition between organisms (Hall et al. 2016). Although studies have focused on responses of upland gamebirds to the establishment or presence of surface water sources (Larsen et al. 2007, Hiller et al. 2009, Tanner et al. 2015), very little research exists for non-game grassland birds during the non-breeding season (Bock 2015).

Within the arid southwest and semi-arid Southern Great Plains of North America, drought severity is predicted to increase in future decades as a result of climate change (Woodhouse and Overpeck 1998, Cook et al. 2015).

Increased drought severity and diminished groundwater recharge of aquifers in this region related to climate change (Rosenberg et al. 1999, Dennehy et al. 2002) will result in decreased availability of surface water (Brikowski 2008). If surface water is an important component of habitat for birds within these arid and semi-arid regions (Bock 2015), a better understanding is needed of how surface water affects avian distribution, abundance, or survival in response to the changing availability of this resource.

We investigated how non-breeding grassland songbirds responded to the presence of artificial surface water in the south-central Great Plains. Specifically, our objective was to evaluate whether avian detections changed with proximity to artificial surface water sources. Furthermore, we tested whether overall avian species richness was influenced by the proximity to artificial surface water sources.

Methods

Study area

We conducted our research on the Beaver River Wildlife Management Area (WMA) located in Beaver County, Oklahoma, USA (36°50′21.62″N, 100°42′15.93″W). The WMA is approximately 11 315 ha and consists of upland rangelands and the floodplain of the Beaver River (which was dry during the study period). During the course of our study (2013–2014), the average temperature during the sampling period (February–March) was 4.21°C and temperatures ranged from –20 to 31.11°C. The long-term (1895–2009) average temperature in this region from February–March is 5.06°C. The annual precipitation during our study ranged from 34.44 to 50.29 cm. This is compared to the long-term average annual precipitation of 50.57 cm for this region. Climate data were obtained from the Beaver Mesonet station located ~2 km from the nearest WMA boundary (Brock et al. 1995, McPherson et al. 2007). During the course of our study, the WMA was classified under severe to exceptional drought conditions and was at no time considered out of drought conditions (The National Drought Mitigation Center, Lincoln, NE, USA).

An Iso Cluster Unsupervised classification from 2 m resolution aerial imagery was used to delineate vegetation imagery using ArcMap 10.1. This method is an unsupervised classification approach that incorporates the Iso Cluster algorithm (to determine the natural grouping of pixels) and maximum likelihood to create a classified raster based on satellite imagery. Aerial imagery (IKONOS multispectral image) was collected in July 2012 when cloud cover was minimized. The primary cover types identified were mixed shrub (consisting of sand plum *Prunus angustifolia* and fragrant sumac *Rhus aromatic*), sand sagebrush *Artemisia filifolia*, mixed grass (consisting of little bluestem *Schizachyrium scopariu*, switchgrass *Panicum virgatum*, and non-native brome *Bromus* spp.), short-grass/yucca (*Yucca glauca*), sparse vegetation/exposed soil, bare ground, non-native salt cedar *Tamarix* spp., open water, developed housing, and food plots (primarily winter wheat *Triticum aestivum*).

At the time of our surveys, a total of 36 artificial surface water sources were available. These water sources consisted of windmills with water tanks, solar water wells, and gallinaceous guzzlers. While some grassland bird species have been shown to avoid tall natural and/or anthropogenic features in open landscapes (Thompson et al. 2014, 2015), we hypothesized that in a semi-arid landscape, the importance of water sources may outweigh any aversion to structures or disturbances at sites (i.e. blade movement and noise; Bock 2015). We did not categorize differences in responses of birds to different water sources (i.e. guzzlers versus windmills) because our central focus was to determine an overall response to artificial surface water sources. Furthermore, as the focus of our study was to determine the effects of artificial surface water sources and not natural water sources, we did not include natural water sources in our analysis. However, there was only one natural permanent water source on our study site measuring < 0.01 ha. The density of artificial water sources was 0.32 artificial water sources km^{-2} during our study. Water sources were examined each year to confirm that they were providing water.

Data collection

We conducted line transect surveys (Buckland et al. 2001) from February–March 2013–2014 and no surveys were conducted beyond the normal earliest date of departure for the focal species (Oklahoma Ornithological Society; <www.okbirds.org/obrc-database-search.htm>). As bird activity is consistent throughout the day during the non-breeding season, we conducted surveys throughout daylight hours (Fletcher et al. 2000, Hovick et al. 2014). Surveys were conducted during days in which there was no precipitation and wind speeds < 40 km h^{-1} (Igl and Ballard 1999). Thirty-six transects were surveyed from February 19 through March 10 and survey times ranged from 0801–1838. We established randomly oriented 500 m (Thompson et al. 2015) transects that were positioned such that each surface water source was located in the center of each transect. Therefore, we sampled up to 250 m from water sources. However, as detections typically occurred beyond our transects, data existed beyond our 250 m distance segment. Thus, we truncated our data so that no detections beyond 25 m from a transect were included in our analysis. Grassland bird detection has been found to be approximately 100% within 25 m from a transect during the breeding season (Diefenbach et al. 2003). Because of the cryptic nature of overwintering grassland birds, detection rates are likely lower than 100% within 25 m of a transect conducted during the non-breeding season, yet this is untested. Based on the lack of empirical data for detection rates for winter grassland birds, we choose 25 m as a conservative distance to truncate our detection data so that our results would be comparable with other studies. We recorded each bird detection by species as well as the perpendicular distance of the detection from the transect using a laser range finder.

Data analysis

We used methods developed by Thompson et al. (2015) to determine species richness and number of detections per species relative to distance to water sources. We divided transects into sub-sections (distance segments) based on

25 m distance intervals relative to water sources (0–25 m from water, 26–50 m from water, etc.). Water sources were surveyed once per year across years. We considered samples surveyed across years to be independent (Thompson et al. 2015), and as each transect was surveyed an equal number of times, our study was balanced allowing us to pool data into our 25 m distance intervals (Murtaugh 2007). Though over-winter site fidelity would preclude us from considering samples across years to be independent, the over-winter site fidelity of many of the species detected during our study is largely unknown. Studies that have investigated this aspect of over-winter ecology have either been based on very small sample sizes ($n = 1$ American tree sparrow; Brooks 1985) or provide evidence of very low over-winter site fidelity (white-crowned sparrow: 6.34%; Gimpel et al. 2014).

We estimated the relationship between number of detections and richness for each distance segment in relation to distance from water and collated data across years. Detection trends were estimated for individual species that had > 30 detections. We also estimated trends for all species combined and for non-breeding functional foraging guilds as described by De Graaf et al. (1985). Species richness was estimated using Menhinick's index (Menhinick 1964). Based on this analysis, three types of trends were expected with songbird responses in relation to artificial surface water: 1) no effect (null model), 2) a plateau effect, and 3) a linear effect. The plateau effect would illustrate a relationship in which detections or richness were influenced by water up until a threshold, with the relationship having a null relationship after the threshold. Thompson et al. (2015) provides an equation to estimate a plateau relationship in this manner. The linear effect would represent a relationship in which there was an effect of water on detections or species richness that continued beyond the maximum distance we surveyed (i.e. 250 m).

We used the package 'segmented' (Muggeo 2008) in program R (<www.r-project.org>) to fit plateau models by constraining the relationship to 0 after an estimated threshold as determined by the package. Linear regression and null models were also estimated using program R. The most plausible model explaining number of detection and species richness in relationship to distance from water was determined using Akaike's information criteria (AIC_c; Burnham and Anderson 2002). Models were nested, and the linear model was not considered a plausible model when it had a $\Delta AIC_c < 2$ when compared to the null model, whereas the plateau model was not considered a plausible model when it had a $\Delta AIC_c < 2$ when compared to the linear model (Arnold 2010, Thompson et al. 2015).

Determining sources of variation in bird detections

Though we avoided conducting transects during extreme weather conditions, we used generalized linear models (GLM) to determine if ambient temperature (°C), wind speed (km perhour), time of day, or Julian date may have affected the number of detections observed during our transects. GLMs were conducted using the package 'AICcmodavg' (Mazerolle 2012) in program R assuming a Poisson error distribution. We used Akaike's information criterion adjusted for small sample sizes (AIC_c) to select the most plausible models, and considered models with a $\Delta AIC_c < 2$ to be plausible (Burnham and Anderson 2002). We used model averaging to obtain estimates of our significant parameters (β) when $\alpha = 0.05$.

Post hoc vegetation analysis

For species specific analyses, if a model other than the null model had the most support, we analyzed vegetation metrics around water sources with and without detections to determine if there were interactive effects between artificial surface water presence and vegetation cover on avian space use. Vegetation variables included in post hoc analyses included compositional metrics of vegetation types (% cover) and class/landscape metrics estimated through Fragstats 4.2.1.603 (McGarigal et al. 2012). Distance buffers were created in ArcGIS 10.2 surrounding all water sources. If a plateau relationship was the best supported model, we created buffered circles around all water sources with radii equivalent to the distance in which a threshold was determined, and compared the vegetation within these circles to the buffered area in which the response became null. When a linear relationship was the best supported model, we created buffers around all water sources with radii of 50, 150 and 250 m, which were arbitrarily chosen. Class metrics included edge density ($(m\ m^{-2}) \times 10\ 000$) of mixed shrub, bare ground, and mixed grass, while landscape metrics included total edge density ($(m\ m^{-2}) \times 10\ 000$) and the contagion index. The contagion index is a measure of interspersion and dispersion of vegetation on the landscape (O'Neill et al. 1988). These Fragstats and compositional metrics were chosen post hoc based on characteristics of habitat use of the species (American tree sparrow *Spizella arborea* and white-crowned sparrow *Zonotrichia leucophrys*) included in our post hoc analyses (Norment 1993, King and Savidge 1995, Delisle and Savidge 1997, Hovick et al. 2014).

When a plateau effect was the best supported model, we compared vegetation characteristics within the distance segments where there was a water effect (either positive or negative relationship) to the vegetation characteristics of distance segments after the threshold (where the water effect became neutral). This comparison was done for both used and unused water sources, in which we assumed water sources were used when we detected a specific species on the transect surrounding that water source. To compare these four possible categories (within-used, outside-used, within-unused and outside-unused), we conducted a one-way ANOVA using PROC GLM in SAS 9.4 (SAS Inst.) for variables that met the assumptions of one-way ANOVA. We tested for heteroscedacity in variables analyzed using a Brown and Forsythe's test (Brown and Forsythe 1974). Three variables (bare ground cover [%], mixed shrub cover [%], and total shrub cover [%]) exhibited heteroscedacity and were analyzed using a Welch's test for unequal variance (Welch 1947). To test between pair-wise combinations with the Welch's test, we used a Bonferroni correction to adjust α to 0.008 (Earl and Whiteman 2009).

When a linear effect was the best supported model, we used logistic regression to determine if certain vegetation characteristics were related to presence. Logistic regression was conducted using program R. We used an AIC_c approach for our model selection criterion, and considered models with a $\Delta AIC_c > 2$ to be a non-plausible model. We tested the predictive ability of any models with a $\Delta AIC_c < 2$ by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC) (Metz 1978) in program R with the package 'ROCR' (Sing et al. 2005). To test predictive abilities of models, we randomly withheld 25% of our data as a test dataset. Finally, the parameters (β) of our top model were estimated to examine the relationship of vegetation variables to the use of artificial surface water by a species. If the confidence intervals of the parameters overlapped 0, the variable was not considered significant.

Results

From 2013–2014, we surveyed 72 transects at artificial surface water sources totaling 36.0 km of surveys. We recorded a total of 210 avian detections along 58 transects (Table 1). Fourteen of the transects had 0 detections across both years. A total of 20 avian species were detected (Table 1). The most commonly detected species was the western meadowlark *Sturnella neglecta* (n = 56 detections), while the *Emberizidae* (sparrows) family was the most commonly detected family (n = 106). Other commonly detected species included the white-crowned sparrow (n = 51) and the American tree sparrow (n = 30; Table 1). The two most common functional foraging guilds observed during our study were granivore ground gleaners (n = 126; GGG) and omnivore ground forager (n = 65; OGF).

With regards to species richness, the null model was the best supported model and there was no effect of artificial surface water on the Menhinick's index (Table 2, Fig. 1). When all detections were pooled, the null effect model was the best supported model (Table 2, Fig. 2A), indicating there was no relationship with water across all species combined. Based on our minimum sample size of n > 30, we were able to analyze the effects of artificial surface water on three individual species (Table 2). The plateau effect was the best supported model for the American tree sparrow (Fig. 2B). The fitted model suggested that American tree sparrows were attracted to water (threshold $\beta = 0.05$, SE = 0.01) up to a threshold of 100 m (SE = 40.19 m; Fig. 2B). The western meadowlark showed no response towards artificial surface water, as the null effect was the best supported model (Table 2, Fig. 2C). The white-crowned sparrow exhibited attraction towards artificial surface water (linear $\beta = -0.01$, SE = 0.006; Fig. 2D), and this relationship was supported beyond the 250 m distance segment as the linear effect was the best supported model for this species (Table 2). However,

Table 1. Avian species present and number of detections per species observed on 500 m transects centered on artificial surface water sources from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

Species	No. of detections
All birds	210
American goldfinch *Carduelis tristis*	6
American robin *Turdus migratorius*	1
American tree sparrow *Spizella arborea*	30
Bewick's wren *Thryomanes bewickii*	2
Dark-eyed junco *Junco hyemalis*	1
Eastern meadowlark *Sturnella magna*	5
European starling *Sturnus vulgaris*	1
Field sparrow *Spizella pusilla*	6
Harris's sparrow *Zonotrichia querula*	4
Horned lark *Eremophila alpestris*	11
Lapland longspur *Calcarius lapponicus*	1
Loggerhead shrike *Lanius ludovicianus*	5
McCown's longspur *Calcarius mccownii*	1
Northern cardinal *Cardinalis cardinalis*	2
Rufous-crowned sparrow *Aimophila ruficeps*	5
Red-winged blackbird *Agelaius phoeniceus*	9
Song sparrow *Melospiza melodia*	6
Spotted towhee *Pipilo maculatus*	1
Unknown spp.	6
Western meadowlark *Sturnella neglecta*	56
White-crowned sparrow *Zonotrichia leucophrys*	51

Table 2. Comparison table of model performance (ΔAIC_c) all combined avian species, two foraging guilds, individual species, and species richness[a] when n ≥ 30 for three model types describing potential avoidance, attraction, or null effects associated with artificial surface water sources from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

		ΔAIC		
Species, guild, or index	n	Null (k = 1)	Slope (k = 2)	Plateau (k = 3)
All species combined	204	0.0	1.7	1.8
Foraging guilds				
granivore ground gleaners	126	9.9	9.0	0.0
omnivore ground foragers	65	0.2	0.0	1.5
Species				
American tree sparrow	30	2.5	2.1	0.0
western meadowlark	60	0.0	0.1	0.7
white-crowned sparrow	48	1.6	0.0	NA
Species richness				
Menhinick's index	823	0.0	1.3	4.8

[a]Species richness is estimated using the Menhinick's index.
[b]NA indicates that the plateau model was unable to converge.

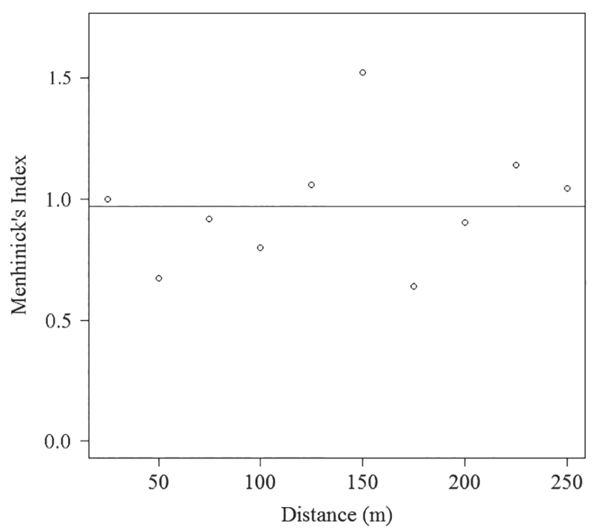

Figure 1. Trend in avian species richness (Menhinick's index) by distance from artificial surface water sources from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

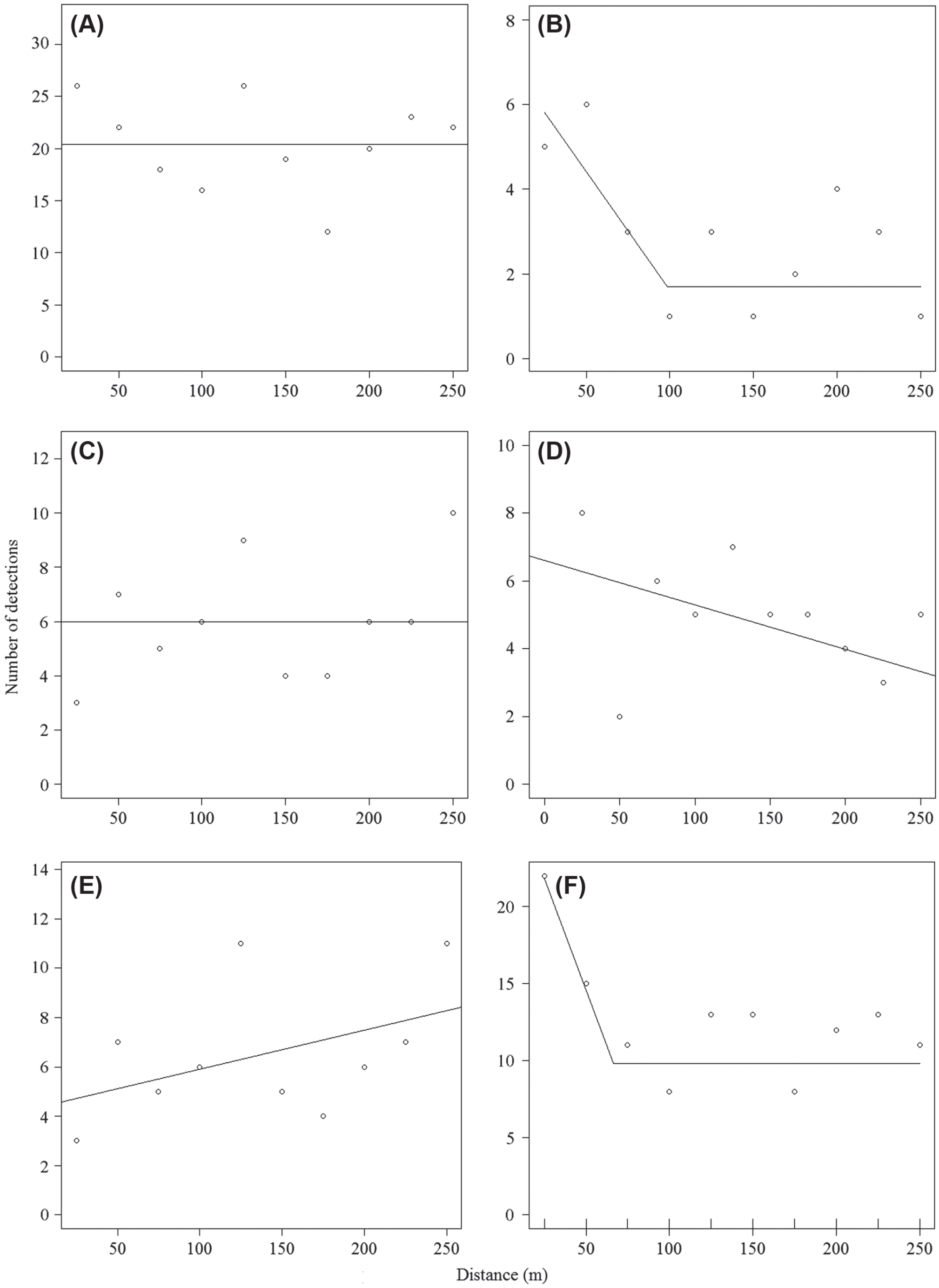

Figure 2. Trends in number of bird detections by distance from artificial surface water sources from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA. Trends were estimated for all species combined (A), American tree sparrows *Spizella arborea* (B), western meadowlarks *Sturnella neglecta* (C), white-crowned sparrows *Zonotrichia leucophrys* (D), and two functional foraging guilds[a]: omnivore ground foragers (E), and granivore ground gleaners (F).

the plateau model was unable to converge for our analysis on the white-crowned sparrow (Table 2). With regards to foraging guilds, the linear model had the best support for the omnivore ground foragers (linear $\beta = 0.02$, $SE = 0.01$; Fig. 2E) and was the only model which suggested a possible avoidance of artificial surface water sources. However, the parameter estimate for the linear relationship was not significant and the null model had a $\Delta AIC_c = 0.21$, therefore we could not consider the linear model over the null model. Finally, the plateau model had the best support for the granivore ground gleaners (threshold $\beta = 0.08$, $SE = 0.01$) and suggested that these species were attracted to water sources up to 67 m ($SE = 14.70$ m; Fig. 2F).

The number of detections observed during surveys was significantly related to the time of day in which the transect was conducted (model average time of day $\beta = -2.02$, $SE = 0.61$, $p < 0.001$) and our top model which only included time of day as a variable accounted for 66% of the variability in our modeling framework (Supplementary material Appendix 1 Table A1). Our models suggested that as time of day increased, the predicted number of detections decreased. Transects conducted at sunrise were predicted to have 4.7 detections compared to the 3.1 detections that are predicted for a transect if it was conducted during the average time of day that we conducted transects during our study (12:25 p.m.). Furthermore, transects conducted at sunset were predicted to have only 1.8 detections per transect.

ANOVA results indicated that water sources used by American tree sparrows had more mixed shrub cover (%) within 250 m of the water sources when compared to unused water sources ($\beta = 6.04$, SE = 2.64; $p = 0.03$, Table 3). However, among used water sources, there was no difference in the amount of mixed shrub cover within distance segments in which they were attracted to water (< 100 m; 8.85%, SE = 1.20) when compared to distance segments in which the relationship became neutral (101–250 m; 8.84, SE 0.85, $p = 0.99$, Table 3). Furthermore, there was also more sand sagebrush cover ($\beta = 18.46$, SE = 6.80, $p < 0.01$) and overall shrub cover ($\beta = 25.50$, SE = 7.64, $p = 0.001$) from 101–250 m surrounding used water sources when compared to proximate sand sagebrush and overall shrub cover at distances of 0–100 m at unused water sources.

Based on the model selection criterion of our logistic regression analysis, the best supported model determining vegetation characteristics around water sources used by white-crowned sparrows included the amount of mixed shrub (% cover) within a 50 m buffer around water sources (Table 4). The model fit significantly better than a null model ($\chi^2 = 9.44$, $p < 0.01$) suggesting this model fit our data well. Furthermore, the AUC of the ROC for this model was 0.81 suggesting good predictive capabilities (Swets 1988). The β for the 50 m mixed shrub cover parameter ($\beta = 0.36$, SE = 0.16, $p = 0.02$) indicated that the probability of water source use by white-crowned sparrows increased as the amount of mixed shrub cover increased within 50 m of the water source. Specifically, for every 1% increase in mixed shrub cover within 50 m of a water source, the probability of white-crowned sparrows using that water source increased by 44%. The observed range of values for the amount of mixed shrub cover within 50 m of a water source during our study ranged from 0–25.23% (Fig. 3). No other model was considered plausible for white-crowned sparrows based on ΔAIC_c values (Table 4).

Discussion

We found that American tree sparrows and white-crowned sparrows were attracted to artificial surface water sources. American tree sparrows were attracted to these features at distances up to 100 m, suggesting that there was a threshold in which this species in general responded to the presence of water. Use of water sources by American tree sparrows was contingent on the amount of mixed shrub cover surrounding the water source within 250 m, in which used water sources had a significantly higher amount of mixed shrub cover compared to unused water sources. Furthermore, water sources used by American tree sparrows had more sand sagebrush and total shrub cover from 101–250 m

Table 3. One-way analysis of variance (ANOVA) and Welch's test results for vegetation metrics inside distances (0–100 m; inside) where American tree sparrows *Spizella arborea* are attracted to artificial surface water sources versus distances (101–250 m; outside) where American tree sparrows show no attraction to surface water sources. Data were collected from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

Variable	Inside used[a] sources		Outside used[a] sources		Inside unused[b] sources		Outside unused[b] sources	
	$\bar{X}$ (SE)	Grouping[c]	$\bar{X}$ (SE)	Grouping[c]	$\bar{X}$ (SE)	Grouping[c]	$\bar{X}$ (SE)	Grouping[c]
Bare ground (% cover)[d]	5.11 (1.26)	A	1.74 (0.28)	A	6.35 (1.37)	A	2.53 (0.57)	A
Mixed grass (% cover)[e]	20.81 (3.01)	A	23.05 (2.87)	A	27.08 (3.76)	A	31.20 (3.23)	A
Mixed shrub (% cover)[d]	8.85 (1.20)	A	8.84 (0.85)	A	1.80 (0.42)	B	2.80 (0.66)	B
Sand sagebrush (% cover)[e]	28.84 (6.85)	BA	36.03 (5.71)	A	17.57 (3.57)	B	24.47 (3.58)	BA
Shrub (% cover)[d]	37.68 (8.15)	BA	44.86 (6.61)	A	19.36 (3.80)	B	27.27 (4.00)	BA
Contagion index[ef]	47.70 (1.93)	A	47.62 (1.86)	A	51.42 (1.99)	A	51.45 (1.79)	A
Edge density ((m m^{-2}) × 10 000)[e]	1955.36 (68.36)	A	1959.74 (63.85)	A	1755.85 (83.60)	A	1783.58 (75.83)	A
Bare ground edge density ((m m^{-2}) × 10 000)[e]	167.36 (23.54)	A	170.95 (24.90)	A	183.56 (19.42)	A	178.26 (17.73)	A
Mixed grass edge density ((m m^{-2}) × 10 000)[e]	1279.82 (63.61)	A	1272.70 (55.21)	A	1253.97 (69.10)	A	1257.53 (63.45)	A
Mixed shrub edge density ((m m^{-2}) × 10 000)[e]	318.45 (83.60)	A	315.91 (76.88)	A	163.67 (35.28)	A	170.21 (36.25)	A

[a]Water sources were considered used if detections were observed for American tree sparrows during transect sampling.
[b]Water sources were considered un-used if no detections were observed for American tree sparrows during transect sampling.
[c]Letter categories represent significant differences between vegetation metric values between water source categories at the $\alpha = 0.05$ level except for bare ground, shrub, and mixed shrub cover. These three variables were tested at the $\alpha = 0.008$ level which was adjusted using a Bonferroni correction factor.
[d]Differences between groups were tested using a Welch's test.
[e]Differences between groups were tested using a one-way ANOVA.
[f]Contagion index is a measure of interspersion and ranges from 0 (high interspersion) to 1 (low interspersion).

Table 4. Model performance metrics (AIC_c) of logistic regression models evaluating the effects of vegetation characteristics on the probability of white-crowned sparrow *Zonotrichia leucophrys* use of artificial surface water sources within 50, 150 and 300 m buffers around water sources. Data was collected from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

Model	k	ΔAIC_c	AIC_c weight	Cumulative weight	Model likelihood
50 m mixed shrub[ae]	2	0	0.52	0.52	–24.35
50 m total shrub[b]	3	2.2	0.17	0.7	–24.28
150 m mixed shrub[a]	2	2.72	0.13	0.83	–25.71
150 m total shrub[b]	3	4.33	0.06	0.89	–25.35
300 m total shrub[b]	3	5.78	0.03	0.92	–26.07
Null	1	7.23	0.01	0.94	–29.06
50 m sand sagebrush[a]	2	7.57	0.01	0.95	–28.13
50 m edge density[c]	2	8.42	0.01	0.96	–28.55
150 m edge density[c]	2	8.48	0.01	0.97	–28.58
300 m edge density[c]	2	8.53	0.01	0.97	–28.61
150 m contagion index[d]	2	8.6	0.01	0.98	–28.65
300 m contagion index[d]	2	8.61	0.01	0.99	–28.65
50 m contagion index[d]	2	8.67	0.01	0.99	–28.68
50 m mixed grass[a]	2	9.39	0	1	–29.04
50 m mixed grass[a] + 50 m bare ground[a]	3	11.51	0	1	–28.94
Global model	19	43.09	0	1	–11.77

[a]Metric is the percent cover surrounding an artificial water source from 0–300 m.
[b]Total shrub is the percent cover of mixed shrub and sand sagebrush combined.
[c]Edge density is measured as ((m m^{-2}) × 10 000).
[d]Contagion index is a measure of interspersion and ranges from 0 (high interspersion) to 1 (low interspersion).
[e]$AIC_c = 53.0$.

compared to proximate distances (0–100 m) around unused water sources. This suggests that American tree sparrows will select surface water sources if they are surrounded by available woody cover. However, there was no difference in the amount of mixed shrub cover within and beyond the estimated attraction threshold (100 m) at used water sources, indicating that the presence of surface water was influencing space use of this species when enough woody cover was available. Likewise, use of water sources by white-crowned sparrows was contingent on the presence of mixed shrub cover within 50 m of the water source. There was no support for an effect of water on the number of detections of all avian species combined, the number of western meadowlark detections, or the overall species richness during the non-breeding season. However, the lack of any relationship for pooled species detections and species richness could have been related to contrasting interspecific space use (i.e. space use of grassland versus shrubland species). This potential contrasting relationship was made evident when analysis was conducted on functional foraging guilds, in which the best supported model for omnivore ground foragers indicated a potential avoidance of water sources (though the null model also had support for this guild. Conversely, granivore ground gleaners, which included many shrubland and generalist species, exhibited a strong attraction to water sources up to 67 m.

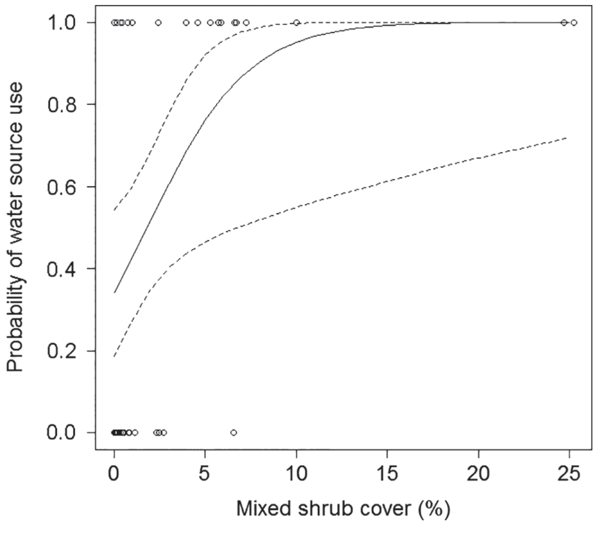

Figure 3. Probability of white-crowned sparrow *Zonotrichia leucophrys* detections around artificial surface water sources in relation to mixed shrub cover with 50 meters of the water source. Data was collected from February–March 2013–2014 at Beaver River WMA, Beaver County, OK, USA.

The three species in which we were able to determine a species' specific relationship (American tree sparrow, the white-crowned sparrow and the western meadowlark) have exhibited distribution-wide population declines since 1959 based on Christmas Bird Count surveys (declines of 2.1%/year, 1.5%/year and 1.4%/year, respectively; Sauer et al. 1996). Our research provides insight into another aspect of the non-breeding ecology of these declining species, which is a largely understudied period of their life history (Hovick et al. 2014, Marra et al. 2015). This has important conservation implications as conditions on wintering grounds can have potential carryover effects for avian species (Norris et al. 2004, Harrison et al. 2011). Space use at wintering grounds for migratory species has traditionally been viewed as a tradeoff between predation risk and foraging opportunities (Grubb and Greenwald 1982, Caraco et al. 1990, McNamara et al. 1994, Watson et al. 2007). More specifically, past research has indicated that space use in wintering sparrows within semi-arid and arid landscapes is influenced by these tradeoffs (Pulliam and Mills 1977, Pulliam 1985). For instance, interactions between woody cover and resource availability on space use by wintering sparrows have been demonstrated in previous research (Beck and Watts 1997), in which individuals were more likely to utilize food resources when woody cover was available. Despite the majority of shrub cover on our study site being located > 250 m from artificial water sources (Supplementary material Appendix 1 Fig. A1–A2), there was an interaction between water source use and mixed shrub cover within 250 m of the water source for American tree sparrows. Furthermore, our results indicate that when enough woody cover is available around a water source, American tree sparrows will begin to respond to water up to 100 m away from the water source. Likewise, there was an interaction between water source use and mixed shrub cover within 50 m of water sources for white-crowned sparrows. In other arid regions, passerines have responded to the interactive effects of surface water and woody cover (Cutler and Morrison 1998). However to our knowledge, this is the first study to illustrate this interaction during the non-breeding season. These results suggest that space use by certain species of overwintering sparrows should not just be viewed as a tradeoff between predation risk and foraging opportunities, but also must consider other resource availability beyond food (e.g. presence of water).

The western meadowlark was the only other species (beyond the American tree sparrow and white-crowned sparrow) in which we were able to measure a species' specific response to surface water (Fig. 2C). Previous research has provided mixed results in relation to western meadowlarks and their use of artificial surface water. Western meadowlarks have been observed (Cutler 1996) during studies examining passerine use of water sources in arid environments. However, our study is the first to estimate a species specific relationship between relative abundance and presence of artificial surface water for the western meadowlark along a distance gradient. There is evidence of ecological convergence between the western meadowlark and the brown songlark *Megalurus cruralis* (Wiens 1991), a species which has expanded its range and has increased in abundance since the establishment of surface watering points within arid regions of Australia (James et al. 1999). However, direct use of surface water by brown songlarks is limited, and typically occurs when temperatures are > 25°C (Fisher et al. 1972). Likewise, use of water sources by western meadowlarks tends to occur during the breeding season (Cutler 1996) and their use during the non-breeding season may be limited. Yet, grassland songbirds have also been shown to avoid vertical structures (Thompson et al. 2015) and trees (Grant et al. 2004, Thompson et al. 2014) that may be similar in height to the windmills with water tanks occurring on our study site. These relationships (along with a limited sample size) could explain why western meadowlarks did not respond to surface water use during our study.

Furthermore, interspecific differences in non-breeding home ranges could have resulted in a null relationship between western meadowlarks and artificial surface water sources. Little information exists on non-breeding season home range sizes of our target species. However, based on studies conducted during the breeding season, western meadowlarks tend to have larger home ranges (from 1.2 to 13 ha, Kendeigh 1941, Laubach 1984, Aweida 1995) compared to American tree sparrows (~ 1 ha, Weeden 1965) and white-crowned sparrows (< 0.5 ha, Chamberlain 1972, Patterson and Petrinovich 1978). This potential interspecific disparity in home range size would suggest that western meadowlarks could still occasionally use water sources though may typically be located beyond the distance of our 250 m transects. Ultimately, our methodology allowed us to determine the relationship of species abundance related to distance to water, but only for areas where water was immediately present. Future research should consider placing additional transects away from artificial water sources to determine if the trends determined in our study are upheld across broader scales.

The inherent difficulty related to surveying overwintering songbirds may have also led to a lack in the detection of any other species' specific relationships with space use and the distance to surface water. As mentioned previously, we were only able to measure species' specific relationships for three species because of low sample sizes. It is possible that other species observed during our study were responding to the presence of surface water in the non-breeding season, as indicated by Bock (2015).

Our study site was under drought conditions during the entirety of our study. Drought conditions have been shown to increase the rate in which avian species use water sources (Lynn et al. 2006). Our data supports the idea that surface water sources are an important resource for certain species during extreme drought conditions. Water inhibition can limit fecundity of passerines in arid landscapes (Roe and Rotenberry 2003) and the water inhibition from winter drought conditions could carry-over and affect breeding season fitness (Norris et al. 2004). It may be that these artificial surface water sources are providing the necessary requirements to prevent water inhibition during periods of drought, and future research should directly test this. Though during wetter periods the attraction of passerines to surface water sources has been shown to diminish (Lynn et al. 2006), we were not able to test this as drought conditions persisted over both years.

It is likely that many species obtain water requirements from other sources such as food contents (Bartholomew and Cade 1956), and observed drinking behavior may be opportunistic rather than a necessity. While a number of species were observed directly drinking from water sources during our surveys, and use has been observed numerous times in the literature for migratory songbirds (Cutler and Morrison 1998, Krausman et al. 2006, Lynn et al. 2006, Bock 2015), this does not mean that surface water increases survival (Tanner et al. 2015). Moreover, as mentioned previously, attraction to these water sources could act as ecological traps for individuals. During the course our study, we did not record any measurements of fitness for individuals. Without a direct measure of fitness for overwintering sparrows, we cannot conclude that use of artificial surface water during these periods influenced the chances of individuals surviving to the following breeding season. With regards to the relationship we observed for American tree sparrows and white-crowned sparrows, the presence of artificial surface water may only act as an attractant. Despite this, changes in local abundance and distribution across the landscape have implications to predation risk, resource allocation and availability, and census of overwintering birds. Therefore relationships with space use and water sources, such as those observed during our study, are of conservation value even in the absence of vital rate data.

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Supplementary material (Appendix wlb-00315 at <www.wildlifebiology.org/appendix/wlb-00315>). Appendix 1.