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RESEARCH ARTICLE

No evidence of displacement due to wind turbines in breeding grassland songbirds

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ABSTRACT

Projected global growth in wind energy development has the potential to negatively affect wildlife populations, and yet the indirect effects of wind turbines on wildlife (e.g., displacement from otherwise suitable habitat) remain largely understudied, compared with investigations of direct effects (e.g., collision mortality). Thus, over a 3-yr period (2009–2011), we used 2 alternative survey methods to study displacement in breeding grassland songbirds at an operational wind facility in the southern Great Plains, USA. Using a line transect method in 2009 and 2010, we estimated the densities of Dickcissels (*Spiza americana*), Eastern Meadowlarks (*Sturnella magna*), and Grasshopper Sparrows (*Ammodramus savannarum*) within 500 m of wind turbines. Dickcissel density was positively related to vegetation structure and was highest 301–400 m from wind turbines in both years; however, this relationship was confounded by fence lines bisecting transects within this single distance bin. By contrast, we found no such relationships in Eastern Meadowlarks or Grasshopper Sparrows. Using a plot-based method in 2011, we estimated Dickcissel and Grasshopper Sparrow densities within 750 m of wind turbines. Again, we found a strong positive relationship between Dickcissel density and vegetation structure. With the change in survey method, however, the confounding effect of fence lines was removed and the relationship between distance to turbine and Dickcissel density disappeared. Variation in Grasshopper Sparrow density in 2011 was not explained by any variable we measured. In summary, we found no evidence of displacement within 500–750 m of wind turbines in the 3 most abundant breeding grassland songbirds at our site. We caution that it may be difficult to isolate the effect of distance to turbine from other factors that covary with distance (e.g., presence of fence lines) when using a line transect method to study displacement at operational wind facilities.

Keywords: breeding-bird density, indirect effects, line transects, renewable energy, territory mapping, wind turbines

No hay evidencia de desplazamiento de las turbinas eólicas en aves canoras que anidan en pastizales

RESUMEN

El crecimiento proyectado global en el desarrollo de energía eólica tiene el potencial de afectar negativamente las poblaciones de fauna silvestre, y sin embargo los efectos indirectos de las turbinas eólicas en la fauna silvestre (e.g., desplazamiento de otrora ambientes adecuados) permanecen en gran medida sin ser estudiados en comparación con las investigaciones sobre los efectos directos (e.g., mortalidad por colisión). Por ende, durante un período de tres años (2009–2011), empleamos dos métodos alternativos de muestreo para estudiar el desplazamiento en las aves canoras que anidan en pastizales en una instalación eólico operativa en el sur de las Grandes Llanuras. Usando un método de transecta lineal en 2009 y 2010, estimamos la densidad de *Spiza americana*, *Sturnella magna* y *Ammodramus savannarum* en un espacio de 500 m desde las turbinas eólicas. La densidad de *S. americana* estuvo positivamente relacionada con la estructura de la vegetación y fue máxima a 301–400 m desde las turbinas eólicas en ambos años; sin embargo, esta relación se vio confundida por líneas de cercos que dividían las transectas dentro de este rango de distancia. En contraste, no encontramos esta relación en *S. magna* o *A. savannarum*. Usando un método basado en parcelas en 2011, estimamos la densidad de *S. americana* y *A. savannarum* dentro de 750 m desde las turbinas eólicas. De nuevo, encontramos una fuerte relación positiva entre la densidad de *S. americana* y la estructura de la vegetación. Con el cambio en el método de muestreo, sin embargo, el efecto de confusión de las líneas de cercos fue removido y la relación entre la distancia a la turbina y la densidad de *S. americana* desapareció. La variación en la densidad de *A. savannarum* en 2011 no fue explicada por ninguna de las variables que medimos. En resumen, no encontramos evidencia de desplazamiento dentro de los 500–750 m desde las turbinas eólicas en las tres aves canoras más abundantes que anidan en pastizales en nuestro sitio. Advertimos que puede ser difícil aislar el efecto de la distancia a la turbina de otros factores que co-varían con la distancia (e.g., presencia de líneas de cercos) cuando se usa un método de transecta lineal para estudiar el desplazamiento en las instalaciones eólicas operativas.

Palabras clave: densidad de aves reproductivas, efectos indirectos, energía renovable, mapeo de territorios, transectas lineales, turbinas eólicas

INTRODUCTION

Wind energy development has increased substantially over the past 2 decades. Despite the recognized environmental benefits of this renewable source of electricity generation, there are concerns over the potential impacts to resident and migratory wildlife, especially birds and bats (e.g., Kunz et al. 2007, Cryan 2011, Piorkowski et al. 2012, Northrup and Wittemyer 2013). Wind turbines can have both direct and indirect effects on wildlife (Drewitt and Langston 2006). Direct effects may include habitat loss due to construction of wind facilities (e.g., Zimmerling et al. 2013), as well as fatalities due to collision with wind turbines (e.g., Barrios and Rodríguez 2004, Stienen et al. 2008). Although estimated bird mortality rates at wind farms tend to be low and are not known to have population-level consequences for most species (Erickson et al. 2001, Kuvlesky et al. 2007, Loss et al. 2013), the implications of collisions for large birds of prey in some locations continue to be a source of concern (e.g., Smallwood and Thelander 2008, Dahl et al. 2012). Indirect effects, on the other hand, may include disruption of migratory pathways or displacement from otherwise suitable habitat (e.g., Larsen and Madsen 2000, Larsen and Guillemette 2007, Stevens et al. 2013) and are more challenging to quantify empirically. As a result, few studies have specifically explored the indirect effects of wind facilities on wildlife, although it has been suggested that such effects, particularly displacement, could represent a greater threat to wildlife populations than the more apparent direct effects (Drewitt and Langston 2006, Kuvlesky et al. 2007).

Because valuable wind resource areas overlap with important wildlife habitats, continued wind energy development may pose a potential threat to the persistence of these populations. For example, the Great Plains of the United States coincide with a major migratory pathway (i.e. the Central Flyway; Brown et al. 2001) and represent critical breeding and wintering habitat for grassland birds, the most threatened group of birds in North America (Sauer et al. 2011). Grassland birds have shown an average 1.3% annual rate of decline from 1966 to 2009 (Sauer et al. 2011), the primary reasons for which include habitat loss, habitat fragmentation, woodland invasion of grassland habitat, afforestation, and lethal doses of pesticides (Brennan and Kuvlesky 2005, Askins et al. 2007, Mineau and Whiteside 2013). At the same time, the Great Plains region has shown tremendous potential for wind power generation and currently represents >50% of the installed wind power capacity in the United States (American Wind Energy Association 2014). Moreover, continued rapid growth in wind turbine deployment is anticipated as the United States tries to meet the Department of Energy's goal for 20% of electricity generation to come from wind energy by 2030 (U.S. Department of Energy 2008). Because a significant portion of the nation's commercially consistent wind speeds occurs in the Great Plains grasslands, much of the development is expected to occur in this region.

Therefore, there is an immediate and pressing need to determine whether the expansion of wind energy development is compatible with the conservation of grassland birds. The purpose of the present study was to determine whether breeding grassland songbirds are being displaced from wind turbines in the southern Great Plains. Although a before–after control-impact (BACI) study design has been recommended for wind–wildlife studies such as this (Kuvlesky et al. 2007), a BACI study design is not always feasible, especially when preconstruction access to the wind resource area or suitable control sites is not possible. Moreover, a BACI study design may not be desirable, given that many proposed wind facilities are ultimately not constructed, in part because of unpredictable economic and political conditions; the time and money spent monitoring wildlife during the preconstruction phase could be wasted. Thus, there is a need to identify alternative displacement study designs that can be implemented effectively at operational wind energy facilities. In this multiyear study, we used 2 survey methods to estimate the densities of 3 species of breeding grassland songbirds within 500 or 750 m of wind turbines in north-central Texas. If displacement were occurring, we would expect to see an increase in breeding-bird density with distance to turbine.

METHODS

Study Area

We conducted our study at the Wolf Ridge wind farm (hereafter "Wolf Ridge") in Cooke County, north-central Texas, USA (33°43′53.538″N, 97°24′18.186″W; Figures 1 and 2), within the South Central Semi-arid Prairies ecoregion of the Great Plains (Griffith et al. 2004). This utility-scale wind facility, owned and operated by NextEra

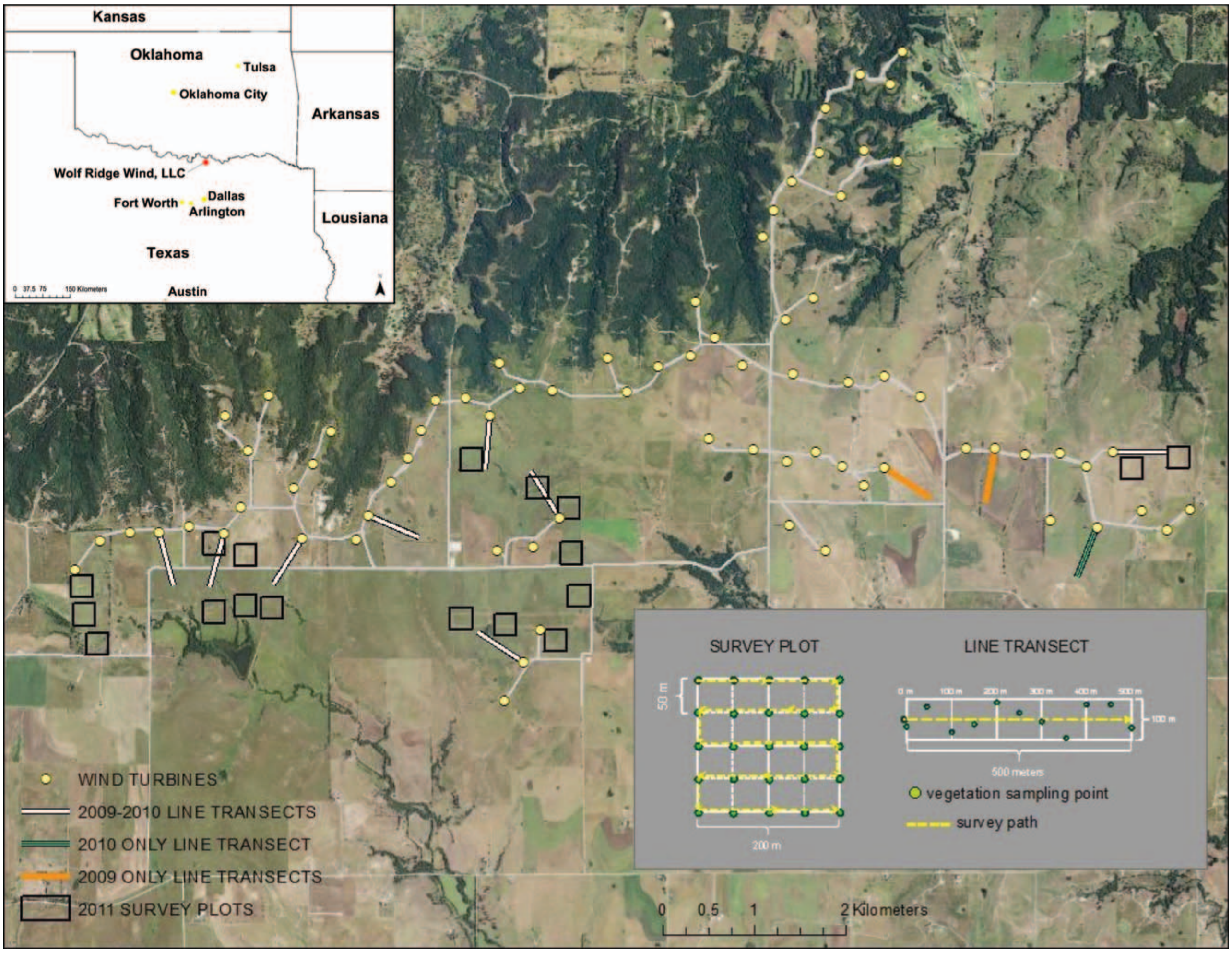

FIGURE 1. Map showing the location of wind turbines, line transects ($n = 10$ transects in 2009 and $n = 9$ transects in 2010), and survey plots ($n = 18$ plots in 2011) within the Wolf Ridge wind farm in Cooke County, Texas, USA.

Energy Resources, began operations in October 2008 and consists of seventy-five 1.5-MW General Electric wind turbines extended over an area of 48 km^2. The turbines have a hub height of 80 m with a maximum tip height of 122 m and are arrayed in a general east–west direction on top of a steep slope that descends from ~335 to ~274 m in elevation to the Red River basin to the north. The wind resource area consists of woodlands, pastures for cattle grazing, hay fields, and croplands. We surveyed the 3 most abundant species of breeding grassland birds at this site, the Dickcissel (*Spiza americana*), Eastern Meadowlark (*Sturnella magna*), and Grasshopper Sparrow (*Ammodramus savannarum*), in a 3-yr study (2009–2011). Over this time, we surveyed these birds using 2 different methods. In 2009 and 2010, we used a line transect method to estimate density, whereas in 2011 we used a plot survey method. The change in survey method was motivated by a companion study on nesting ecology in the Dickcissel (see Hatchett et al. 2013).

Line Transect Surveys

We estimated breeding-bird density for each focal species using a fixed-width line transect method in 2009 and 2010 (Bibby et al. 2000). Suitable transect locations were identified using aerial images and geographic information system software (ArcMap version 9.3; ESRI, Redlands, California; Figure 1). Each transect was 500 m in length ($n = 10$ transects in 2009 and $n = 9$ transects in 2010), starting at the base of a wind turbine tower and ending at a 1.5-m fiberglass post. We randomized the orientation of each transect from its starting point (i.e. the wind turbine) with the following constraints: the entire length of each transect was within grassland habitat, and no transect was within 100 m of another transect or within 500 m of another wind turbine. Because of landowner constraints, 2 of the 2009 transects could not be surveyed in 2010, and we were able to identify only 1 suitable replacement transect at that time. Because wind turbines are often microsited on high points within the landscape, each transect had a negative

FIGURE 2. Chris Goates and Erin Hatchett search for breeding grassland birds at the Wolf Ridge wind farm in Cooke County, Texas, USA.

slope (mean [± SD] change in elevation = –8.3 ± 0.8 m; n = 11 transects). Five of the transects surveyed in each year were bisected by a barbed wire fence within the 301–400 m distance bin.

We surveyed each transect weekly, except on days of inclement weather (heavy rain or wind speeds ≥40 km hr^{-1}) from May 13 to July 30, 2009, and from April 30 to July 15, 2010. All surveys occurred between 0.5 hr after sunrise and 1100 hours CST. Because we were able to drive directly to turbines, we started each transect at the turbine rather than varying the direction of the survey. Varying the direction of the survey would have limited the number of transects because of the time necessary to walk around the transect to start at the other end. We recognize that this protocol could bias detection toward turbines if birds have higher detection probability earlier in the morning, but recent work suggests little effect of time of morning on detection of grassland birds (Thompson et al. 2014). The possible temporal effect on detection probability was also minimized because each transect took only ~15 min (~2 km hr^{-1}, an optimal pace for estimating bird density in equivalent open-grassland habitats; Bibby et al. 2000). Further, the order in which transects were surveyed was rotated each week to minimize temporal bias. Teams of 2 observers (J.A.M. was the primary observer in 2009; E.S.H. was the primary observer in 2010) recorded the location of each focal species flushed, singing, or moving within 50 m of either side of the transect, for a total search area of 5 ha transect^{-1}. Because transect width was narrow, we did not account for changes in detectability with distance to transect line. We also assumed that detectability was constant across transects. Birds that were seen flying overhead or those that were observed entering the transect area during the search were not included in density estimates because these individuals may have been transients that were not holding territories in the area.

Habitat characteristics such as grass height and vegetation structure have been shown to affect the distribution of grassland birds (Fisher and Davis 2010), so we used a Robel pole to obtain visual-obstruction readings along the transects (Robel et al. 1970). Visual-obstruction readings, which provide an estimate of vegetation structure, were taken at sampling points randomly located 0–50 m perpendicular to the transect line at 50-m intervals, for a total of 11 points transect^{-1}.

We calculated breeding-bird density using observations collected during the core breeding period for each species at our site (Vickery 1996, Temple 2002, Jaster et al. 2012). Thus, we estimated Dickcissel density using data from the first 4 survey weeks in 2009 and from the first 5 survey weeks in 2010. For Grasshopper Sparrows and Eastern Meadowlarks, we estimated density from the first 8 survey weeks in both years. To estimate density, we divided each transect into five 1-ha distance bins: 0–100 m, 101–200 m, 201–300 m, 301–400 m, and 401–500 m from the wind turbine. Each distance bin represented 20% of the surveyed habitat at each wind turbine (Bibby et al. 2000). For each species, we calculated the mean number of birds seen each week per distance bin during the core breeding season for each transect. We report density as the mean number of birds per 10 ha.

Plot Surveys

In 2011, as part of a nesting-success study in Dickcissels (for details, see Hatchett et al. 2013), we were able to use an alternative survey technique, a modified territory-mapping method (Bibby et al. 2000), to estimate breeding-bird densities across a distance gradient from wind turbines. For this, we established eighteen 4-ha (200 × 200 m) plots in the same general areas as the 2009 and 2010 transects (Figure 1). These plots were located within 6 core search areas, ranging in size from 17.2 to 64.8 ha. These plots contained potentially suitable breeding habitat for grassland birds near 17 wind turbines. The centroids of 6 plots were 150–300 m from the nearest turbine, the centroids of 6 plots were 301–500 m from the nearest turbine, and the centroids of 6 plots were 501–750 m from the nearest turbine. On average (± SD), the centroid of each plot was 6.8 ± 1.1 m lower in elevation than the nearest wind turbine; however, there was no relationship between distance to wind turbine and plot elevation ($r = -0.27$, $P = 0.28$, $n = 18$ plots). Only 2 plots, 1 in the nearest distance category and 1 in the farthest distance category, were bisected by a barbed wire fence.

Within the survey plots, a team of 2 observers (E.S.H. was the primary observer) used a modified territory-mapping method (Bibby et al. 2000) to count breeding male Dickcissels and Grasshopper Sparrows, the 2 most abundant breeding bird species at our site. The plot size selected to effectively sample these 2 species was too small to provide reliable density estimates for Eastern Meadowlarks (Jaster et al. 2012). Each plot was surveyed 3 or 4 times between April 30 and June 18, 2011, between sunrise and 1100 hours CST. We navigated the survey plots along 50-m transects using a handheld submeter Trimble GeoXH GPS unit with the plot transects in ArcPad version 10 (ESRI). We recorded the location and behavior (singing; movements within, into, and out of the plot; interactions with bordering or transient males; copulation; and mate guarding) of each breeding male observed within the plots. We report density as the number of birds per 10 ha. We also collected visual-obstruction readings at 25 evenly distributed locations within each survey plot from May 12 to May 23, 2011.

Statistical Analyses

For the line transect data, it was likely that visual obstruction, a measure of vegetation structure, and distance to turbine would be confounded because of the elevation gradient inherent to each transect. We therefore used a general linear model (GLM) to first examine the relationship between visual obstruction and distance to turbine; transect was included in the model as a random factor, and year (2009 or 2010) and distance bin (0–100, 101–200, 201–300, 301–400, or 401–500 m) were included as fixed factors.

For the analysis of mean breeding-bird density, we then created a GLM for each study species separately with year and distance bin as fixed factors, transect as a random factor, and visual obstruction as a covariate. We also tested for an effect of fence lines bisecting the line transects (fixed factor: present or absent) on the density of breeding birds, because fence lines provide conspicuous perches for singing territorial males and may therefore increase either bird abundance or the probability of detecting a breeding bird. Because fence lines were present only in the 301–400 m distance bin (i.e. unbalanced nesting), we could not simultaneously test for the effect of both distance to turbine and fence line on breeding-bird density. We therefore created an additional GLM for each species with year and fence line as fixed factors, transect as a random factor, and visual obstruction as a covariate.

We examined the residual plots to assess the assumptions of each GLM and found no obvious problems with deviations from normality or unequal variance among groups (Zar 2010). We checked for interactions between factors and retained all interactions that were significant in the models ($\alpha = 0.05$). We then used Tukey simultaneous tests (95% family-level confidence) to conduct all pairwise post hoc comparisons among distance bin levels when this factor was deemed significant in the overall model ($\alpha = 0.05$).

For the plot survey data, we used multiple regression to determine whether breeding-bird density varied with distance to nearest wind turbine and visual obstruction for Dickcissels and Grasshopper Sparrows separately. Unless otherwise noted, results are presented as means ± SE. All statistical tests were conducted using Minitab version 17.1.0 (Minitab, State College, Pennsylvania, USA).

RESULTS

Line Transect Surveys

Overall, we observed more Dickcissels than Eastern Meadowlarks or Grasshopper Sparrows during the 2009 and 2010 breeding seasons at Wolf Ridge. Mean Dickcissel density was 5.6 ± 1.6 birds ha^{-10} in 2009 ($n = 10$ transects) and 8.0 ± 2.3 birds ha^{-10} in 2010 ($n = 9$ transects). Mean Eastern Meadowlark density was 2.3 ± 0.4 birds ha^{-10} in 2009 ($n = 10$ transects) and 1.3 ± 0.4 birds ha^{-10} in 2010 ($n = 9$ transects). Mean Grasshopper Sparrow density was 0.5 ± 0.2 birds ha^{-10} in 2009 ($n = 10$ transects) and 2.8 ± 0.4 birds ha^{-10} in 2010 ($n = 9$ transects).

Mean visual-obstruction readings varied among transects ($F_{9,75} = 7.65$, $P < 0.001$) and with distance to turbine ($F_{4,75} = 6.38$, $P < 0.001$), but not between years ($F_{1,75} = 0.15$, $P = 0.70$). Across both years and all transects, mean (± SD) visual-obstruction reading was 19.5 ± 12.1 cm. Among the distance bins, visual obstruction was significantly greater 301–400 m from the wind turbines than for all other distance categories (Tukey simultaneous tests, $P < 0.02$ in all cases). We therefore included visual obstruction as a covariate in all subsequent models of breeding-bird density.

For the Dickcissel, we found a significant effect of distance to turbine, visual obstruction, and a year × visual obstruction interaction on breeding-bird density (Table 1). In both years, bird density was significantly higher in the 301–400 m distance bin than in all other distance bin categories (Tukey simultaneous tests, $P <$

TABLE 1. Results of general linear model of breeding-bird density in relation to year (2009 or 2010), distance to wind turbine (0–100 m, 101–200 m, 201–300 m, 301–400 m, or 401–500 m), and visual obstruction (covariate) within the Wolf Ridge wind farm in Cooke County, Texas, USA. Transect was included in the models as a random factor, and nonsignificant interaction terms were removed; 10 transects were surveyed in 2009, and 9 were surveyed in 2010.

	Dickcissel		Eastern Meadowlark		Grasshopper Sparrow	
Factor [a]	*F**	*P*	*F***	*P*	*F***	*P*
Year	1.18	0.28	4.50	0.04	25.01	<0.001
Distance bin	6.04	<0.001	0.72	0.58	1.67	0.16
Visual obstruction	17.60	<0.001	0.61	0.44	0.01	0.91
Year*visual obstruction	7.99	0.006	–	–	–	–
Transect	7.12	<0.001	1.36	0.22	1.46	0.18

[a] $df_{year} = 1$, $df_{distance\ bin} = 4$, $df_{visual\ obstruction} = 1$, $df_{year*visual\ obstruction} = 1$, $df_{transect} = 9$, $*df_{error} = 73$, and $**df_{error} = 74$.

0.005 in all cases; Figure 3). Dickcissel density also increased significantly with increasing vegetation structure (β = 0.266 ± 0.063, $P < 0.001$), but the effect was more pronounced in 2010 than in 2009 (β = –0.133 ± 0.047, $P = 0.006$). However, when we replaced distance to wind turbine with fence line as a fixed factor in the general linear model of Dickcissel density, we found a significant effect of fence line, visual obstruction, and a year × visual obstruction interaction (Table 2). Dickcissel density was significantly higher in distance bins with fence lines than in those without (β = –3.391 ± 0.927, $P < 0.001$; Figure 4). As seen in the previous model, Dickcissel density increased significantly with increasing vegetation structure (β = 0.340 ± 0.061, $P < 0.001$), and this effect was more pronounced in 2010 than in 2009 (β = –0.132 ± 0.049, $P = 0.009$). It is important to note, however, that fence lines were present only within the 301–400 distance bin, and we therefore could not isolate the effect of fence line from distance to turbine in these models.

For the Eastern Meadowlark, we found no relationship between bird density and vegetation structure (β = –0.024 ± 0.031, $P = 0.44$) or distance to wind turbine (0–100 m: β = –0.184 ± 0.524; 101–200 m: β = 0.334 ± 0.493; 201–300 m: β = –0.397 ± 0.492; 301–400 m: β = 0.697 ± 0.556; $P > 0.21$ in all cases) in either year (Table 1 and Figure 5A, 5B). Nor did we find a relationship between Grasshopper Sparrow density and vegetation structure (β = –0.003 ± 0.024, $P = 0.91$) or distance to wind turbine (0–100 m: β = –0.454 ± 0.409; 101–200 m: β = –0.273 ± 0.385; 201–300 m: β = –0.222 ± 0.384; 301–400 m: β = –0.010 ± 0.434; $P > 0.27$ in all cases) in either year (Table 1 and Figure 5C, 5D). Eastern

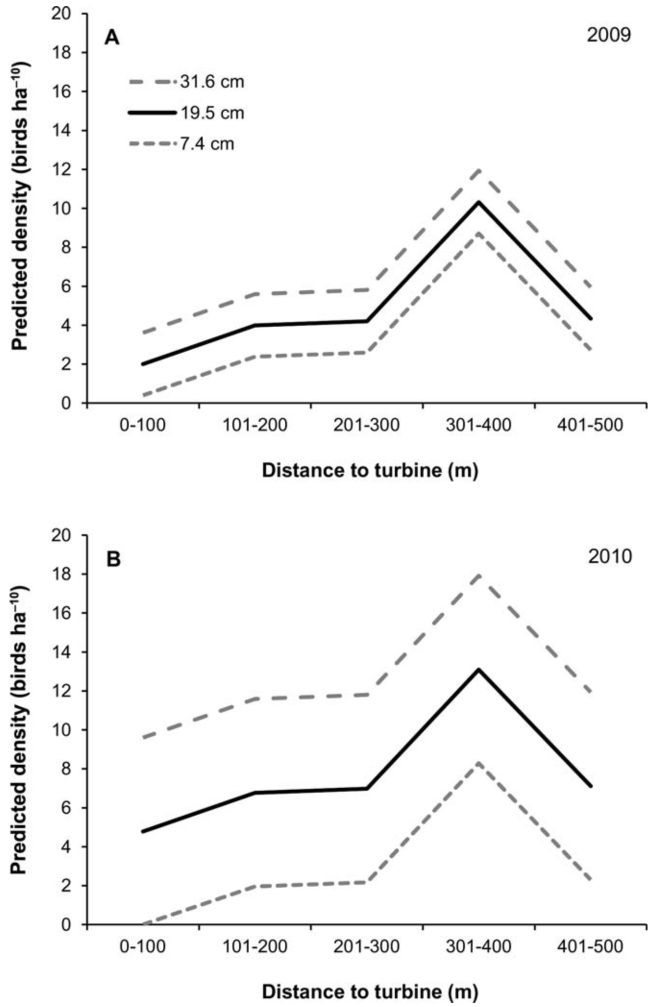

FIGURE 3. Predicted Dickcissel density within the Wolf Ridge wind farm in Cooke County, Texas, USA, from the general linear model including year and distance to turbine as fixed factors and transect as a random factor, with visual obstruction held constant at 3 different levels (+1 SD = 31.6 cm; mean = 19.5 cm; –1 SD = 7.4 cm) in (**A**) 2009 and (**B**) 2010.

Meadowlark density, like Dickcissel density, was higher in distance bins with fence lines than in those without (GLM results not shown: β = –0.928 ± 0.428, $P = 0.03$). We detected no effect of fence lines on Grasshopper Sparrow density (GLM results not shown: β = 0.101 ± 0.352, $P = 0.78$).

Plot Surveys

We observed more Dickcissels (mean density = 10.9 ± 5.8 birds ha^{-10}) than Grasshopper Sparrows (mean density = 4.1 ± 3.3 birds ha^{-10}) at Wolf Ridge in 2011 (paired *t*-test, $t_{17} = 3.61$, $P = 0.002$). The results of the multiple regression indicated that visual obstruction and distance to wind turbine explained 61.8% of the variance in Dickcissel density ($F_{2,15} = 12.12$, $P < 0.001$). Visual obstruction was a

TABLE 2. Results of general linear model of Dickcissel density in relation to year (2009 or 2010), fence line (present or absent), and visual obstruction (covariate) within the Wolf Ridge wind farm in Cooke County, Texas, USA. Transect was included in the models as a random factor, and nonsignificant interaction terms were removed; 10 transects were surveyed in 2009, and 9 were surveyed in 2010.

Factor [a]	*F*	*P*
Year	0.99	0.32
Fence line	13.38	<0.001
Visual obstruction	30.81	<0.001
Year*visual obstruction	7.24	0.009
Transect	5.95	<0.001

[a] $df_{year} = 1$, $df_{fence\ line} = 1$, $df_{visual\ obstruction} = 1$, $df_{year*visual\ obstruction} = 1$, $df_{transect} = 9$, and $df_{error} = 76$.

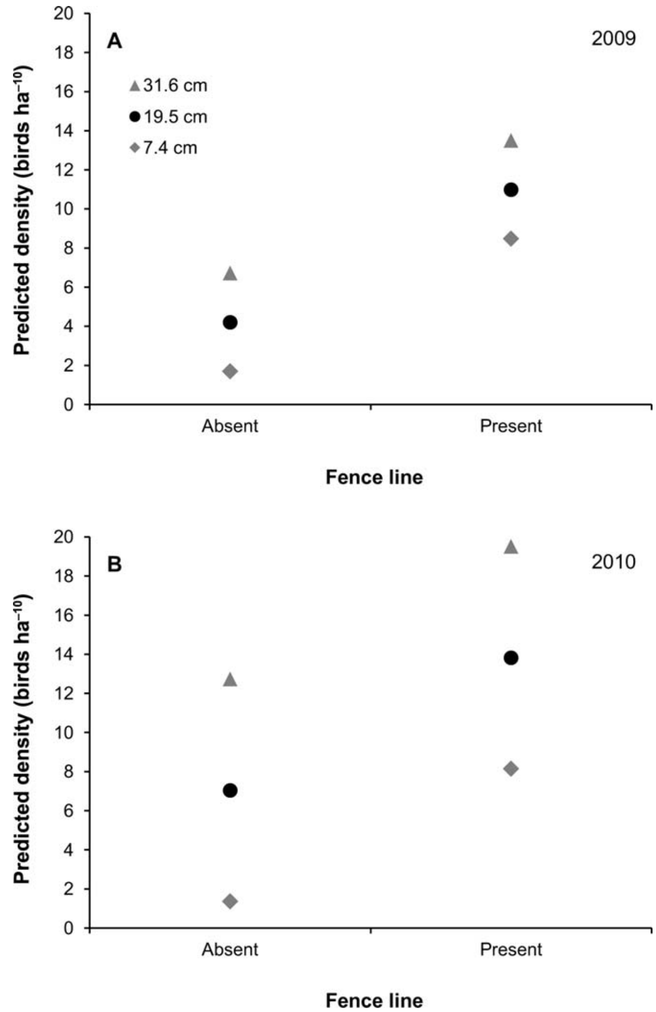

FIGURE 4. Predicted Dickcissel density within the Wolf Ridge wind farm in Cooke County, Texas, USA, from the general linear model including year and fence line as fixed factors and transect as a random factor, with visual obstruction held constant at 3 different levels (+1 SD = 31.6 cm; mean = 19.5 cm; –1 SD = 7.4 cm) in (**A**) 2009 and (**B**) 2010.

significant predictor ($\beta = 1.04 \pm 0.212$, $P < 0.001$; Figure 6A), whereas distance to wind turbine was not ($\beta = -0.0026 \pm 0.004$, $P = 0.57$; Figure 6B). By contrast, visual obstruction and distance to wind turbine did not explain variation in Grasshopper Sparrow density ($R^2 = 19.4\%$, $F_{2,15} = 1.81$, $P = 0.20$; Figure 6C, 6D).

DISCUSSION

In summary, we found no evidence of displacement within 500 or 750 m of wind turbines in breeding grassland songbirds during the first 3 breeding seasons following construction of the wind facility. Although we observed a noticeable peak in Dickcissel density 301–400 m from wind turbines in 2009 and 2010, this pattern was best explained by the presence of fence lines within that distance bin. By contrast, we found no such relationship for either Grasshopper Sparrows or Eastern Meadowlarks.

Previous research has demonstrated that Dickcissels are more likely to establish territories and nest in areas with tall, dense vegetation (Zimmerman 1971, Harmeson 1974, Hughes et al. 1999). At our study site, Dickcissel nest density has been shown to be positively related to vegetation structure; visual-obstruction readings were significantly higher at nest locations than at non-nest locations, regardless of proximity to wind turbines (Hatchett et al. 2013). It is therefore not surprising that visual obstruction was a positive predictor of Dickcissel density and that the highest numbers were recorded in the distance bin with the greatest vegetation structure (i.e. 301–400 m from the wind turbines). Furthermore, this distance bin was bisected by a barbed wire fence in ≥50% of the transects surveyed each year. Given that fence lines provide singing perches that are commonly used by male Dickcissels to establish and defend territories (Knodel-Montz 1981, Vickery and Hunter 1995), it is likely that the presence of fence lines may have increased both abundance and detection of this species in the 301–400 m distance bin.

Using the plot method in 2011, we found that visual obstruction alone significantly predicted variation in Dickcissel density within 750 m of wind turbines at our study site. As in previous years, neither distance to wind turbine nor vegetation structure predicted Grasshopper Sparrow density. The plot-method study design obviated the nonrandom association between fence lines and distance to wind turbine, thereby allowing us to disentangle the effects of these 2 factors on Dickcissel density. These data support our conclusion that the variation in density of breeding Dickcissels that we observed in 2009 and 2010 was best explained by the abundance of suitable perches and vegetation associated with fence lines that

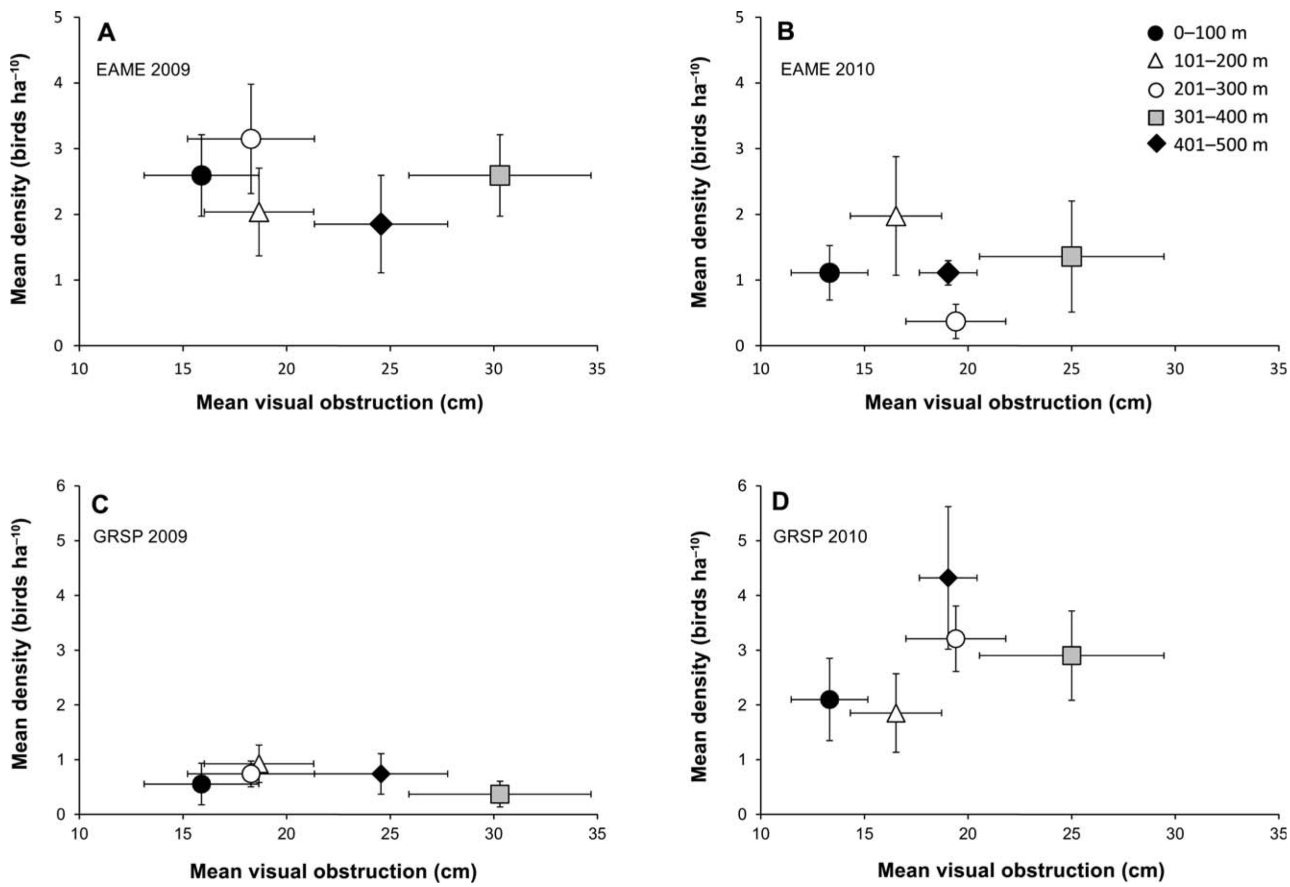

FIGURE 5. Relationship between Eastern Meadowlark (EAME) and Grasshopper Sparrow (GRSP) density and visual obstruction within 500 m of wind turbines in 2009 (**A** and **C**; $n = 10$ transects) and 2010 (**B** and **D**; $n = 9$ transects) within the Wolf Ridge wind farm in Cooke County, Texas, USA. Distance bins are indicated by the different symbols. Vertical error bars are SE of mean bird density; horizontal error bars are SE of mean visual obstruction.

intercepted 5 of the transects 301–400 m from the wind turbines.

We speculate that nonrandom associations between habitat features and wind turbines are likely to occur because individual wind turbines are microsited on low-profile ridges within wind resource areas. Such siting could result in subtle habitat gradients that distort or mask causal relationships in wind–wildlife displacement studies. If these gradients or other confounding variables can be identified, they can be incorporated into the statistical analysis of displacement. Furthermore, an analysis of microtopography associated with turbines as well as the distribution of fence lines, roads, or other anthropogenic features would be most helpful in the study design phase, because the results could be used to inform transect or plot placement within the wind resource area.

Among the wind-turbine displacement studies that have been conducted to date, no clear pattern has emerged, likely because of species-specific behavioral responses to wind turbines as well as variation in study design and survey methods. For example, Leddy et al. (1999) conducted surveys of breeding grassland birds in the United States and, across 10 species, found higher grassland bird densities 100–180 m from wind turbines than within 80 m of turbine strings (i.e. series of wind turbines in a row), and lower densities in fields with turbines than in those without. Similarly, in upland wind farms in the United Kingdom, Pearce-Higgins et al. (2009) documented displacement during the breeding season only among wading shore birds, wetland birds, and raptors (representing 7 of 12 species included in their study). By contrast, Devereaux et al. (2008) found no evidence of displacement resulting from wind turbines in 4 functional groups of winter farmland birds in the United Kingdom. However, in a study of winter grassland birds in Texas, Stevens et al. (2013) found evidence of displacement in 1 of 4 species and cautioned that if they had analyzed their data by functional group rather than at the level of individual species, this displacement would not have been detected. More research is needed if we are to understand the extent

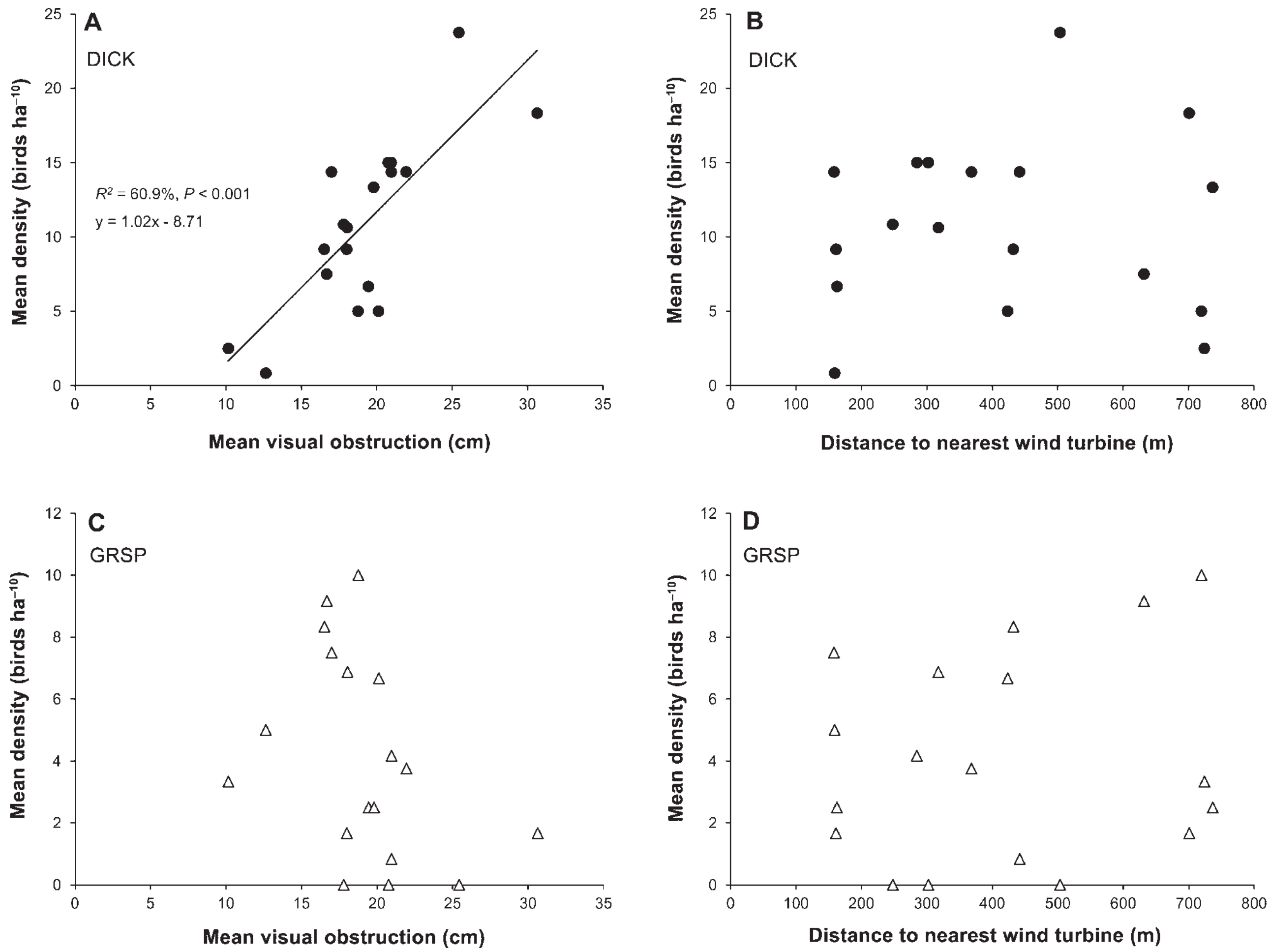

FIGURE 6. Relationship between Dickcissel (DICK) and Grasshopper Sparrow (GRSP) density and visual obstruction (**A** and **C**) and distance to nearest wind turbine (**B** and **D**) during the 2011 breeding season ($n = 18$ survey plots) within the Wolf Ridge wind farm in Cooke County, Texas, USA.

to which indirect effects of wind energy are likely to threaten the persistence of wildlife populations.

In conclusion, our results suggest that there will be minimal indirect effects of wind energy development on settlement by breeding Dickcissels, Grasshopper Sparrows, and Eastern Meadowlarks, at least during the operation of wind facilities. This is good news in light of the expected continued growth in wind energy development, because each of our focal species has shown significant range-wide population declines over the past several decades (Sauer et al. 2011), and their current breeding ranges overlap with areas with the greatest wind energy potential in the United States (i.e. the Great Plains; U.S. Department of Energy 2008; http://www.awea.org). The present study contributes quantitative data to the growing body of knowledge regarding the indirect effects of wind turbines on breeding grassland birds at utility-scale wind farms and highlights the need to consider turbine layout, habitat gradients, and the location of other anthropogenic features such as fence lines when choosing survey methods for wildlife displacement studies.

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