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Source: Waterbirds, 36(3) : 263-276

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.036.0304

Influence of Wind Turbines on Presence of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on Wetlands in the Prairie Pothole Region of North Dakota and South Dakota

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Abstract.—The millions of wetlands that define the Prairie Pothole Region (PPR) harbor large proportions of continental populations of several species of North American waterfowl, waterbirds, and shorebirds. The PPR also has some of the highest wind energy potential in the United States. Thousands of wind turbines are being erected in the PPR to produce electricity and have the potential to affect migratory bird populations through collisions, displacement, barriers to movement, habitat fragmentation, and habitat loss. We assessed occurrence of waterbirds and shorebirds from 2008 through 2010 on wetlands in two wind energy development sites, defined as wetlands within 805 m of a wind turbine, and two reference sites in the PPR of North and South Dakota. We conducted 10,321 wetland visits on 3,542 individual wetland basins and related bird occurrence to wetland characteristics, upland characteristics, survey type (roadside vs. off-road), seasonal timing of sampling, year of sampling, and site type (wind energy development vs. reference). Models characterizing occurrence of Willet (*Catoptrophorus semipalmatus*), Marbled Godwit (*Limosa fedoa*), Wilson's Phalarope (*Phalaropus tricolor*) and Black Tern (*Chlidonias niger*) indicated that occurrence varied with wetland characteristics and among sites and years, was not substantially reduced on either wind energy site, but was slightly and consistently lower on one of the wind energy sites for the three shorebird species. Our results suggest that wetlands have conservation value for these species when wind turbines are present, but additional sampling across time and space will be necessary to understand the effects of wind turbines on shorebird and waterbird presence, density, survival, and reproductive success. *Received 24 July 2012, accepted 23 January 2013.*

Key words.—assessment, habitat, landscape, Missouri Coteau, Prairie Pothole Region, shorebirds, waterbirds, wetlands, wind energy development.

Waterbirds 36(3): 263-276, 2013

The Prairie Pothole Region (PPR) is located in north-central North America where areas of high wetland density intersect with grasslands of the northern Great Plains. Because of the extensive areas of wetland and grassland habitat in the region, the PPR is renowned for harboring large proportions of continental waterfowl, waterbird, shorebird, and grassland bird populations (Batt *et al.* 1989; Peterjohn and Sauer 1999; Brown *et al.* 2001; Beyersbergen *et al.* 2004). For example, the PPR is estimated to host > 50% of the North American breeding populations of Pied-billed Grebe (*Podilymbus podiceps*), American Bittern (*Botaurus lentiginosus*), Sora (*Porzana carolina*), American Coot (*Fulica americana*) and Black Tern (*Chlidonias niger*) (Beyersbergen *et al.* 2004), as well as approximately 80% of the North American population of Marbled Godwit (*Limosa fedoa*); estimate following methods of Rosenberg and Blancher (2005).

Another abundant resource in the PPR is wind. Combined, the states of North Dakota, South Dakota, Montana, Iowa, and Minnesota have > 3,100 gigawatts (GW) of wind energy potential; individually, total available wind energy potential in each state in

the PPR exceeds state goals set by the U.S. Department of Energy for the nation to produce 20% of its electricity from wind by one to two orders of magnitude (U.S. Department of Energy 2008; Kiesecker *et al.* 2011). This abundance of wind energy potential is appealing both economically and from the standpoint of helping the United States reduce reliance on fossil fuels. However, generation of electricity from wind has a larger land footprint per unit of energy produced than other forms of energy production, with the exception of biofuels (McDonald *et al.* 2009). In addition, turbines and infrastructure associated with wind energy production are known to negatively affect many species of wildlife (Arnett *et al.* 2007; Kuvlesky *et al.* 2007; Stewart *et al.* 2007), especially if wildlife concerns are not considered when wind turbine sites are selected. Conflicts between wind energy development and wildlife may be particularly problematic in the PPR, where areas of highest wind potential often coincide with land that has not been converted to row crop agriculture (Niemuth 2011). These areas typically have high conservation value for migratory bird populations because they contain intact wetland complexes and large blocks of native grasslands (Naugle *et al.* 2001; Reynolds *et al.* 2006; Niemuth *et al.* 2008).

Loss and degradation of grassland and wetland habitat through conversion to cropland is the most pressing current threat to populations of migratory birds in the PPR (Higgins *et al.* 2002; Stephens *et al.* 2008; Fargione *et al.* 2009; Rashford *et al.* 2010). Consequently, extensive landscape-level programs have been developed in the PPR to conserve grasslands and wetlands and their associated wildlife (Ringelman 2005; Reynolds *et al.* 2006; Niemuth *et al.* 2008). However, the value of conserved grassland and wetland habitats would be diminished if wildlife avoids or is otherwise negatively affected by wind turbines or associated roads, transmission lines, and maintenance activities.

Much remains to be known about the effects of wind energy development on birds (Kuvlesky *et al.* 2007; Stewart *et al.* 2007), but identified effects include collisions, displacement due to disturbance, barriers to movement, and habitat change and loss (Drewitt and Langston 2006). Effects vary among bird species, locations, turbine size and configuration, and length of time that turbines have been operational (reviewed in Stewart *et al.* 2007), which complicates assessment of the effects of wind energy development on birds (see Strickland *et al.* 2011). In addition, effects may be expressed directly, as in mortality from collisions, or indirectly, as in displacement of birds or reductions in body condition or reproductive success (Drewitt and Langston 2006). Research in other systems suggests that densities of some waterbird and shorebird species are reduced in proximity to wind turbines because these species avoid wind turbines and associated infrastructure such as roads (Everaert and Stienen 2007; Stewart *et al.* 2007; Pearce-Higgins *et al.* 2008, 2009). Understanding the effects of wind energy development on migratory birds in the PPR is necessary to ensure that bird populations and conservation efforts in the region are not compromised. However, no information presently exists regarding the response of shorebirds and waterbirds to wind turbines in the PPR.

We sampled wetlands over 3 years in two wind energy sites and two reference sites in the PPR of North Dakota and South Dakota to determine if wetland use by seven species of waterbirds and shorebirds during spring migration/breeding season differed between areas with and without wind turbines. We used a model-based approach that, in addition to assessing effects of wind turbine presence on birds, also included variables describing wetland characteristics, landscape composition, survey method and timing, and annual variation. These variables were included to account for potential habitat and year effects that could confound or influence interpretation of results. We hypothesized that a lower mean probability of occupancy or a lower mean abundance in areas with wind turbines would, other things being equal, indicate avoidance by birds (Burton 2007; Strickland *et al.* 2011).

METHODS

Study Area and Site Selection

"Pothole" basins in the PPR were formed by glacial action from the late Wisconsin glacial episode that ended about 13,000 years ago (Bluemle 1991). Wetlands in the PPR range from wet meadows and shallow-water ponds to saline lakes, marshes, and fens with a mean size of 0.45 ha; wetland density is highly variable across the PPR and ranges from 0-40 wetlands/km^2 (Cowardin *et al.* 1979; Kantrud *et al.* 1989).

We used a geographic information system (GIS) to identify all wetlands completely or partially within 805 m of wind turbines, which we defined as wind energy sites. This distance was consistent with habitat selection analyses for breeding shorebirds in the PPR and corresponds with avoidance of wind turbines by the Eurasian Curlew (*Numenius arquata*) in the United Kingdom (Niemuth *et al.* 2008; Pearce-Higgins *et al.* 2009). In addition, 805 m is the scale at which conservation actions in the region are commonly made, specifically the acquisition of conservation easements on cadastral quarter-sections of land, which are square with sides equal to 805 m.

We sampled wetlands at two wind energy sites and two paired reference sites (Fig. 1) in the Missouri Coteau physiographic region of North Dakota and South Dakota, which is an area with high densities of wetlands and large amounts of grassland. The 2,992-ha Kulm-Edgeley wind energy site (KE WIND) began operation in 2003, consisted of 41 towers, and was located 3.2 km east of Kulm, North Dakota. The 6,767-ha Tatanka wind energy site (TAT WIND) contained 120 towers and was located 9.7 km northeast of Long Lake, South Dakota. Approximately 50% of the Tatanka wind turbines were operational by 28 April 2008 and all were operating by 21 May 2008. Tower locations were on-screen digitized using ArcGIS software (Environmental Systems Research Institute 2006) and aerial photographs (circa 2006-2007) from the National Agriculture Imagery Program (NAIP; U.S. Department of Agriculture 2009).

For each wind site, we identified and assessed three potential reference sites of approximately the same area. We considered proximity to the corresponding wind site, land use, wetland density, wetland area, anticipated wetland conditions, and wetland class composition in the selection of the reference sites. The most similar of the three potential sites was selected as a paired reference for each of the wind sites. The 4,203-ha Kulm-Edgeley reference site (KE REF) was located 11.3 km southwest of the KE WIND site, and the 8,269-ha Tatanka reference site (TAT REF) site was located 3.2 km northwest of the TAT WIND site (Fig. 1). The KE WIND and KE REF sites were both dominated by cropland, and the TAT WIND and TAT REF sites were dominated by grassland (Table 1).

Wetland Identification and Sampling

We determined wet area of wetland basins each year using modified digital National Wetlands Inventory (NWI; Wilen and Bates 1995) data as a baseline. Wetlands with > 1 wetland zone (see Cowardin *et al.* 1979) mapped by the NWI are represented in digital data as polygons with shared boundaries. We combined these into individual depressional wetland basins classified by the most permanent water regime associated with the constituent zones (Cowardin *et al.* 1995; Johnson and Higgins 1997). Wetland water regimes characterized the duration of inundation each year (i.e., temporarily, seasonally, or semipermanently flooded; Cowardin *et al.* 1979). Because a survey of the entire wetland was to be conducted, wetlands that extended > 400 m beyond the boundary of a site were not surveyed.

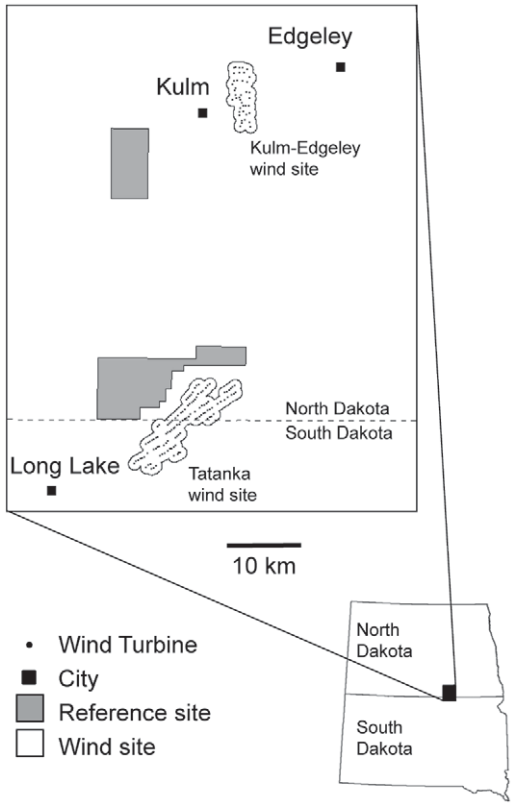

Figure 1. Location of Kulm-Edgeley and Tatanka wind energy sites and corresponding reference sites in which occurrence of waterbirds and shorebirds on wetland basins was assessed during nesting season survey period 2008 through 2010.

Wetland and Avian Surveys

We surveyed most wetlands twice to encompass the varying migration and breeding phenology of the target species, as some (e.g., Marbled Godwit) return and nest early in spring and others (e.g., Black Tern) return and nest later (Kantrud and Stewart 1984; Kantrud and Higgins 1992). We attempted to survey all temporary, seasonal, and semipermanent basins within each study site (Table 1); no lake wetlands were surveyed as no lake

Table 1. Number of wetlands, by water regime, and area of upland cover classes in the Kulm-Edgeley wind (KE WIND), Kulm-Edgeley reference (KE REF), Tatanka wind (TAT WIND), and Tatanka reference (TAT REF) sites where waterbirds and shorebirds were sampled during spring of 2008, 2009, and 2010. Wind sites were defined as areas < 805 m from wind turbines; paired reference sites were selected to have similar size, wetland communities, and landscape characteristics. Wetland numbers were obtained from National Wetlands Inventory data processed to basins; land cover estimates were obtained from classified satellite imagery, circa 2002 (U.S. Fish and Wildlife Service Region 6 Habitat and Population Evaluation Team, unpubl. data).

Habitat metric	KE WIND	KE REF	TAT WIND	TAT REF
Temporary wetland (*n*)	272	283	362	462
Seasonal wetland (*n*)	372	240	917	815
Semipermanent wetland (*n*)	37	37	322	231
Perennial cover[a] (ha)	416	1,324	5,428	6,040
Cropland (ha)	2,121	2,233	455	431
Other (ha)	7	13	18	11

[a]Includes native grassland, idle planted tame grass, and alfalfa hay land cover classes.

wetlands were present in either wind site. All accessible sample wetlands were visited during the first sample period, 28 April-18 May. Wetlands that were dry during the first sample period were not revisited during the second survey period, 21 May-7 June. Where permission to access wetlands was denied, we also sampled wetland basins from public section lines, adjacent land where permission had been obtained, or from public roads. Two-member crews conducted surveys on each of three crew areas daily, with wetlands allotted to crew areas in a grid pattern based on public land survey sections with an area of 2.6 km^2. Technicians rotated among crew areas and partners to reduce potential systematic bias, such as confounding of technicians and sites. Crew members used maps that showed the perimeter of the wetland basins overlain on NAIP photography to assist navigation to survey wetlands. Surveys began at 0800 and continued until 1800 and were discontinued during steady rainfall or when winds exceeded 45 kph.

We surveyed for Eared Grebe (*Podiceps nigricollis*), Western Grebe (*Aechmophorus occidentalis*), American White Pelican (*Pelecanus erythrorhynchos*), Willet (*Catoptrophorus semipalmatus*), Marbled Godwit, Wilson's Phalarope (*Phalaropus tricolor*) and Black Tern in 2008, 2009, and 2010. Species were selected based on their conservation status, relative abundance in the region, and the ease of technicians to detect and identify birds during concurrent, daytime waterfowl surveys (see Loesch *et al.* 2013). Most wetland basins (67%) were approached on foot and the entire wetland basin was visually scanned. Technicians noted if wetlands were surveyed from a public road. Data were recorded for all wetland basins that contained surface water regardless of whether birds were detected.

When possible, we observed wetlands from one or more distant, strategic positions to minimize disturbance while viewing the basin. Portions of basins that were not visible were approached and surveyed. Wetlands with dense vegetation were entered on foot to ensure that all birds present were counted. Technicians followed standardized protocols to ensure uniform counts of birds and recorded wetland characteristics at the conclusion of each avian survey. The extent of the wet area of the wetland was estimated as percent full by comparing the current surface water area with the wetland basin polygon on the field map. A basin with no surface water was recorded as dry and was not surveyed. Additionally, patterns of vegetation and open water interspersion were assigned to one of four cover classes (Stewart and Kantrud 1971), and height class (i.e., < 25 cm or ≥ 25 cm) of wetland vegetation was recorded.

We used 2009 NAIP imagery, on-screen photointerpretation, and field visits to manually classify basins relative to their adjacent land cover (i.e., cropland or perennial cover comprised of native grassland, idle planted tame grass, or alfalfa hayland). For wetlands embedded within multiple upland land cover classes, we assigned the class based on the largest wetland perimeter length.

Statistical Analyses

We considered a suite of candidate predictor variables (Table 2) that would potentially account for variation in presence and abundance of each species of waterbird and shorebird on wetlands in wind energy development sites and reference sites. Candidate predictor variables focused on habitat characteristics that were well supported by past work in the region (Kantrud and Stewart 1984; Ryan and Renken 1987; Fairbairn and Dinsmore 2001; Naugle *et al.* 2001). We primarily assessed main effects of variables in our regression models. However, we did consider a year*site interaction term because the distribution and abundance of target species fluctuate among years in response to water conditions (Niemuth and Solberg 2003) and effects of wind energy production on birds can be affected by the length of time that turbines have been operational (Stewart *et al.* 2007; Pearce-Higgins *et al.* 2012).

To provide an initial assessment of patterns of bird presence on wetlands and insight into appropriate structure for statistical models, we examined the distribution of bird detections among species, study sites, years, and wetland characteristics. Given the infrequent detection of target species, non-independence of flocking birds, and irregular numeric distributions of individuals for our target species, we used logistic regression (Hosmer and Lemeshow 2000; Agresti 2007) to analyze the presence/non-detection of birds, by species, on wetlands as

Table 2. Candidate variables considered in assessment of waterbird and shorebird response to wind energy development in the Prairie Pothole Region of North Dakota and South Dakota.

Variable Name	Variable Description
Site	Categorical variable providing intercept adjustments for the two wind energy sites (Kulm-Edgeley Wind and Tatanka Wind) and second reference site (Tatanka Reference). Kulm-Edgeley Reference site served as the baseline site.
Year	Categorical variable providing intercept adjustments for the years 2009 and 2010. The year 2008 served as the baseline year.
Land cover	Categorical variable describing the dominant land cover class (cropland vs. perennial cover) surrounding each study wetland, where perennial grassland served as the baseline cover type with an intercept adjustment for cropland.
Water regime	Categorical variable providing intercept adjustments for wetland basins with temporary and semipermanent water regimes. Wetlands with seasonal water regimes served as the baseline regime.
Period	Categorical variable providing an intercept adjustment indicating the second survey period. The first survey period served as the baseline.
Roadside	Categorical variable providing an intercept adjustment indicating that a wetland was surveyed from a road. Off-road surveys served as the baseline.
Wet area (ha)	Continuous variable indicating mapped area of each wetland basin from National Wetlands Inventory basin data multiplied by the proportion of the basin estimated to be covered by water. The square root of this term was also included in candidate models to accommodate anticipated nonlinear response in bird presence.
Vegetation height	Categorical variable providing an intercept adjustment indicating that height of emergent vegetation on the wetland exceeded 25 cm. Vegetation with height < 25 cm served as the baseline.
Vegetation cover class	Categorical variable providing intercept adjustments for four cover classes indicating coverage and configuration of emergent wetland vegetation (Stewart and Kantrud 1971). Wetland cover class 1 (emergent vegetation covering > 95% of wetland area) served as the baseline cover class.
Year*site interaction	Categorical variables providing intercept adjustments for interactions of the two year (2008 and 2009) adjustments and three site (Kulm-Edgeley Wind, Tatantaka Reference, and Tatanka Wind) adjustments.

a function of a suite of predictor variables. Bird occurrence that we modeled was a function of bird presence on wetlands and detection by technicians; it is likely that target species used, but were not detected on, some wetlands that we sampled (see Nichols *et al.* 2000). Imperfect detection of bird use of wetlands would cause lower estimated probabilities of occurrence for modeled species, but our rotation of technicians and use of standardized methodology should have prevented systematic bias in our results relative to potential avoidance of wind turbines by birds.

The full model (i.e., all variables in Table 2 plus the intercept) included 23 parameters. Even though our full model was biologically justified and well supported by past research, we discriminated among reduced versions of the full model using Akaike's Information Criterion (AIC; Burnham and Anderson 2002) to parsimoniously describe patterns of occurrence of target species and reduce variance in parameter estimates. Specifically, we started with the full model and held out one parameter or set of parameters at a time and assessed improvements in AIC values (Burnham and Anderson 2002). Our goal was not to identify a "best" model describing habitat use by the target species, but to provide a biologically sound framework for assessing potential effects of wind turbines on bird occurrence and account for variation in wetland and landscape characteristics that could not be controlled for in our study design.

We evaluated potential displacement of target species by examining parameter estimates along with improvements in model fit when site variables were included in best-approximating regression models. If the best-approximating model (i.e., the model with lowest AIC value) for each species contained the site variable, we also calculated the AIC value for the same model without the site variable. If the best-approximating model did not contain the site variable, we calculated the AIC value for the same model with the site variable added. This enabled us to assess the weight of evidence for site effects by calculating Akaike weights (w_i; Burnham and Anderson 2002) for the best-approximating model for each species with and without the site variable. Because the suite of site variables included intercept adjustments for the KE WIND, TAT REF, and TAT WIND sites (KE REF was the baseline), improved model fit when the site variable was included did not necessarily demonstrate that bird detections were reduced at sites with wind turbines. Parameter estimates and associated variances indicated direction and strength of effects for each site. We chose to assess individual site effects rather than include an additional variable denoting the presence of turbines because: 1) sites and presence of wind turbines were confounded; and 2) dominant upland cover differed between the pairs of sites.

To better evaluate differences among sites, we plotted the modeled probability of occurrence and 95% confidence intervals, by year, for all combinations of sites and years. We used a seasonal wetland with mean area observed at all sites during the study and wetland cover class 1 (emergent vegetation covering > 95% of wetland area) and the KE REF site as baseline categories. Plots did not include intercept adjustments for roadside sampling, cover class, vegetation height, or survey period, with the exception of Wilson's Phalarope and Black Tern, for which we plotted second survey-period results given low numbers of detections during the first survey period. We calculated confidence intervals as the predicted probability of occurrence for each study area ± 1.96 times the associated standard error (Hosmer and Lemeshow 2000). Our use of 95% confidence intervals was not completely consistent with an information-theoretic approach (Arnold 2010), but we chose this threshold because of its accepted use and interpretation in the scientific literature. For each best-approximating model, we calculated the area under the curve of receiver operating characteristics (ROC) to provide insight into how well models predicted presence/non-detection of birds on wetlands (Swets 1988; Hosmer and Lemeshow 2000). All analyses were conducted using Number Cruncher Statistical System (Hintze 2009).

RESULTS

We conducted 10,321 wetland visits on 3,542 individual wetland basins during 2008 (n = 2,079), 2009 (n = 3,349), and 2010 (n = 4,893). Increased numbers of wetlands sampled in 2009 and 2010 reflected a change from drought to wet conditions. Slightly more visits were made to wetlands in wind energy sites (54.3%, n = 5,607) than wetlands in reference sites (45.7%, n = 4,714). Wetlands with seasonal water regimes were most abundant (57.7% of visits), followed by wetlands with temporary and semipermanent water regimes (22.7% and 19.6% of visits, respectively). Wet area of wetland basins increased with permanency of wetland water regime, with a mean (range) of 0.16 ha (0.002 - 7.3 ha) for temporary wetlands, 0.65 ha (0.02 - 28.3 ha) for seasonal wetlands, and 2.8 ha (0.03 - 112.5 ha) for semipermanent wetlands. Time spent surveying each wetland varied with wetland size and vegetative cover and ranged from 1 min to 3 hr. Survey effort was nearly evenly split between the two sample periods, with 51.6% of visits (n = 5,323) in the first period and 48.4% of visits (n = 4,998) in the second period.

Few target species were observed on survey wetlands, ranging from 23 detections (< 0.3% of total wetland visits) for Western Grebe to 202 detections (2% of total wetland

visits) for Black Tern (Table 3). Numbers of individuals detected per occurrence was highly variable, which emphasized the difficulty of modeling numbers of individuals rather than the occurrence of a given species on a wetland. For example, 1,000 of the 3,040 Wilson's Phalaropes detected over the course of the study were observed on a single wetland visit. We were unable to develop models and assess response of Eared Grebe, Western Grebe, and American White Pelican to wind energy development because of the small number of detections for these species; we had sufficient detections to develop models and present results for Willet, Marbled Godwit, Wilson's Phalarope, and Black Tern. Maximum-likelihood estimators converged without errors for all models except the full model for Black Tern, which exhibited quasi-complete separation (Hosmer and Lemeshow 2000) due to strong avoidance by Black Terns of wetlands without emergent vegetation. The model for Black Tern converged without error when cover class was excluded; this slightly reduced model was then used as the full model from which further reductions were assessed.

For all species, probability of occurrence increased curvilinearly with wet area of basins and varied among years (Table 4). With the exception of upland cover class, all candidate variables entered into best-approximating models for one or more species, although factors influencing presence and detection of birds varied among species (Table 4). Ability of best-approximating models to explain variation in presence of target species on wetlands also varied, with ROC values in the low range for Marbled Godwit (0.68) and Willet (0.64), in the acceptable range for Wilson's Phalarope (0.76), and in the excellent range for Black Tern (0.87; Swets 1988; Hosmer and Lemeshow 2000).

Akaike weights indicated strong support ($w_i > 0.93$) for the site variable to be included in best-approximating models for Black Tern and Marbled Godwit. Inclusion of the site variable had limited support ($w_i < 0.27$ in both cases) for best-approximating models for Willet and Wilson's Phalarope (Table 5). However, even when the inclusion of the site

Table 3. Number of individuals detected and number of visits on which Eared Grebe, Western Grebe, American White Pelican Willet, Marbled Godwit, Wilson's Phalarope and Black Tern, were detected during wetland surveys on reference and wind energy sites late April- early June 2008, 2009, and 2010.

	Eared Grebe		Western Grebe		American White Pelican		Willet		Marbled Godwit		Wilson's Phalarope		Black Tern	
Type	Birds	Visits	Birds	Visits	Birds	Visits	Birds	Visits	Birds	Visits	Birds	Visits	Birds	Visits
Wind	12	10	34	12	72	12	98	72	169	84	2,059	91	403	99
Reference	37	15	31	11	101	20	147	94	213	111	981	93	522	103
Total	49	25	65	23	173	32	245	166	382	195	3,040	184	925	202

Table 4. Parameter estimates and standard errors for best approximating, basin-level logistic regression models for detections of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern in wind and reference sites during season survey period 2008, 2009, and 2010.

	Willet		Marbled Godwit		Wilson's Phalarope		Black Tern	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-6.025	0.520	-5.016	0.264	-6.413	0.600	-11.927	0.928
regime = semipermanent							0.509	0.190
regime = temporary							-1.223	0.525
cover class = 2	1.191	0.546			1.300	0.629		
cover class = 3	1.365	0.522			2.057	0.594		
cover class = 4	2.057	0.525			2.591	0.600		
vegetation > 25 cm							0.607	0.193
wet area (ha)	-0.104	0.026	-0.137	0.024	-0.181	0.034	-0.250	0.035
square root wet area (ha)	1.160	0.153	1.540	0.142	1.512	0.175	2.324	0.198
upland = agricultural								
survey period = second					0.509	0.160	3.938	0.461
survey type = roadside	-0.313	0.199	-0.638	0.207			-0.520	0.211
site = KE WIND			-0.758	0.318			2.150	0.842
site = TAT REF			0.193	0.207			2.578	0.787
site = TAT WIND			0.136	0.207			1.928	0.784
year = 2009	-0.766	0.230	-0.468	0.219	-1.425	0.198	0.487	0.952
year = 2010	-0.486	0.192	0.020	0.177	-1.901	0.207	2.329	0.780
KE WIND * 2009							-1.910	1.202
TAT REF * 2009							-2.245	1.077
TAT WIND * 2009							0.174	1.012
KE WIND * 2010							-3.474	1.031
TAT REF * 2010							-1.808	0.836
TAT WIND * 2010							-1.348	0.835

Table 5. Akaike's Information Criterion (AIC) differences (Δ_i), AIC weights (w_i), and receiver operating characteristics (ROC) values for best approximating model, by species, with and without inclusion of site variable.

	Without Site Variable			With Site Variable		
Species	Δ_i AIC	w_i	ROC	Δ_i AIC	w_i	ROC
Willet	0.0	0.73	0.64	2.0	0.27	0.64
Marbled Godwit	6.8	0.03	0.67	0.0	0.97	0.68
Wilson's Phalarope	0.0	0.79	0.76	2.6	0.21	0.76
Black Tern	43.0	<0.01	0.85	0.0	>0.99	0.87

variable substantially improved models and had strong support (i.e., models for Black Tern and Marbled Godwit), parameter estimates and associated variances indicated that probability of detections varied among sites but was not consistently and substantially reduced on wind energy sites (Table 4; Fig. 2). With the exception of Black Tern in 2008 and 2009, predicted probability of occurrence was consistently lowest at the KE WIND site for all species, site, and year combinations. However, 95% confidence intervals for the KE WIND site substantially overlapped with those of the KE REF site. There was little or no difference between TAT WIND and TAT REF, again with substantial overlap in 95% confidence intervals for all species.

DISCUSSION

Our results demonstrate that Willet, Marbled Godwit, Wilson's Phalarope and Black Tern did not consistently avoid wetland basins < 805 m from wind turbines on our study sites. Although we conducted > 10,000 wetland visits over the course of 3 years, our ability to make inferences regard-

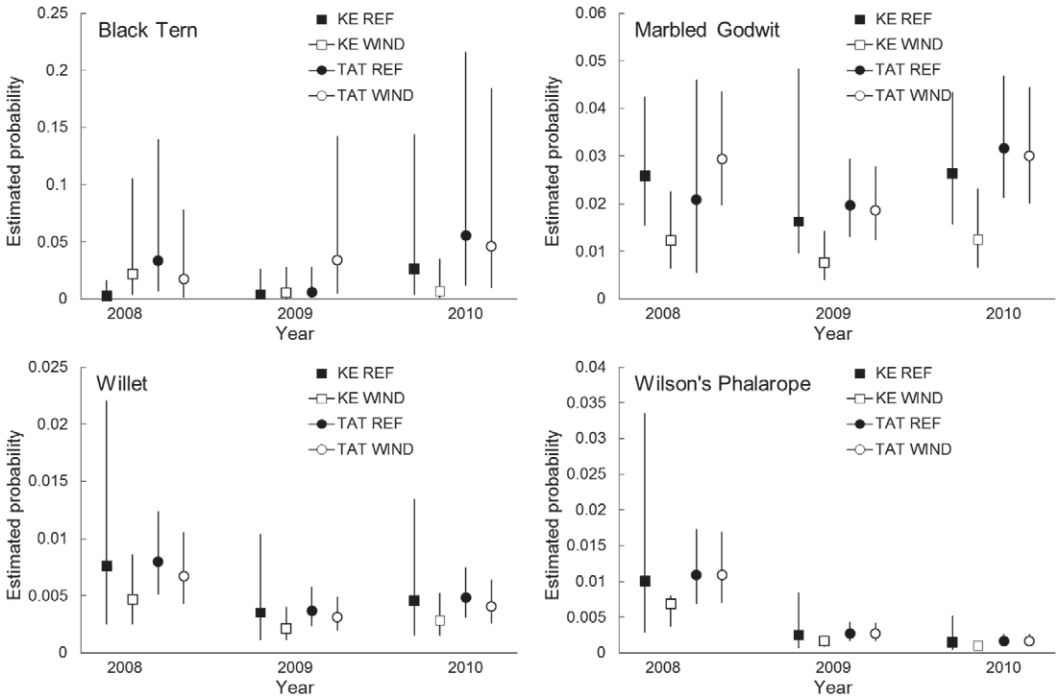

Figure 2. Site- and year-specific estimates of mean probability of detecting Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on wetland basins in study sites with (Kulm-Edgeley wind [KE WIND], Tatanka wind [TAT WIND]) and without (Kulm-Edgeley reference [KE REF], Tatanka reference [TAT REF]) wind turbines. Lines are 95% confidence intervals.

ing avoidance of wetlands in the vicinity of wind turbines by our target species was limited because of infrequent occurrence and detection of the target species, resulting high variance associated with parameter estimates, and differences among the limited number of replicates that were available to be sampled. Patterns of slightly lower mean occupancy in wind energy sites for Marbled Godwit and Black Tern suggest that our study species might occupy wetlands in wind developments at a lower rate than could be detected with our data. Nonetheless, our results indicate that wetlands < 805 m from wind turbines retain conservation value for the species we sampled, and also provide guidance for future evaluations of the effects of wind turbines on wetland-dependent birds in the PPR.

The positive association of our target species with grasslands (Naugle *et al.* 2001; Niemuth *et al.* 2012) might explain the consistent slightly higher occupancy at the grassland-dominated TAT WIND and TAT REF sites relative to the cropland-dominated KE sites. Differences in the amount of grassland between the pairs of study sites also might explain why upland cover class did not enter models, as the landscape-level influence of grass was likely captured by the site variable. However, patterns in our data might also be an artifact of small sample size; our limited number of replicates in time and space reduces our ability to make inferences about factors influencing bird use of wetlands in proximity to wind turbines. Our results illustrate some of the difficulties commonly associated with making reliable inferences about effects of wind on wildlife, which include variable age of sites, confounding of variables, limited replication, the inability to manipulate sites, and difficulties in collecting pre- and post-construction data (Stewart *et al.* 2007; Strickland *et al.* 2011).

Our survey design and analysis did not account for variation in detection probability, but this limitation does not invalidate our conclusions. Because survey effort and methods were consistent among years and across treatments in our study, relative differences should not be affected, even if actual probability of occurrence is higher than estimated (Johnson 2008). Detection of waterfowl and breeding shorebirds is generally high (Andres 2006; Jones *et al.* 2008; Baschuck *et al.* 2012), although detection of migrant shorebirds has been shown to be variable and influenced by vegetation height and structure (Farmer and Durbian 2006). Consequently, it is possible that detection of shorebirds was reduced on wetlands with a greater proportion of emergent vegetation or increased height of emergent vegetation. However, this should not have compromised our results as we selected wind and reference sites with similar wetland communities and land use to control for such biases, and included the cover class and vegetation height variables to account for variation among wetlands.

Our study spanned 3 years. Effects of wind turbines may increase over time (Stewart *et al.* 2007; but see Pearce-Higgins *et al.* 2012), and it is possible that avoidance might occur—or be more readily detected—at these same wind sites in the future. Year effects were evident, but appear to be related to variation in regional wetland conditions rather than a lag in response to wind turbines. If lags in avoidance of wind turbines do exist, they will likely vary among species, as the mechanism for a lag effect may be related to patterns of longevity, mortality, reproductive success, and philopatry (see Brooks *et al.* 1999; Keeling *et al.* 2000; Walker *et al.* 2007). Marbled Godwits appear to be long-lived and highly philopatric (Gratto-Trevor 2000), but many other species in the PPR are nomadic, with low philopatry and high inter-annual variation in population size and distribution depending on water conditions, which are highly variable (Stewart and Kantrud 1973; Niemuth and Solberg 2003; Jones *et al.* 2007). Consequently, the response of birds to wind energy development could vary among years depending on regional and local water conditions, further complicating detection of effects related to presence of wind turbines.

Our findings indicate that wetlands within wind energy sites still have conservation value for the species we assessed, but also suggest that occupancy of these wetlands

might be slightly reduced. Because birds continued to occupy wetlands in proximity to wind turbines, factors such as behavioral avoidance, direct mortality, and reproductive success should also be assessed in the future to determine if wind turbines negatively affect populations of priority species. Our results are but one part of a larger, still-incomplete picture that must be considered given the many migratory bird species, many of which might have differing responses to presence of wind turbines, that conservation programs in the PPR are designed to benefit. For example, a concurrent study that assessed waterfowl response to wind energy development on the same study sites found that estimated densities of duck pairs on wetlands in wind sites were reduced 4-56% for 25 of 30 site, species, and year combinations (Loesch *et al.* 2013).

A better understanding of the effects of wind energy development on wetland-dependent birds in the PPR will require substantial funding and effort. Low densities of waterbirds and shorebirds present a substantial challenge to researchers and managers seeking to understand potential effects of wind energy development on these species, and we suggest that strong conclusions will most likely continue to be elusive without substantial, ongoing research and monitoring. Continued investigation of landscape-level patterns of occupancy and density is a logical investigative path to follow. We suggest that future efforts involve sampling of wetland basins across extensive spatial and temporal scales using repeated visits within years to better ascertain occupancy and reduce variance in estimates. To this end, the U.S. Fish and Wildlife Service has initiated breeding shorebird surveys along 13 40-km roadside transects in North Dakota, South Dakota, and Montana; these surveys sample uplands as well as wetlands and use a before-after-control-impact study design (see Niemuth *et al.* 2012). The success of that effort will depend in part on whether or not turbines are actually built on several planned wind energy development sites where pre-construction data are being collected. Determining occupancy of wetlands by secretive marshbirds such as rails will require dedicated surveys that include audio playback and narrow seasonal and daily survey windows (Gibbs and Melvin 1993). Finally, future efforts might want to consider experimental designs that can assess avoidance at distances < 805 m, as some species of passerines, shorebirds, and raptors avoid wind turbines at smaller scales (Pearce-Higgins *et al.* 2008; Shaffer and Johnson 2008; Leddy *et al.* 2009).

We consider our research to be a first step in understanding effects of wind energy development on birds in the PPR. Additional wind farms that are being built in the region have the potential to reduce landscape-level carrying capacity for migratory birds in the PPR (Loesch *et al.* 2013), but also provide additional opportunities and replicates for study. As the effects of wind energy development on birds in the PPR are better understood, the relative and cumulative effects of wind energy development and other stressors, such as urbanization and continued conversion of wetlands and grasslands to agricultural fields, can more effectively be compared. Understanding the effects of different stressors on wildlife communities will enable conservationists to weigh the relative effects of these stressors, thus ensuring maximum benefits from conservation efforts.

ACKNOWLEDGMENTS

We thank C. Billat, D. Brandt, S. Cunningham, M. Felin, J. Foth A. Geisler, T. Gue, B. Hall, P. Hunter, J. Korkos, D. LaRochelle, M. McClanahan, T. Mitacek, A. Northrup, D. Oates, K. Peterson, M. Rake, J. Rehar, and J. Weiler for conducting surveys. We also thank the many landowners who granted access to their properties. Support for this study was provided by the North Dakota Game and Fish Department, NextEra Energy, Ducks Unlimited, and the U.S. Fish and Wildlife Service. An earlier draft of this manuscript was greatly improved by comments by K. E. Doherty, W. A. Meeks, and two anonymous reviewers. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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