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Contributed Paper

Effects of wind-energy facilities on breeding grassland bird distributions

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Abstract: *The contribution of renewable energy to meet worldwide demand continues to grow. Wind energy is one of the fastest growing renewable sectors, but new wind facilities are often placed in prime wildlife habitat. Long-term studies that incorporate a rigorous statistical design to evaluate the effects of wind facilities on wildlife are rare. We conducted a before-after-control-impact (BACI) assessment to determine if wind facilities placed in native mixed-grass prairies displaced breeding grassland birds. During 2003–2012, we monitored changes in bird density in 3 study areas in North Dakota and South Dakota (U.S.A.). We examined whether displacement or attraction occurred 1 year after construction (immediate effect) and the average displacement or attraction 2–5 years after construction (delayed effect). We tested for these effects overall and within distance bands of 100, 200, 300, and >300 m from turbines. We observed displacement for 7 of 9 species. One species was unaffected by wind facilities and one species exhibited attraction. Displacement and attraction generally occurred within 100 m and often extended up to 300 m. In a few instances, displacement extended beyond 300 m. Displacement and attraction occurred 1 year after construction and persisted at least 5 years. Our research provides a framework for applying a BACI design to displacement studies and highlights the erroneous conclusions that can be made without the benefit of adopting such a design. More broadly, species-specific behaviors can be used to inform management decisions about turbine placement and the potential impact to individual species. Additionally, the avoidance distance metrics we estimated can facilitate future development of models evaluating impacts of wind facilities under differing land-use scenarios.*

Keywords: avoidance, before-after-control-impact design, climate change, displacement, renewable energy, upland birds, wind turbine

Efectos de las Instalaciones de Energía Eólica sobre la Distribución de las Aves de Pastizales en Época Reproductiva

Resumen: *La contribución de la energía renovable para cumplir con las demandas mundiales sigue creciendo. La energía eólica es uno de los sectores renovables con mayor crecimiento, pero continuamente se colocan nuevas instalaciones eólicas en los principales hábitats de fauna silvestre. Los estudios a largo plazo que incorporan un diseño estadístico riguroso para evaluar los efectos de estas instalaciones sobre la fauna son escasos. Realizamos una evaluación de control de impacto de antes y después (CIAD) para determinar si las instalaciones eólicas colocadas en praderas de pastos mixtos nativos desplazaron a las aves de pastizales en época reproductiva. Durante el periodo 2003-2012, monitoreamos los cambios en la densidad de aves en tres áreas de estudio en Dakota del Norte y del Sur (E.U.A). Examinamos si había ocurrido desplazamiento o atracción un año después de la construcción (efecto inmediato) y también el promedio de desplazamiento o atracción 2-5 años después de la construcción (efecto retardado). Analizamos estos efectos en general y dentro de franjas de distancia de 100, 200, 300 y >300 m de las turbinas. Observamos desplazamiento en siete de las nueve especies. Una especie no fue afectada por las instalaciones eólicas y una especie mostró atracción. El desplazamiento y la atracción ocurrieron generalmente dentro de los 100 m y frecuentemente se extendieron hasta los 300 m. En algunos casos, el desplazamiento se extendió más allá de los 300 m. El desplazamiento y la atracción ocurrieron un año después de la construcción y continuaron durante por lo*

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menos cinco años. Nuestra investigación proporciona un marco de trabajo para aplicar el diseño CIAD a los estudios de desplazamiento y resalta las conclusiones erróneas que pueden hacerse sin el beneficio de adoptar dicho diseño. En términos más generales, los comportamientos específicos de especie pueden usarse para informar a las decisiones de manejo sobre la colocación de turbinas y el impacto potencial para las especies individuales. Además, las medidas de distancia de evitación que estimamos pueden facilitar el desarrollo futuro de los modelos de evaluación de impacto de las instalaciones eólicas bajo escenarios diferentes de uso de suelo.

Palabras Clave: aves de tierras altas, cambio climático, desplazamiento, diseño de control de impacto de antes y después, energía renovable, evitación, turbina de viento

Introduction

Renewable energies will help meet energy demands while reducing carbon emissions and providing energy security (IPCC 2012). Globally, the contribution of wind power to energy demand is anticipated to be 20% by 2050 (IPCC 2011). The United States became the global leader in new wind capacity in 2012, representing 29% of global installed capacity due to sustained growth throughout the interior of the country (i.e., within the Great Plains) (USDOE 2013).

The Great Plains also supports the last remaining expanses of native temperate grasslands in North America (Stephens et al. 2008; Rashford et al. 2011; Doherty et al. 2013); thus, the increase in habitat loss and fragmentation associated with wind development has adverse impacts on wildlife (McDonald et al. 2009; Kiesecker et al. 2011). Wildlife are directly affected by wind facilities via collision mortality (Johnston et al. 2013; Péron et al. 2013) and indirectly affected through avoidance of turbines and related infrastructure (i.e., displacement [Drewitt & Langston 2006]). Per unit energy, wind energy has a larger terrestrial footprint than other forms of energy production (Kiesecker et al. 2011). Although the ground disturbance per turbine is relatively small (about 1.2 ha), other disturbances such as construction and operation of the facility, vehicular traffic, maintenance visits, turbine noise and movement, and changes to predator activity contribute to the impact of wind facilities (Arnett et al. 2007; Helldin et al. 2012; Gue et al. 2013).

Although displacement research on an international level has been ongoing for about 2 decades, Drewitt and Langston (2006) note that few displacement studies are conclusive, often because of the minimal magnitude of the effect, poor precision of estimates, and lack of study design allowing for strong inference assessments. For observational studies, the before-after-control (reference)-impact (BACI) design is considered the “optimal impact study design” (Green 1979) as exemplified by Irons et al. (2000) and Smucker et al. (2005) and is the preferred method to determine displacement of wildlife from wind facilities (Strickland et al. 2011). However, of the numerous displacement studies, most are short-term, are not BACI designs, and occur on only one wind facility (Supporting Information). Effective conservation strategies that reduce negative effects of wind facilities to sensitive wildlife require information from well-designed studies (Strickland et al. 2011). Preferred characteristics include a multi-species approach to understand prevalence of displacement behavior, a long-term perspective, and a design that allows for strong inference (e.g., BACI) (Stewart et al. 2007; Strickland et al. 2011). Pearce-Higgins et al. (2012) provide an example of a well-implemented wind-specific BACI design.

Our overall goal was to determine if wind facilities influenced distribution of sensitive and declining grassland-nesting birds (Supporting Information). Specifically, our objectives were to assess immediate and delayed effects of the placement of wind facilities. We assessed potential changes in bird distribution overall and at varying distances from wind turbines. We implemented a BACI design that incorporated multiple years, replicated impact and reference sites within 3 facilities, and 9 species, making our study one of a few that used a rigorous optimal impact assessment design (Supporting Information). Thus, our research provides a strong foundation for building a more refined understanding of how wind facilities influence grassland bird distribution temporally and spatially.

Methods

Collaboration with wind companies provided locations of impending construction within North Dakota and South Dakota (U.S.A.). We selected wind facilities situated within expanses of native grassland and in landscapes characterized by morainic rolling plains interspersed with wetlands, mixed-grass prairie pastures, and few planted grasslands, hayfields, or cropland (Bluemle 1991). Three wind facilities (hereafter, study areas) met our criteria: NextEra Energy’s (NEE) South Dakota Wind Energy Center (SD), Highmore, South Dakota; Acciona’s Tatanka Wind Farm (TAT), Forbes, North Dakota; and NEE’s Oliver Wind Energy Center (OL), Oliver County, North Dakota (Table 1, Fig. 1). The study areas differed in several anthropogenic features (Table 1). The SD site was within the most heterogeneous landscape and had

Table 1. Summary characteristics of 3 wind facilities in North Dakota and South Dakota (U.S.A.) for which field survey data were collected for the study on effects of wind facilities on grassland birds.

Facility	*Pre-treatment year*	*Post-treatment years*	*No. treatment plots (size range, ha)*	*No. reference plots (size range, ha)*	*Row crop area (%)*	*Total area (km^2)*	*Roads* (km/km^2)*	*No. of turbines/km^2*
NextEra Energy SD Wind Energy Center	2003	2004-6, 8, 10, 12	5 (55-158)	3 (34-46)	20	34.5	0.6	0.8
Acciona Tatanka Wind Farm	2007	2009-10, 12	2 (43-441)	4 (11-109)	0	31.6	0.4	0.6
NextEra Energy Oliver Wind Energy Center	2006	2007, 9, 11	2 (122-260)	2 (37-274)	13	24.3	0.7	0.7

* *Includes paved, gravel, and turbine roads.*

the highest percentage of lands under row-crop cultivation and the second most kilometers of roads, whereas TAT was within the least heterogeneous landscape of primarily grasslands. During the years we were on each study area (Table 1), TAT and OL had above-average precipitation and SD received below-average precipitation (NOAA 2015).

Because of the short time frame between facility site selection and construction, we conducted only 1 year of pre-treatment surveys. Within a study area, we selected turbine strings (i.e., turbines connected by a road) that would be placed in grazed mixed-grass prairie. We defined a turbine site as the area encompassing the turbines and extending 0.8 km on all sides of the turbine string, as long as the land and land cover remained grazed mixed-grass prairie. Reference sites were selected based on proximity to paired wind facilities (within 3.2 km) and similarity of land use and cover, topography, and elevation to turbine sites. Measures of vegetation structure were similar between turbine and reference sites and therefore were excluded as a possible confounding effect (Supporting Information).

We conducted total-area avian surveys (Stewart & Kantrud 1972) within a grid system (Shaffer & Thiele 2013) 2 times annually from late May to early July, from 0.5 hours after sunrise to 1100, on days of good visibility and good aural detectability (i.e., days with little or no precipitation and low to moderate winds [<40 km/hour]). We established avian survey plots with grids of fiberglass posts arranged in parallel lines spaced 200 m apart. Transect lines were established 100 m apart perpendicular to the grid lines. Observers recorded all birds seen and heard within 50 m of transects established within the grids. Genders of non-dimorphic species were determined by the presence or absence of song. For 9 grassland bird species (Table 2; Supporting Information), we computed the number of breeding pairs for each site (turbine and reference), survey, and year combination. A male and female observed together was considered a breeding pair; a male or female observed alone was also considered a breeding pair. The number of pairs was divided by the suitable breeding area in each turbine and reference site, as determined by breeding habitat for each species (Supporting Information), and multiplied by 100 to determine density per 100 ha (Supporting Information). We used the maximum of the biannual survey densities for each species-site-year combination to reflect peak breeding density.

We employed a BACI design (McDonald et al. 2000) to examine turbine effects on bird density. We used data from surveys conducted prior to and after turbine construction at turbine and reference sites. Using 2 different treatment specifications, we conducted analyses separately for each species and study area. The first analysis consisted of 2 treatment levels, turbine sites and reference sites, to assess overall effects of turbines on

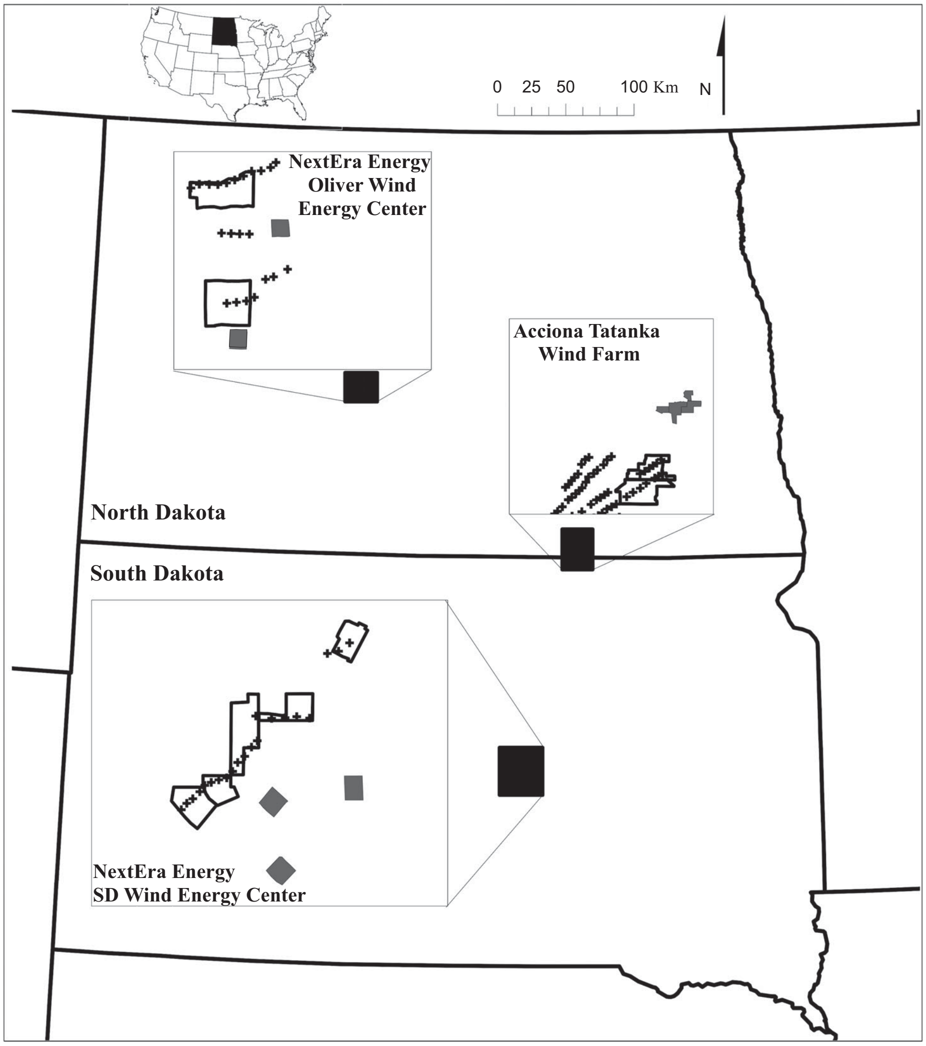

Figure 1. Map of studied wind-energy facilities in North Dakota and South Dakota (U.S.A.) (white polygons, turbine treatment sites; gray polygons, reference sites; plus symbol, turbine locations).

densities of breeding birds. For the second analysis, we divided turbine sites into 4 100-m distance bands from turbines (0-100 m, 100–200 m, 200–300 m, and >300 m), for a total of 5 treatment levels including the reference sites. We used repeated measures analysis of variance (RMANOVA) in SAS PROC MIXED (SAS Institute 2012) to assess effects of treatment and year on bird density (Verbeke & Molenberghs 2000). In the first treatment specification, year was the repeated measure and site within treatment was the experimental unit sampled each year. For the second treatment specification, site was included as a random block, year was the repeated measure, and site-by-treatment combinations were the experimental units sampled yearly. We accounted for autocorrelation among years by running a correlated error model (auto-regressive) (Littell et al. 2006).

Using the BACI design, we conducted planned contrasts among treatment means (Milliken & Johnson 2009) to estimate turbine effects. The contrasts tested whether average density for first post-treatment year minus average density for pre-treatment year was equal between turbine and reference treatments (H_0: $[density_{turbine,1yr\text{-}post} - density_{turbine,pre}] - [density_{reference,1yr\text{-}post} - density_{reference,pre}] = 0$) and if average 2- to 5-year post-treatment mean density (i.e., mean density for the 2 to 5 calendar years following turbine construction) minus average density for pre-treatment year was equal between turbine and reference treatments (H_0: $[density_{turbine,2\text{-}5yr\text{-}post} - density_{turbine,pre}] - [density_{reference,2\text{-}5yr\text{-}post} - density_{reference,pre}] = 0$). The former contrast tested for an immediate turbine effect, whereas the latter contrast tested for a delayed effect. Immediate effects were not testable at TAT because 1-year post-treatment data were not collected. For the delayed effects, the span of years in which surveys were conducted varied among study areas, and surveys were not done every year within that time span. To achieve a consistent time frame that could be assessed at all 3 study areas, we used the average of 2–5 years post-treatment to assess the delayed effect, rather than assessing effects for each post-treatment year separately.

Table 2. Test statistics from the contrasts comparing changes in bird density per 100 ha between reference and turbine sites from pre-treatment year to 1 year post-treatment in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (NEE Oliver Wind Energy Center [OL]), (U.S.A.) 2003–2012.*

Location and distance from turbines (m)	*Grasshopper Sparrow*	*Western Meadowlark*	*Bobolink*	*Upland Sandpiper*	*Killdeer*	*Savannah Sparrow*	*Clay-colored Sparrow*	*Chestnut-collared Longspur*	*Vesper Sparrow*
SD									
0-100	$t_{76} = -1.84$, $p = 0.07$	$t_{77} = -3.90$, $p<0.01$	$t_{57} = -1.25$, $p = 0.22$	$t_{83} = -1.33$, $p = 0.19$	$t_{92} = 3.21$, $p<0.01$			$t_{69} = 0.62$, $p = 0.54$	
100–200	$t_{76} = -0.31$, $p = 0.76$	$t_{77} = -0.73$, $p = 0.47$	$t_{57} = -0.26$, $p = 0.80$	$t_{83} = 0.38$, $p = 0.70$	$t_{92} = 0.70$, $p = 0.49$			$t_{69} = -1.09$, $p = 0.28$	
200–300	$t_{76} = -0.25$, $p = 0.81$	$t_{77} = -0.67$, $p = 0.50$	$t_{57} = -1.28$, $p = 0.20$	$t_{83} = -1.63$, $p = 0.11$	$t_{92} = 1.60$, $p = 0.11$			$t_{69} = -0.81$, $p = 0.42$	
>300	$t_{76} = 0.21$, $p = 0.83$	$t_{77} = -1.23$, $p = 0.22$	$t_{57} = -1.65$, $p = 0.10$	$t_{83} = -1.07$, $p = 0.29$	$t_{92} = 0.88$, $p = 0.38$			$t_{69} = 1.10$, $p = 0.27$	
Overall	$t_{29} = -0.11$, $p = 0.91$	$t_{20} = -2.27$, $p = 0.03$	$t_{36} = -1.71$, $p = 0.10$	$t_{32} = -1.23$, $p = 0.23$	$t_{25} = 2.01$, $p = 0.06$			$t_{39} = 0.50$, $p = 0.62$	
OL									
0–100	$t_{20} = -1.80$, $p = 0.09$	$t_{14} = 0.46$, $p = 0.65$	$t_{18} = -1.21$, $p = 0.24$	$t_{18} = -2.39$, $p = 0.03$	$t_{27} = 2.85$, $p = 0.01$	$t_{21} = -1.43$, $p = 0.17$	$t_{22} = -1.79$, $p = 0.09$		$t_{20} = 0.58$, $p = 0.57$
100–200	$t_{20} = -0.71$, $p = 0.49$	$t_{14} = 1.14$, $p = 0.27$	$t_{18} = -0.47$, $p = 0.64$	$t_{18} = 1.00$, $p = 0.33$	$t_{27} = 0.71$, $p = 0.48$	$t_{21} = -2.45$, $p = 0.02$	$t_{22} = -1.77$, $p = 0.09$		$t_{20} = 0.21$, $p = 0.83$
200–300	$t_{20} = 0.09$, $p = 0.93$	$t_{14} = 1.94$, $p = 0.07$	$t_{18} = 2.14$, $p = 0.05$	$t_{18} = -0.23$, $p = 0.82$	$t_{27} = -0.33$, $p = 0.74$	$t_{21} = -3.41$, $p<0.01$	$t_{22} = -0.76$, $p = 0.46$		$t_{20} = -1.64$, $p = 0.12$
>300	$t_{20} = 1.14$, $p = 0.27$	$t_{14} = 1.45$, $p = 0.17$	$t_{18} = 1.93$, $p = 0.07$	$t_{18} = -0.17$, $p = 0.87$	$t_{27} = -0.15$, $p = 0.88$	$t_{21} = -0.50$, $p = 0.62$	$t_{22} = -1.62$, $p = 0.12$		$t_{20} = 0.29$, $p = 0.77$
Overall	$t_{9} = 0.78$, $p = 0.46$	$t_{8} = 1.17$, $p = 0.28$	$t_{9} = 1.40$, $p = 0.20$	$t_{9} = -0.02$, $p = 0.99$	$t_{8} = -0.03$, $p = 0.98$	$t_{12} = -1.03$, $p = 0.32$	$t_{10} = -2.07$, $p = 0.06$		$t_{12} = 0.22$, $p = 0.83$

Cells with no values indicate an analysis for that species was not conducted because of low number of observations.

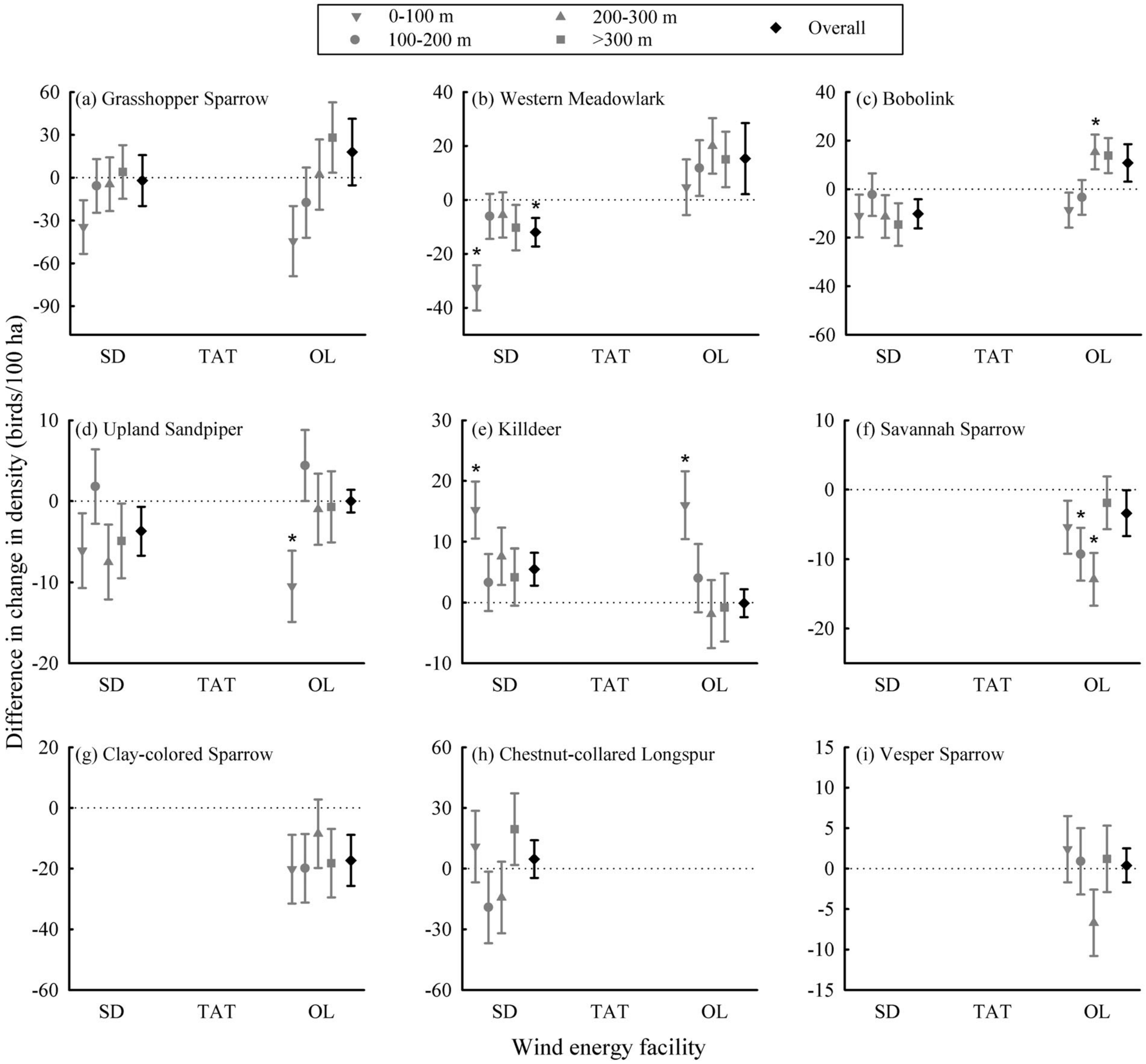

Figure 2. Difference in change in bird density/100 ha between reference and wind turbine sites from pre-treatment year to 1 year post-treatment (immediate effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy Center [OL]), 2003–2012 for (a) Grasshopper Sparrow, (b) Western Meadowlark, (c) Bobolink, (d) Upland Sandpiper, (e) Killdeer, (f) Savannah Sparrow, (g) Clay-colored Sparrow, (h) Chestnut-collared Longspur, and (i) Vesper Sparrow (difference = [$density_{turbine,1yr\text{-}post}$ – $density_{turbine,pre}$] – [$density_{reference,1yr\text{-}post}$ – $density_{reference,pre}$]; error bars, SE; value >0, positive effect; value <0, negative effect; asterisk, significant [$\alpha = 0.05$] difference).

One strength of a BACI design is that it allows researchers to assume that any naturally occurring changes occur at both the impact and control sites; thus, any changes observed at the impact sites can be attributed to the impact (Manly 2001). Therefore, we assumed annual variation in bird populations and weather effects were the same for turbine and reference sites within a study area. Vegetation structure also was similar between sites (Supporting Information). In addition, turbine and reference sites were spatially replicated within wind facilities; this allowed us to account for variability among sites and to test if, on average, changes in density differed between turbine and reference sites. Therefore, any immediate or delayed effects were due to the construction of the wind facility.

Results

Immediate Effects

We detected statistically significant immediate (1-year) displacement behavior for 3 of 9 species (Western

Table 3. Test statistics from the contrasts comparing changes in bird density/100 ha between reference and turbine sites from pre-treatment year to 2-5-years post-treatment in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy Center [OL]), (U.S.A.), 2003–2012.*

Location and distance from turbines (m)	*Grasshopper Sparrow*	*Western Meadowlark*	*Bobolink*	*Upland Sandpiper*	*Killdeer*	*Savannah Sparrow*	*Clay-colored Sparrow*	*Chestnut-collared Longspur*	*Vesper Sparrow*
SD									
0-100	$t_{142} = -3.94$, $p<0.01$	$t_{145} = -3.86$, $p<0.01$	$t_{110} = -1.10$, $p = 0.27$	$t_{145} = -1.31$, $p = 0.19$	$t_{149} = 0.97$, $p = 0.33$			$t_{140} = -2.27$, $p = 0.02$	
100–200	$t_{142} = -1.94$, $p = 0.05$	$t_{145} = -1.34$, $p = 0.18$	$t_{110} = 0.41$, $p = 0.69$	$t_{145} = -1.32$, $p = 0.19$	$t_{149} = -0.56$, $p = 0.58$			$t_{140} = -2.52$, $p = 0.01$	
200–300	$t_{142} = -1.54$, $p = 0.13$	$t_{145} = -1.97$, $p = 0.05$	$t_{110} = -0.96$, $p = 0.34$	$t_{145} = -1.92$, $p = 0.06$	$t_{149} = -0.76$, $p = 0.45$			$t_{140} = -2.54$, $p = 0.01$	
>300	$t_{142} = -1.66$, $p = 0.10$	$t_{145} = -2.32$, $p = 0.02$	$t_{110} = -0.91$, $p = 0.37$	$t_{145} = -2.82$, $p = 0.01$	$t_{149} = 0.28$, $p = 0.78$			$t_{140} = -1.10$, $p = 0.27$	
Overall	$t_{54} = -1.99$, $p = 0.05$	$t_{52} = -4.12$, $p<0.01$	$t_{54} = -0.36$, $p = 0.72$	$t_{54} = -2.79$, $p = 0.01$	$t_{54} = 0.07$, $p = 0.94$			$t_{55} = -2.19$, $p = 0.03$	
TAT									
0-100	$t_{38} = -3.49$, $p<0.01$	$t_{41} = 0.16$, $p = 0.87$	$t_{33} = -5.34$, $p<0.01$	$t_{39} = 0.11$, $p = 0.91$	$t_{43} = 1.74$, $p = 0.09$	$t_{31} = -0.94$, $p = 0.35$	$t_{39} = -3.57$, $p<0.01$		$t_{47} = 1.18$, $p = 0.24$
100–200	$t_{38} = -2.54$, $p = 0.02$	$t_{41} = -0.01$, $p = 0.99$	$t_{33} = -5.69$, $p<0.01$	$t_{39} = -0.28$, $p = 0.78$	$t_{43} = 0.80$, $p = 0.43$	$t_{31} = -2.78$, $p = 0.01$	$t_{39} = -3.52$, $p<0.01$		$t_{47} = -0.61$, $p = 0.54$
200–300	$t_{38} = -2.43$, $p = 0.02$	$t_{41} = -0.21$, $p = 0.84$	$t_{33} = -6.85$, $p<0.01$	$t_{39} = -0.48$, $p = 0.63$	$t_{43} = 1.73$, $p = 0.09$	$t_{31} = -2.53$, $p = 0.02$	$t_{39} = -1.83$, $p = 0.08$		$t_{47} = -0.15$, $p = 0.88$
>300	$t_{38} = -1.75$, $p = 0.09$	$t_{41} = 0.13$, $p = 0.90$	$t_{33} = -4.78$, $p<0.01$	$t_{39} = -0.32$, $p = 0.75$	$t_{43} = 0.52$, $p = 0.60$	$t_{31} = -0.52$, $p = 0.61$	$t_{39} = -1.55$, $p = 0.13$		$t_{47} = 0.84$, $p = 0.41$
Overall	$t_{23} = -1.67$, $p = 0.11$	$t_{23} = 0.19$, $p = 0.85$	$t_{23} = -4.55$, $p<0.01$	$t_{23} = -0.15$, $p = 0.88$	$t_{11} = 1.51$, $p = 0.16$	$t_{22} = -0.93$, $p = 0.36$	$t_{20} = -1.37$, $p = 0.18$		$t_{22} = 0.37$, $p = 0.71$
OL									
0-100	$t_{36} = -3.62$, $p<0.01$	$t_{33} = -0.79$, $p = 0.43$	$t_{39} = -2.75$, $p = 0.01$	$t_{35} = -2.90$, $p = 0.01$	$t_{37} = 0.70$, $p = 0.49$	$t_{34} = -0.41$, $p = 0.68$	$t_{36} = -1.62$, $p = 0.11$		$t_{33} = 1.97$, $p = 0.06$
100–200	$t_{36} = -3.41$, $p<0.01$	$t_{33} = -1.41$, $p = 0.17$	$t_{39} = -2.31$, $p = 0.03$	$t_{35} = 0.15$, $p = 0.88$	$t_{37} = 0.42$, $p = 0.68$	$t_{34} = -1.32$, $p = 0.20$	$t_{36} = -1.61$, $p = 0.12$		$t_{33} = -0.52$, $p = 0.61$
200–300	$t_{36} = -3.35$, $p<0.01$	$t_{33} = -0.05$, $p = 0.96$	$t_{39} = 0.33$, $p = 0.74$	$t_{35} = -0.99$, $p = 0.33$	$t_{37} = -0.14$, $p = 0.89$	$t_{34} = -2.88$, $p = 0.01$	$t_{36} = -1.68$, $p = 0.10$		$t_{33} = -1.40$, $p = 0.17$
>300	$t_{36} = -0.98$, $p = 0.33$	$t_{33} = -0.56$, $p = 0.58$	$t_{39} = 0.01$, $p = 0.99$	$t_{35} = -0.58$, $p = 0.57$	$t_{37} = -0.72$, $p = 0.47$	$t_{34} = -0.28$, $p = 0.78$	$t_{36} = -2.09$, $p = 0.04$		$t_{33} = 0.25$, $p = 0.80$
Overall	$t_{12} = -1.82$, $p = 0.09$	$t_{16} = -0.53$, $p = 0.60$	$t_{16} = -0.34$, $p = 0.74$	$t_{16} = -1.01$, $p = 0.33$	$t_{7} = -1.34$, $p = 0.22$	$t_{16} = -0.65$, $p = 0.53$	$t_{16} = -1.79$, $p = 0.09$		$t_{16} = -0.09$, $p = 0.93$

**Cells with no values indicate an analysis for that species was not conducted because of low number of observations.*

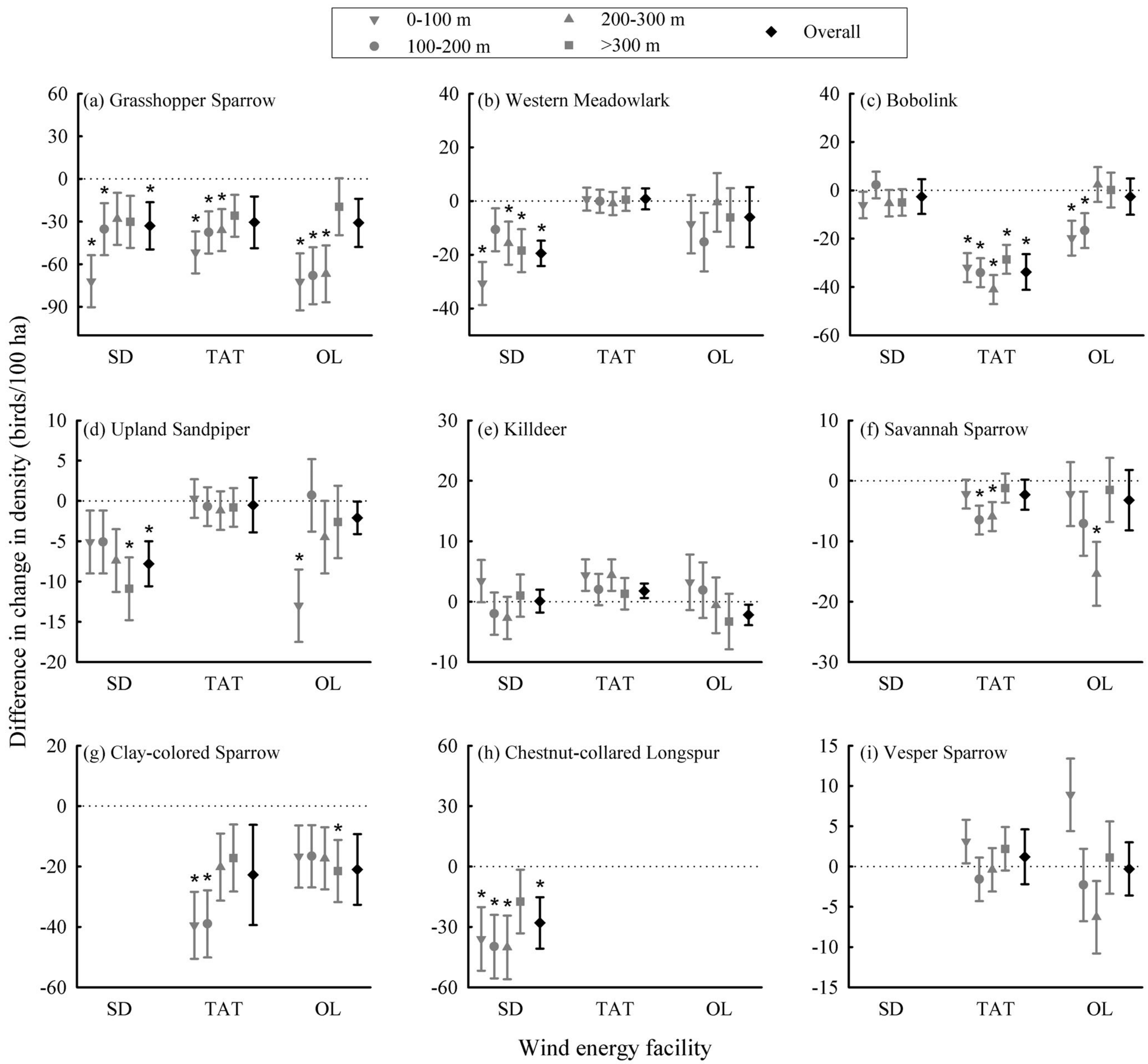

Figure 3. Difference in change in bird density/100 ha between reference and wind turbine site from pre-treatment year to 2–5 years post-treatment (delayed effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy Center [OL]), 2003–2012 for (a) Grasshopper Sparrow, (b) Western Meadowlark, (c) Bobolink, (d) Upland Sandpiper, (e) Killdeer, (f) Savannah Sparrow, (g) Clay-colored Sparrow, (h) Chestnut-collared Longspur, and (i) Vesper Sparrow (difference = $[density_{turbine,2\text{-}5yr\text{-}post} - density_{turbine,pre}] - [density_{reference,2\text{-}5yr\text{-}post} - density_{reference,pre}]$; error bars, SE; value >0, positive effect; value <0, negative effect; asterisk, significant [$\alpha = 0.05$] difference).

Meadowlark [*Sturnella neglecta*], Upland Sandpiper [*Bartramia longicauda*], and Savannah Sparrow [*Passerculus sandwichensis*]) and attraction for 2 species (Killdeer [*Charadrius vociferous*] and Bobolink [*Dolichonyx oryzivorus*]) (Table 2). For Western Meadowlark, displacement was detected at SD; effects were apparent overall and within 100 m (Fig. 2b). For Upland Sandpiper, displacement was detected at OL, but only within 100 m (Fig. 2d). Change in density of Savannah Sparrow was lower 100–300 m from turbines than at reference sites at OL, the one study area in which immediate effects could be determined for this species (Fig. 2f). Killdeer expressed attraction within 100 m of turbines at both study areas 1 year post-construction (Fig. 2e, Table 2). Bobolink exhibited a positive difference 200–300 m at OL (Fig. 2c, Table 2).

Wind facilities had no significant immediate effect on Grasshopper Sparrow (*Ammodramus savannarum*), Clay-colored Sparrow (*Spizella pallida*), or Chestnut-collared Longspur (*Calcarius ornatus*) (Table 2). However, the magnitude of differences (≥20 birds/100 ha) between turbine sites and reference sites suggested these species may have exhibited immediate displacement (Fig. 2a, 2g, 2h). Vesper Sparrow (*Pooecetes gramineus*) appeared unaffected by wind facilities (Fig. 2i).

Delayed Effects

We detected significant displacement behavior beyond 1 year for 7 species (Table 3). For Grasshopper Sparrow, we detected displacement overall at SD, within 200 m at all 3 study areas, and within 200–300 m at TAT and OL (Fig. 3a). Bobolink, Upland Sandpiper, Savannah Sparrow, and Clay-colored Sparrow exhibited displacement at 2 study areas each (Fig. 3c, 3d, 3f, 3g). Displacement occurred overall and at all distances for Bobolink at TAT, but only within 200 m at OL. Upland Sandpiper exhibited displacement overall and beyond 300 m at SD, but only within 100 m at OL. Displacement was observed within 200–300 m for Savannah Sparrow at both TAT and OL and within 100–200 m at TAT. For Clay-colored Sparrow, significant displacement occurred within 200 m at TAT and >300 m at OL. For Western Meadowlark and Chestnut-collared Longspur, displacement was detected at SD only. Effects were apparent overall, within 100 m, and beyond 200 m for Western Meadowlark (Fig. 3b) and overall and within 300 m for Chestnut-collared Longspur (Fig. 3h). Killdeer and Vesper Sparrow showed no delayed effects (Fig. 3e, 3i).

Discussion

The preferred design for testing impacts of energy infrastructure on wildlife is the BACI design (Evans 2008; Strickland et al. 2011), but examples are rare (Supporting Information). Our work provides a framework for applying a BACI design to behavioral studies and highlights the erroneous conclusions that can be made when the BACI approach is not used. If we had data from only impact sites (i.e., no reference sites) or had only post-treatment data (i.e., no pre-treatment monitoring) and thus not been able to use a BACI design, our conclusions would have been different. Obtaining data from impact and reference sites allowed us to discern changes in avian densities due to wind facilities as opposed to naturally occurring changes. For example, Grasshopper Sparrow at SD showed a large change in density on the turbine sites (i.e., a decrease of more than 60 birds/100 ha) from the pre-treatment year to the first year post-treatment (Supporting Information). Without reference sites, we may have interpreted this decrease in density to be due to turbine operation. However, we observed a similar change in density at reference sites, indicating the change on the turbine sites was probably due not to turbine operation but rather to normal annual variation in avian density. Pre-treatment data were used to account for differences among the turbine and reference sites prior to turbine construction, which allowed us to attribute post-treatment differences to turbine operation. For example, Grasshopper Sparrows at SD had higher average density for reference sites (60.1 birds/100 ha) than for turbine sites (38.3 birds/100 ha) in the first post-construction year (Supporting Information). Without pre-treatment data, this difference might have been interpreted as a turbine effect. However, pre-treatment data provided evidence of existing site differences of the same magnitude (Supporting Information) and therefore indicates there was no turbine effect.

By collecting data the year following construction and beyond 1 year post-construction, we were able to assess whether species exhibited immediate effects, delayed effects, or sustained effects. Because our turbine and reference sites were near one another and were similar with respect to landscape composition, vegetation, topography, and weather, the BACI design allowed us to assume that any naturally occurring changes happen at both the turbine and reference sites and therefore can be ruled out as alternative explanations. In addition, spatial replication of turbine and reference sites within study areas accounts for inherent variability among sites (Underwood 1992). Thus, any effects we observed were attributed to the operation of the wind facility.

Immediate effects were manifested by displacement or attraction the year following turbine construction. Birds returning in the spring following construction would encounter an altered landscape and would need to decide whether to settle near a wind facility or move elsewhere. In our study areas, Vesper Sparrows and Killdeer showed a high degree of tolerance to newly constructed wind facilities. Vesper Sparrows are often the first species to occupy disturbed areas (Jones & Cornely 2002); therefore, lack of displacement is not surprising given this life-history characteristic. Moreover, Johnson et al. (2000) reported attraction of Vesper Sparrows to turbines 1 year post-construction at grassland sites in Minnesota (U.S.A.). Killdeer prefer gravel substrates for nesting, and roadsides are preferred habitat (Jackson & Jackson 2000). Our finding that Killdeer density increased nearest to newly constructed turbines likely reflects similar habitat selection. Similarly, Johnson et al. (2000) reported higher than expected use of turbine plots in Minnesota by Horned Larks (*Eremophila alpestris*), another species that prefers disturbed areas. However, Erickson et al. (2004) found no evidence of attraction (or displacement) for this species in Oregon (U.S.A.).

Some species in our study areas did not exhibit immediate effects, yet we observed displacement in years beyond the first year post-construction (i.e., delayed effects). Species exhibiting breeding site fidelity might be more inclined to show delayed effects than immediate effects. Individuals will return to a turbine site 1 year post-construction due to site fidelity, but they may not return in subsequent years because of intolerance of the wind facility. In addition, new individuals may be unwilling to settle near turbines. We detected delayed displacement for Grasshopper Sparrow, Western Meadowlark, Bobolink, Upland Sandpiper, Clay-colored Sparrow, and Chestnut-collared Longspur, all of which exhibit breeding site fidelity (Hill & Gould 1997; Jones et al. 2007). Likewise, Johnson et al. (2000) reported delayed effects for Grasshopper Sparrow, Bobolink, and Savannah Sparrow, which also shows breeding site fidelity (Fajardo et al. 2009). On a Scottish wind facility 3 years post-construction, Douglas et al. (2011) detected delayed effects for 2 upland species, Red Grouse (*Lagopus lagopus scotica*) and European Golden Plover (*Pluvialis apricaria*); these 2 species are also site faithful (Jenkins et al. 1963; Parr 1980).

We considered a species to be exhibiting a sustained effect if displacement continued from 1 year post-construction into 2–5 years post-construction. In our study, sustained displacement usually occurred within 100 m (e.g., Western Meadowlark at SD and Upland Sandpiper at OL). Few other researchers have examined sustained effects. Pearce-Higgins et al. (2012) detected positive long-term effects in the United Kingdom for 2 upland species and negative effects for 2 waterbird species.

Consistency of behavioral responses to wind facilities varied across the 9 species of grassland nesting birds we monitored. Grasshopper Sparrows and Clay-colored Sparrows exhibited the most consistent results across study areas. The Grasshopper Sparrow is an area- and edge-sensitive species (Grant et al. 2004; Ribic et al. 2009) for which amount of grassland in the surrounding landscape is important (Berman 2007; Greer 2009). Wind facilities appear to be an additional landscape change not tolerated by Grasshopper Sparrows, and the construction of additional wind facilities throughout native grasslands could be detrimental to the species. Clay-colored Sparrows prefer grasslands intermixed with shrubs and woody edges (Grant & Knapton 2012). We speculate that removal of woody vegetation during construction of roads and turbines reduced breeding habitat for this species.

Bobolinks, Western Meadowlarks, Upland Sandpipers, and Savannah Sparrows exhibited inconsistent displacement behavior across study areas. Because we were not always present on study areas in the same years, we suspect inconsistencies resulted from habitat differences specific to study area that may have been influenced by variable precipitation patterns. The interaction of habitat conditions and species-specific life-history strategies may have influenced behavior. For example, Bobolinks exhibited strong displacement at TAT, which was the largest wind facility with the most intact grasslands and the highest precipitation. Densities of Bobolinks also were greatest at TAT (Supporting Information); hence, density dependent effects may arise at these higher densities and may result from habitat loss (both grassland and wetland) with construction of turbines. As a result of high precipitation, grasslands at this site were interspersed with many small wetlands containing nesting pairs of Red-winged Blackbirds (*Agelaius phoeniceus*). Red-winged Blackbirds and Bobolinks are antagonistic. Red-winged Blackbirds may displace Bobolinks from perches, and Bobolinks appear to avoid nesting near active blackbird nests (Martin & Gavin 1995). Thus, displacement of Bobolinks at TAT could have been more evident because of intra- or interspecific competition.

For other species, cumulative effects of wind facilities and other landscape changes might be the cause of inconsistent results. Western Meadowlarks are a gregarious species not reported to be sensitive to habitat area or habitat edges (Johnson & Igl 2001), and some degree of anthropogenic activity appears acceptable to them. However, we speculate that the degree of anthropogenic disturbance at SD surpassed the species' threshold of tolerance to human activity. The sustained displacement observed at SD could be the species' response to the additive stressors of wind-facility operation and recent land conversion from grassland to agricultural fields (Wright & Wimberly 2013). Increasing urbanization had a strong negative effect on the density of a congeneric species, Eastern Meadowlark (*Sturnella magna*), in grasslands (McLaughlin et al. 2014). Conversely, TAT, where no displacement effects were observed for Western Meadowlarks, has undergone little land conversion, was composed of 92% perennial grasslands (Loesch et al. 2013), and was located in a remote area rarely traversed by humans other than personnel associated with the wind facility. Upland Sandpiper displayed the most inconsistent results and a similar pattern as Western Meadowlark. The species is highly sensitive to habitat fragmentation (Ribic et al. 2009), and the strongest displacement effects occurred on the most fragmented study areas, SD and OL. No displacement was detected on the least fragmented study area. As with Western Meadowlarks, Upland Sandpipers may have reached a threshold beyond which additional landscape disturbance could not be tolerated and displacement behavior became apparent.

Our results for displacement distances for Grasshopper Sparrow (300 m), Bobolink (>300 m), Western Meadowlark (>300 m), Upland Sandpiper (100 m), Clay-colored Sparrow (200 m), Savannah Sparrow (300 m), and Chestnut-collared Longspur (300 m) were consistent with those reported by other researchers. In a literature review of North American grassland birds, Johnson and Stephens (2011) reported displacement extending 50–180 m from turbines. Stevens et al. (2013) found that mean plot occupancy for Le Conte's Sparrows

(*Ammodramus leconteii*) wintering in Texas was 4 times lower in plots <200 m from nearest wind turbine relative to >400 m from the nearest turbine. In the United Kingdom, 7 of 12 upland species exhibited displacement within 500 m (Pearce-Higgins et al. 2009). Winkelman (1992) found that shorebirds in a Netherlands wind facility occurred in significantly smaller numbers within 500 m from turbines. Thus, although displacement can occur as far as 500 m from turbines, most studies show displacement within 200 m.

Evaluating turbine effects overall and by distance from turbine allowed us to differentiate between localized displacement and site abandonment. For several species, immediate or delayed effects occurred by distance at a site, but there was no significant reduction in density at that site overall. This may have occurred because breeding pairs near turbines relocated short distances from turbines but not off the site completely. For example, Grasshopper Sparrow at OL showed an immediate reduction in density of birds near turbines and an increased density at distance categories >300 m and overall. Thus, Grasshopper Sparrows may not abandon sites completely; rather, they may relocate away from the turbines and establish territories farther from turbines. Without examining displacement by distance band, we would have missed this localized displacement and instead concluded there was no displacement. Niemuth et al. (2013) also found near-turbine displacement. They modeled mean occupancy for 4 waterbird species at 2 wind facilities in North Dakota, one of which was TAT, and found that species occurrences were not substantially reduced overall at either facility post-construction. However, occupancy was slightly and consistently lower for 3 of the 4 species at one wind facility. Thus, effects of wind facilities should be examined overall and by distance from turbines.

Our identification of species-specific behaviors to wind facilities can be used to inform management decisions about turbine placement in grasslands and the potential impact at an individual species level. Metrics of displacement distances can be used to parameterize models that quantify the potential loss of habitat under scenarios of differing land uses and corresponding avian community composition. Output from these models may help drive conservation planning, such as prioritizing landscapes of highest value for preservation or restoration.

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Supporting Information

A comparison of avian and mammal displacement studies in which impact assessment designs were used (Appendix S1), a description of avian habitat preferences and population status of focal species (Appendix S2), a description of vegetation surveys and a related table of least squares means for vegetation variables (Appendix S3), and 3 tables with least squares means for density of birds on reference and turbine sites (Appendix S4) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Supporting Information - Appendix S1.

Table S1.1. Studies of avian and mammal displacement from onshore wind facilities that used impact assessment designs of Before-After Control-Impact (BACI), Control-Impact (CI), Before-After (BA), and Impact-Gradient (IG) (Manly 2001).

Source	Country	Taxonomic group	Variable of interest	Season	No. wind Facilities	Impact assessment design	No. Yrs. Pre-Treatment	No. Yrs. Post-Treatment[a]
Winkelman 1992	Netherlands	multiple avian	abundance	year-round	1	IG, BACI	1-3	1
Osborn et al. 1998	USA	multiple avian	abundance flight height	breeding migration	1	CI	0	2
Leddy et al. 1999	USA	passerine	density	breeding	1	CI	0	1
Johnson et al. 2000a	USA	multiple avian	avian use	breeding migration	1	BACI	2	2
Johnson et al. 2000b	USA	multiple avian and mammal	abundance distribution use	year-round	1	BACI	2	1
Larsen and Madsen 2000	Denmark	waterbird	field utilization	winter	2	IG	0	1
Barrios and Rodriguez 2004	Spain	raptor	flight behavior	year-round	2	IG	0	1
de Lucas et al. 2004	Spain	passerine raptor	abundance productivity flight behavior	year-round	1	CI	0	2
Erickson et al. 2004	USA	passerine	avian use	breeding	1	BA, IG	1	1
de Lucas et al. 2005	Spain	multiple avian and mammal	abundance flight behavior	breeding	1	BACI, IG	1	1
Rabin et al. 2006	USA	ground squirrel	antipredator behavior	breeding	1	CI	0	1

Walter et al. 2006	USA	elk	distance home range	year-round	1	BA	1	2
Devereaux et al. 2008	UK	multiple avian	occurrence	winter	2	IG	0	1
Madsen and Boertmann 2008	Denmark	waterbird	field utilization	migration	3	IG	0	2
Pearce-Higgins et al. 2009	UK	multiple avian	occurrence flight height	breeding	12	CI	0	1
Douglas et al. 2011	UK	game bird waterbird	abundance occurrence	breeding	1	CI	0	2
Garvin et al. 2011	USA	raptor	abundance flight height	breeding	1	BA, CI	1	2
Jain et al. 2011	USA	bats	activity	migration breeding	1	CI	0	2
Pearce-Higgins et al. 2012	UK	game bird passerine waterbird	density	breeding	18	BACI	1	1-5
Rubenstahl et al. 2012	USA	passerine	productivity	breeding	1	IG	0	1
Hatchett et al. 2013	USA	passerine	productivity	breeding	1	IG	0	2
Loesch et al. 2013	USA	waterbird	density	breeding	2	CI	0	3
Niemuth et al. 2013	USA	waterbird	occurrence	breeding	2	CI	0	3
Stevens et al. 2013	USA	passerine	occupancy	winter	1	IG	0	2
Bennett et al. 2014	USA	passerine	productivity	breeding	1	IG	0	1
LeBeau et al. 2014	USA	game bird	fitness productivity	breeding	1	IG	0	2
McNew et al. 2014	USA	game bird	site selection productivity	breeding	1	BA, IG	2	3
Winder et al. 2014a	USA	game bird	fitness	year-round	1	BA, IG	2	3

Winder et al. 2014b	USA	game bird	home range distribution	year-round	1	BA, IG	2	3
Shaffer and Buhl, this paper	USA	passerine waterbird	density	breeding	3	BACI	1	3-4[b]

[a]Construction years were not included.
[b]We had 3-4 post-treatment years of data over the 5-year post-treatment time frame (i.e., 5 calendar years) used for analyses.

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Supporting Information - Appendix S2.

Table S2.1. Habitat classification, population trend, and conservation status of avian species that were sufficiently abundant to include in analyses examining the effects of wind energy development on avian density in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD], U.S.A.) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy Center [OL], U.S.A.), 2003-2012.

Species	Habitat classification[a]	Population trend (%)[b]	Species of concern[b]
Grasshopper sparrow *Ammodramus savannarum*	grassland obligate	-2.5	no
Bobolink *Dolichonyx oryzivorus*	grassland obligate	-2.1	yes
Western meadowlark *Sturnella neglecta*	grassland obligate	-1.3	no
Killdeer *Charadrius vociferous*	generalist	-1.2	no
Upland sandpiper *Bartramia longicauda*	grassland obligate	0.5	yes
Clay-colored sparrow *Spizella pallida*	grassland/shrubland	-1.4	no
Vesper sparrow *Pooecetes gramineus*	grassland obligate	-0.9	no
Savannah sparrow *Passerculus sandwichensis*	grassland obligate	-1.2	no
Chestnut-collared longspur *Calcarius ornatus*	grassland obligate	-4.3	yes

[a]Habitat classification and concern rankings from NABCI (2014).

[b]Breeding Bird Survey population trends from Sauer et al. (2013).

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Supporting Information

Appendix S3. Description of vegetation surveys and analysis for the study on effects of wind energy facilities on grassland birds in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD], U.S.A.) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy Center (OL), U.S.A.), 2003-2012.

The mixed-grass prairie biome in North Dakota and South Dakota (U.S.A.) is a heterogeneous landscape of wetland complexes embedded within grasslands of highly scattered patches of low-growing trees and shrubs, such as S*ymphoricarpos occidentalis* (Hook) and *Prunus virginiana* (L.). Non-grassland habitats within sites were mapped using GPS units and digital photography because our focal species did not breed within all available habitat types within any particular site. For example, grasshopper sparrows were never detected within wetlands or colonies of black-tailed prairie dogs *Cynomys ludovicianus* (Ord). We accounted for the fact that some of our focal species have particular breeding habitat preferences by mapping area of wetlands (open water), woodlands, colonies of black-tailed prairie dogs, and exceptionally lush grass and deleting these areas from total area of each site, as applicable, so as to calculate suitable breeding area at a species level. Wetland area was removed for all nine of our focal species, woodland area was removed for all species except clay-colored sparrow, area of prairie-dog colony was removed for grasshopper sparrow (JAS, personal observation), and area of lush grass was removed for chestnut-collared longspur (Hill & Gould 1997).

Vegetation measurements were taken within the 50 m by 200 m cells formed by the avian survey grids. Cells were systematically chosen and sampling was conducted along 1-2 sampling lines. Percent composition of six basic life forms, bare ground (e.g., bare ground, cow pie, rock), grass, forb, shrub, standing residual, and lying litter, was estimated using a step-point sampler (Owensby 1973). Height-density (i.e., visual obstruction) was measured with a Robel pole (Robel et al. 1970). Vegetation height and litter depth were measured with a meter stick. Measurements were averaged to characterize each site.

To examine the similarity in vegetation metrics (e.g., vegetation height, proportion bare ground) between turbine and reference sites, a repeated measures analysis of variance was conducted to estimate and compare mean habitat features between turbine and reference sites and among years.

Vegetation characteristics did not significantly vary between reference and turbine sites except for VOR at TAT, where the difference was still quite small (see Appendix Table S2.1). As expected, yearly differences did occur for most vegetation characteristics. Therefore, the habitat was similar between reference and turbine sites and can be excluded as a possible confounding factor.

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Table S3.1. Least squares means of each vegetation variable for reference and turbine sites, at SD Wind Energy Center (SD) in Highmore, South Dakota (2003-2012); Acciona's Tatanka Wind Farm (TAT) in Forbes, North Dakota (2007-2012); and Oliver Wind Energy Center (OL) in Oliver Co., North Dakota (2006-2011), U.S.A. Sig. column indicates significance at a significance level of 0.05, t indicates significant difference between reference and turbine sites, y indicates significant difference among years, and t*y indicates a significant turbine*year interaction.

	SD			TAT			OL		
	Reference	Turbine	Sig. [a]	Reference	Turbine	Sig.	Reference	Turbine	Sig. [a]
VOR	0.97 (0.16)	0.74 (0.12)	y	0.93 (0.05)	1.33 (0.07)	t	1.09 (0.07)	0.77 (0.07)	t*y
Litter Depth	2.58 (0.41)	2.11 (0.32)	t*y	3.05 (0.28)	3.71 (0.38)	y	2.92 (0.34)	2.48 (0.34)	y
Veg Height	26.47 (2.32)	23.48 (1.81)	y	29.30 (1.90)	33.67 (2.65)	y	29.76 (2.05)	23.41 (2.05)	t*y
Bare Ground	0.03 (0.01)	0.03 (0.01)	y	0.02 (0.00)	0.01 (0.01)		0.01 (0.01)	0.04 (0.01)	
Forbs	0.11 (0.02)	0.10 (0.02)	t*y	0.17 (0.01)	0.21 (0.02)	y	0.12 (0.02)	0.15 (0.02)	y
Grass	0.64 (0.02)	0.65 (0.01)	y	0.62 (0.03)	0.58 (0.04)	y	0.68 (0.03)	0.59 (0.03)	
Lying Litter	0.16 (0.02)	0.17 (0.02)	t*y	0.08 (0.01)	0.05 (0.01)	y	0.09 (0.02)	0.09 (0.02)	
Res. Litter	0.05 (0.01)	0.05 (0.01)	y	0.04 (0.01)	0.05 (0.01)	y	0.08 (0.01)	0.07 (0.01)	y
Shrubs	---	---		0.07 (0.02)	0.09 (0.03)		0.02 (0.02)	0.05 (0.02)	y

[a]Most interaction effects were significant due to year differences rather than to differences between reference and turbine sites.

Supporting Information

Appendix S4. Least squares means (SE) of density / 100 ha for reference and turbine sites for 3 study sites in North Dakota and South Dakota (U.S.A.), 2003-2012.

Table S4.1. Least squares means (SE) of density/100 ha for reference and turbine sites each year at SD Wind Energy Center (SD) in Highmore, South Dakota.

	Year	Grasshopper Sparrow	Chestnut-collared Longspur	Western Meadowlark	Bobolink	Upland Sandpiper	Killdeer
Reference Sites	2003	124.3 (11.2)	56.7 (10.4)	22.0 (3.2)	8.5 (5.2)	2.3 (1.9)	3.2 (1.3)
	2004	60.1 (11.2)	42.3 (10.4)	22.0 (3.2)	12.9 (5.2)	1.5 (1.9)	0.0 (1.3)
	2005	62.1 (11.2)	36.2 (10.4)	15.5 (3.2)	6.6 (5.2)	2.9 (1.9)	0.7 (1.3)
	2006	100.6 (11.2)	65.8 (10.4)	30.3 (3.2)	5.2 (5.2)	3.7 (1.9)	2.2 (1.3)
	2008	130.7 (11.2)	120.6 (10.4)	37.6 (3.2)	14.8 (5.2)	1.8 (1.9)	0.8 (1.3)
	2010	87.4 (11.2)	39.8 (10.4)	23.2 (3.2)	18.2 (5.2)	5.1 (1.9)	0.0 (1.3)
	2012	79.4 (11.2)	60.3 (10.4)	15.5 (3.2)	42.4 (5.2)	2.6 (1.9)	1.7 (1.3)
Turbine Sites	2003	104.6 (8.6)	47.3 (8.1)	36.6 (2.5)	7.2 (4.0)	9.8 (1.5)	4.7 (1.0)
	2004	38.3 (8.6)	37.5 (8.1)	24.6 (2.5)	1.3 (4.0)	5.3 (1.5)	7.1 (1.0)
	2005	31.6 (8.6)	23.7 (8.1)	16.5 (2.5)	3.1 (4.0)	2.2 (1.5)	1.8 (1.0)
	2006	52.0 (8.6)	38.4 (8.1)	28.3 (2.5)	5.6 (4.0)	3.2 (1.5)	4.2 (1.0)
	2008	51.4 (8.6)	48.2 (8.1)	23.9 (2.5)	6.1 (4.0)	2.1 (1.5)	2.8 (1.0)
	2010	34.5 (8.6)	35.3 (8.1)	20.3 (2.5)	2.3 (4.0)	3.7 (1.5)	4.3 (1.0)
	2012	53.9 (9.7)	43.7 (8.8)	27.7 (2.8)	9.7 (4.5)	5.3 (1.6)	4.3 (1.2)
Reference Average		92.1 (4.6)	60.2 (7.1)	23.7 (1.2)	15.5 (2.9)	2.9 (0.8)	1.2 (0.5)
Turbine Average		52.3 (3.6)	39.1 (5.5)	25.4 (1.0)	5.0 (2.3)	4.5 (0.6)	4.2 (0.4)
Overall Average		72.2 (2.9)	49.7 (4.5)	24.6 (0.8)	10.3 (1.8)	3.7 (0.5)	2.7 (0.3)

Table S4.2. Least squares means (SE) of density/100 ha for reference and turbine sites each year at Acciona's Tatanka Wind Farm (TAT) in Forbes, North Dakota.

	Year	Grasshopper Sparrow	Clay-colored Sparrow	Western Meadowlark	Bobolink	Upland Sandpiper	Killdeer	Savannah Sparrow	Vesper Sparrow
Reference Sites	2007	67.6 (8.8)	27.1 (11.6)	13.8 (2.0)	39.0 (3.6)	8.8 (1.9)	0.2 (0.6)	5.2 (1.4)	6.4 (1.7)
	2009	55.1 (8.8)	31.9 (11.6)	13.1 (2.0)	22.1 (3.6)	10.3 (1.9)	1.4 (0.6)	3.0 (1.4)	4.6 (1.7)
	2010	84.4 (8.8)	30.6 (11.6)	17.2 (2.0)	31.0 (3.6)	11.5 (1.9)	1.2 (0.6)	4.3 (1.4)	1.9 (1.7)
	2012	93.7 (10.2)	92.4 (12.6)	10.8 (2.3)	31.4 (4.2)	4.1 (2.1)	2.9 (0.7)	10.5 (1.5)	5.7 (1.9)
Turbine Sites	2007	87.8 (12.5)	47.1 (16.4)	10.6 (2.9)	70.9 (5.1)	3.9 (2.7)	1.2 (0.9)	6.6 (1.9)	2.7 (2.4)
	2009	47.3 (12.5)	35.3 (16.4)	12.1 (2.9)	24.8 (5.1)	3.2 (2.7)	3.1 (0.9)	4.8 (1.9)	2.4 (2.4)
	2010	89.6 (12.5)	30.3 (16.4)	9.8 (2.9)	25.0 (5.1)	4.3 (2.7)	5.3 (0.9)	3.7 (1.9)	1.2 (2.4)
	2012	65.6 (12.5)	80.8 (16.4)	11.8 (2.9)	28.9 (5.1)	2.0 (2.7)	5.6 (0.9)	6.7 (1.9)	1.5 (2.4)
Reference Average		75.2 (4.6)	45.5 (10.0)	13.7 (1.0)	30.9 (2.0)	8.7 (1.4)	1.4 (0.3)	5.8 (1.0)	4.7 (0.8)
Turbine Average		72.6 (6.3)	48.4 (14.1)	11.1 (1.4)	37.4 (2.7)	3.3 (1.9)	3.8 (0.4)	5.4 (1.4)	2.0 (1.1)
Overall Average		73.9 (3.9)	46.9 (8.6)	12.4 (0.8)	34.1 (1.7)	6.0 (1.2)	2.6 (0.3)	5.6 (0.9)	3.3 (0.7)

Table S4.3. Least squares means (SE) of density/100 ha for reference and turbine sites each year at Oliver Wind Energy Center (OL) in Oliver County, North Dakota.

	Year	Grasshopper Sparrow	Clay-colored Sparrow	Western Meadowlark	Bobolink	Upland Sandpiper	Killdeer	Savannah Sparrow	Vesper Sparrow
Reference Sites	2006	105.2 (10.2)	25.6 (6.8)	28.0 (6.6)	42.0 (4.3)	7.7 (1.2)	1.3 (1.0)	2.5 (3.1)	1.3 (2.2)
	2007	65.6 (10.2)	21.2 (6.8)	10.0 (6.6)	19.0 (4.3)	4.9 (1.2)	1.3 (1.0)	7.9 (3.1)	2.4 (2.2)
	2009	133.6 (10.2)	33.4 (6.8)	49.3 (6.6)	16.1 (4.3)	8.0 (1.2)	2.7 (1.0)	8.0 (3.1)	0.0 (2.2)
	2011	56.3 (10.2)	13.7 (6.8)	31.5 (6.6)	49.5 (4.3)	6.9 (1.2)	1.4 (1.0)	1.4 (3.1)	0.0 (2.2)
Turbine Sites	2006	84.4 (10.2)	55.3 (6.8)	17.3 (6.6)	21.2 (4.3)	6.5 (1.2)	4.0 (1.0)	3.5 (3.1)	6.3 (2.2)
	2007	62.9 (10.2)	33.5 (6.8)	14.7 (6.6)	9.0 (4.3)	3.6 (1.2)	4.0 (1.0)	5.5 (3.1)	7.8 (2.2)
	2009	47.1 (10.2)	44.1 (6.8)	25.1 (6.6)	5.2 (4.3)	4.8 (1.2)	2.4 (1.0)	3.4 (3.1)	5.3 (2.2)
	2011	39.5 (10.2)	20.4 (6.8)	22.4 (6.6)	13.7 (4.3)	3.6 (1.2)	2.7 (1.0)	1.5 (3.1)	3.9 (2.2)
Reference Average		90.2 (4.7)	23.5 (4.6)	29.7 (3.1)	31.6 (2.2)	6.9 (0.8)	1.7 (0.5)	4.9 (2.3)	0.9 (1.8)
Turbine Average		58.5 (4.7)	38.3 (4.6)	19.9 (3.1)	12.3 (2.2)	4.6 (0.8)	3.3 (0.5)	3.5 (2.3)	5.8 (1.8)
Overall Average		74.3 (3.4)	30.9 (3.3)	24.8 (2.2)	22.0 (1.5)	5.7 (0.5)	2.5 (0.3)	4.2 (1.6)	3.4 (1.2)