

BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION

DOCKET NO. EL18-053

**IN THE MATTER OF THE APPLICATION BY DEUEL HARVEST WIND
ENERGY, LLC FOR A PERMIT OF A WIND ENERGY FACILITY AND A 345
KV TRANSMISSION LINE IN DEUEL COUNTY, SOUTH DAKOTA, FOR
DEUEL HARVEST WIND FARM**

Direct Testimony of Tom Kirschenmann
On Behalf of the Staff of the South Dakota Public Utilities Commission
March 13, 2019



1 **Q: State your name.**

2 A: Tom Kirschenmann.

3

4 **Q: State your employer.**

5 A: State of South Dakota, Department of Game, Fish, and Parks (GF&P).

6

7 **Q: State the program for which you work.**

8 A: Division of Wildlife, Terrestrial Resource Section.

9

10 **Q: State the program roles and your specific job with the department.**

11 A: The role of the Terrestrial Resources section is to study, evaluate, and
12 assist in the management of all wildlife and their associated habitats.
13 Management includes game and non-game wildlife populations, habitat
14 management on public lands and technical assistance and habitat
15 development on private lands, population and habitat inventory, and
16 environmental review of local and landscape projects. As the Deputy
17 Director of the Wildlife Division and Chief of the Terrestrial Resources
18 Section, I oversee and am involved with wildlife management and
19 research, as well as habitat management consisting of the department's
20 public lands and private lands programs.

21

22

23

1 **Q: Explain the range of duties you perform.**

2 A: Duties include leading the Terrestrial Resources section that includes
3 three program administrators (Wildlife, Habitat, Wildlife Damage) and 23
4 wildlife biologists; coordinate and assist with the Division of Wildlife's
5 Operations at four administrative regions; oversee wildlife research,
6 management, and the establishment of hunting seasons for game
7 species; oversee private lands habitat programs; coordinate
8 environmental review evaluations and responses related to terrestrial
9 issues with department staff; serve as the Department's liaison for several
10 state and federal agencies; and represent the Department on state and
11 national committees.

12

13 **Q: On whose behalf was this testimony prepared?**

14 A: This testimony was prepared on behalf of the Staff of the South Dakota
15 Public Utilities Commission.

16

17 **Q: What role does the Department of Game, Fish and Parks have in the**
18 **permitting process of a wind energy development project?**

19 A: Game, Fish and Parks has no regulatory authority when it comes to
20 permitting wind energy development projects. The agencies role is to
21 consult with developers and provide recommendations and suggestions
22 on how to avoid, minimize or mitigate impacts of wind energy development

1 to wildlife and associated habitats and provide available information to
2 make informed decisions as related to natural resources.

3

4 **Q: Have you reviewed the Application, attachments, and Deuel**
5 **Harvest's responses to PUC Staff data requests?**

6 A: Yes, relevant sections of the application and attachments and also
7 received briefings provided by GFP biologists.

8

9 **Q: Did the GF&P provide comments and recommendations to Deuel**
10 **Harvest about the project area? Please identify who provided those**
11 **comments and provide a brief summary of them.**

12 A: Yes, Casey Heimerl, Wildlife Biologist responded to a June 20, 2016
13 inquiry from WEST Inc., (on behalf of the developers of Deuel Harvest) to
14 provide information on listed, proposed, and candidate threatened or
15 endangered species, or sensitive environmental areas in or near the
16 project area. Mrs. Heimerl conducted a search of the South Dakota
17 Natural Heritage database within the proposed project boundary. Mrs.
18 Heimerl's response included locations of three bald eagle nests, records
19 of Northern redbelly dace, a state threatened fish species and historic
20 records of two rare butterfly species, the threatened Dakota Skipper and
21 the endangered Poweshiek Skipperling in the project area. Silka
22 Kempema, Wildlife Biologist, provided comments to developers initially in
23 August of 2016. During this initial consultation, information about the

1 project area and concerns over sensitive species and sensitive
2 environmental areas were shared with the applicant. This consultation
3 continued with conference calls, emails, and review of reports and draft
4 documents associated with the proposed project. Leslie Murphy, prior
5 Environmental Review Coordinator for GF&P also provided comments at
6 meetings and during conference calls beginning in spring 2017 through
7 August 2018.

8

9 A summary of those comments include suggestions on the types, timing
10 and number of surveys for grassland birds (songbirds and grouse), survey
11 recommendations for raptors, placement of turbines and associated
12 infrastructure considering the avoidance of untilled native prairie and large
13 contiguous blocks of grasslands and to focus on disturbed lands such as
14 fields currently cultivated. Game, Fish & Parks also suggested avoidance
15 of activities that will fragment contiguous blocks of grasslands, avoidance
16 of wetland basins or areas of high concentrations of wetlands, pre-
17 construction surveys for bat use and habitats plus post-construction
18 mortality surveys, and recommendations on transmission line placement.
19 Prairie grouse (greater prairie chicken and sharp-tailed grouse) lek
20 surveys were suggested by GF&P during the initial August 2016
21 consultation; however no pre-construction grouse lek surveys were
22 completed.

23

1 **Q: Do you agree with the comments and recommendations provided to**
2 **Deuel Harvest by Mrs. Heimerl, Mrs. Kempema and Mrs. Murphy? If**
3 **not, please explain.**

4 A: Yes. These are standard recommendations and comments our
5 Department would provide to wind power companies to identify, minimize,
6 or reduce impacts to wildlife and wildlife habitats, especially those projects
7 that are proposed in grassland and wetland habitats.

8

9 **Q: Based on the information provided in the Application, in your opinion**
10 **did Deuel Harvest utilize the proper studies and wildlife surveys**
11 **necessary to identify potential impacts to the terrestrial**
12 **environment?**

13 A: The US Fish and Wildlife Service (USFWS) Land-Based Wind Energy
14 Guidelines (hereafter referred to as USFWS guidelines) are intended to
15 encourage scientifically rigorous survey, monitoring, assessment and
16 research designs, produce potentially comparable data across the nation,
17 and improve the ability to predict and resolve effects of wind energy
18 development locally, regionally and nationally. These guidelines, along
19 with GF&P siting guidelines
20 (https://gfp.sd.gov/userdocs/docs/SDSitingGuides_2018-10-17.pdf) are
21 voluntary suggestions (USFWS 2012).

22

1 While survey methods were reasonable and appropriate approaches, pre-
2 construction survey methodology and timing differed between years,
3 making comparisons of data across years difficult. For example, the raptor
4 nest survey timing in 2016 was earlier in spring (March 28-April 1) than in
5 2017 (May 27-30). The increase in vegetative growth between March-April
6 and late May could influence the results of the survey (e.g. raptor
7 observations would be much more difficult after leaf-out).

8
9 The USFWS states that it is appropriate to follow the Range Wide Indiana
10 Bat Survey Guidelines to survey for the presence of the Northern Long
11 Eared Bat. Bat acoustics studies were completed using different
12 equipment across years, as well as during different times of the year.
13 Specifically, the second year of bat acoustic monitoring was shorter (July
14 20-October 17 2017) than the first year of monitoring (April 13-November
15 3 2016). Tree-roosting bats in South Dakota are generally active from
16 April-November, and the Indiana Bat Survey Guidelines define the optimal
17 sampling period as 15 May through 15 August. The study site used was
18 located adjacent to a woodlot, wetland and travel corridor (generally
19 considered typical bat habitat), however little information was gathered for
20 bat activity levels in grassland and wetland areas. Only one site was
21 monitored of the 72,737 acres in the project area. Although GF&P did not
22 recommend a specific number of survey sites, the number of survey sites
23 should consider the proposed project size and diversity of bat habitat.

1 Ideally, detectors should be distributed throughout the proposed project
2 area and adequately represent the habitats available and the areas for
3 which turbines are to be placed (National Research Council 2007, Collins
4 and Jones 2009, Weller and Baldwin 2012).

5
6 The USFWS guidelines include recommendations for prairie grouse lek
7 surveys. Additionally, GF&P biologists typically offer suggestions on
8 grouse lek avoidance during turbine siting (1 mile buffer) and construction
9 (2 mile no-construction buffer during breeding season 1 March - 30 June).
10 SDGFP would have preferred grouse lek surveys to be conducted prior to
11 construction to assist in the developer's ability to avoid or minimize
12 adverse impacts to prairie grouse species.

13
14 Wetland delineation surveys were completed in August-September of
15 2018, and follow-up surveys were completed November 14 2018. The
16 developer indicated in their application to the PUC, that the US Army
17 Corps of Engineers Wetland Delineation Manual was used to complete
18 these surveys (Environmental Laboratory 1987). Game, Fish & Parks
19 would prefer that the developers conduct wetland delineation surveys
20 during spring (May-June), so surveys would encompass the wet portion of
21 the growing season. Wetland indicators (hydrology, soil, vegetation) can
22 be masked if they are observed outside the growing season.

23

1 Different approaches in survey methods across years make it difficult to
2 effectively evaluate impacts and risk to wildlife species in a scientifically
3 rigorous manner. Pre-construction surveys data usually incorporates a
4 small snap-shot in time (ex. monthly large bird counts) but is used to
5 assess risks for the life of a project (~30 years) therefore, it is important to
6 perform surveys with a high degree of scientific rigor.

7
8 Game, Fish & Parks would prefer performing post-construction mortality
9 monitoring for at least two years; one year of post-construction surveys is
10 currently proposed by the developer in the PUC application with a second
11 year to be considered if year one results show a high level of uncertainty
12 (Appendix O: Bird and Bat Conservation Strategy). That uncertainty could
13 be determined with more assurance with two years of data.

14
15 **Q: Are there different types of grasslands?**

16 A: Yes.

17
18 **Q: Please define the following: native prairie, hayland, pasture, CRP,**
19 **grassland, cropland and agriculture.**

20 A: Grasslands are areas that contain plant species such as graminoids and
21 commonly used for grazing or set aside for conservation purposes. They
22 can also be areas which are planted to a mixture of grasses and legumes
23 for livestock grazing or feed. Native prairie is grassland upon which the

1 soil has not undergone a mechanical disturbance associated with
2 agriculture or any other type of development. Hayland is grassland that is
3 managed by frequent mowing and often contains non-native plant species
4 either intentionally or by encroachment. Pasture is grassland that may
5 contain non-native plant species either intentionally or by encroachment
6 and is managed by through grazing. Rangeland is similar to pasture
7 however; these areas are often larger and less invaded by exotic plant
8 species. In some instances, hayland, pasture, and rangeland could be
9 native prairie; in other situations hayland and pasture in particular could be
10 land once cultivated and restored to grassland habitat. CRP is grassland
11 that occurs on land that was once tilled and used for crop production.
12 These lands are often not as productive as other cropland and grassland
13 restoration is intentional.

14
15 **Q: What are remnant prairie tracts?**

16 **A:** Remnant prairie tracts are pieces of native prairie remaining in a
17 landscape that is dominated by tillage agriculture that have never been
18 tilled or have never undergone other mechanical disturbances for
19 agriculture or other purposes. Prairie is a naturally occurring ecosystem in
20 central North America characterized by certain precipitation levels, grazing
21 pressure and fire. Dominant plant forms characteristic of and adapted to
22 these environmental conditions include native grass, forb and sedge
23 species.

1 **Q: Do remnant prairie tracts have high conservation value?**

2 A: Yes.

3

4 **Q: Why do remnant prairie tracts have high conservation value?**

5 A: North American prairies (tallgrass, mixed-grass and shortgrass),
6 especially those with higher precipitation levels have had a long history of
7 being converted to cropland. Once tilled, this system cannot be fully
8 restored. In the Prairie Coteau ecoregion, 1 million acres of potentially
9 undisturbed lands (e.g. prairie) remain (Bauman et al. 2014) and represent
10 some of the last remaining areas of native prairie habitat. There are
11 several endemic grassland bird species that require native prairie. Many of
12 these populations are rare or declining and one of the main reasons for
13 their decline is habitat loss.

14

15 **Q: To your knowledge, are there grazed grasslands in the project area?**

16 A: Yes.

17

18 **Q: Do grazed grasslands have any conservation value?**

19 A: All grasslands have a conservation value when considering both wildlife
20 and livestock. Grasslands (native prairie, restored/replanted grasslands,
21 pastures, hayland, etc.) provide habitat that can and will be used by
22 grassland birds and waterfowl. Management activities, in particular
23 managed grazing, can help maintain healthy grassland habitats or

1 enhance its current state. Various grazing strategies can also determine
2 which bird species and other wildlife will use individual tracts.

3

4 **Q: Briefly explain the role of grazing on grasslands.**

5 A: Grazing provides different plant heights that result in different types of
6 wildlife cover, allows for nutrient recycling, and helps to maintain
7 grassland especially in areas with higher levels of precipitations. Grazing
8 can be used as a management activity to either manage for a specific
9 diversity or to manage unwanted plant species.

10

11 **Q: One of the GF&P's recommendations was that efforts should be**
12 **made to avoid placement of turbines and new roads in grasslands,**
13 **especially untilled native prairie. Based on the information in the**
14 **Application and the proposed turbine layout, did Deuel Harvest**
15 **demonstrate efforts to address this recommendation?**

16 A: From reviewing the maps, resources, and other information available there
17 were efforts to avoid placement of turbines on untilled native prairie. It
18 appears that in some instances the placement of the turbine is on the
19 edge of native prairie and other land use types which is also a positive
20 approach. Some turbines were placed on other types of grassland
21 habitats that are classified as herbaceous cover (hay and pasture) within
22 the project area; these too are important grassland habitats to many
23 wildlife species. Avoidance of all grassland habitat will be challenging in

1 this part of the state and in the project area as a high proportion of the
2 total area is some type of grassland/herbaceous habitat (~50%).
3 Placement of turbines in cultivated land (disturbed) is a positive siting
4 approach.

5
6 **Q. Does the state or GF&P have specific mitigation recommendations**
7 **that will minimize or compensate potential impacts from wind energy**
8 **development if they cannot be avoided?**

9 A. At this current time South Dakota does not have a state mitigation policy
10 that can be provided to wind energy developers. However, there are
11 resources available which can provide guidance and suggestions that can
12 be considered as well as self-imposed actions or activities that can
13 minimize impacts to wildlife and wildlife habitat.

14
15 **Q: Beyond avoidance, initial consultation with GF&P recommended that**
16 **impacts to native prairie and wetlands should be mitigated. What**
17 **does mitigation mean?**

18 A: In its broader context, mitigation can be an enhancement, restoration,
19 creation and/or a preservation project or activity that serves to offset
20 unavoidable impacts to a resource. It can also be measures taken in the
21 design, materials, timing, layout/siting locations and all associated
22 infrastructure during construction and operation.

23

1 **Q: What are potential mitigation considerations?**

2 A: Mitigation can take multiple forms and can be accomplished in a number
3 of ways. It could be an approach which implements an applied
4 management activity/strategy on impacted lands which elevates these
5 lands to a more productive state or higher ecological state (example –
6 grazing management) to an approach which is more sophisticated and
7 detailed using scientific information to calculate acres of habitat to be
8 restored or created based on impacted acres and other relevant research
9 data (example – decision support tool). Two examples that are available
10 specifically for wind energy projects is a research study conducted by
11 Loesch et al. (2013) that considers breeding waterfowl and another which
12 focuses on breeding grassland songbirds resulting from research findings
13 of Shaffer and Buhl (2016). As stated earlier South Dakota does not have
14 a state mitigation policy nor does the state endorse either study and
15 resulting products, however it is worthy of mentioning these studies that
16 demonstrate available options to developers and land managers.

17

18 **Q: Can you explain the difference between temporary and permanent**
19 **habitat impacts and suggested methods to address these changes?**

20 A: There will be temporary and permanent losses of grassland and
21 potentially wetland habitats resulting from the construction of turbine pads,
22 roads, and other associated infrastructure. Construction of a wind farm
23 often requires wider roads, crane paths, laydown yards, etc., to erect

1 turbines. These construction activities will have temporary impacts that
2 likely can be reclaimed by restoring impacted areas by grading and
3 reseeding. Disturbed areas should be restored using native seed sources
4 to reduce the introduction of new or discourage encroachment of already
5 present exotic and/or invasive species.

6

7 For those areas that are permanently changed, it is a typical
8 recommendation for lost grassland or wetland acres to be replaced.
9 Disturbed areas again should be restored using native seed sources to
10 reduce the introduction of new or discourage encroachment of already
11 present exotic and/or invasive species. It would also be recommended to
12 replace lost acreage within the Prairie Coteau ecoregion.

13

14 **Q: Are there any other impacts besides temporary and permanent**
15 **habitat impacts that are likely to occur as a result of the project?**

16 A: Indirect habitat impacts are also a consideration. Indirect impacts caused
17 by wind turbines and associated infrastructure raise concerns with habitat
18 fragmentation and potential displacement, especially with regards to
19 breeding grassland and wetland species. Research into the effects of
20 wind energy on habitat avoidance has shown that some species will use
21 grassland or wetland habitats to a lesser extent within a certain distance of
22 a wind turbine (Loesch et al. 2013, Exhibit _TK-2; Shaffer and Buhl 2016,
23 Exhibit_TK-3).

1 **Q: One of GF&P’s concerns involved the fragmentation of contiguous**
2 **blocks of grasslands. Why is fragmentation a concern?**

3 A: Fragmentation results in the direct loss of habitat and diminishes the value
4 of remaining habitat. Habitat fragmentation is the division of large
5 contiguous blocks of habitat into smaller, and in some instances isolated
6 patches.

7
8 **Q: The GF&P recommended avoiding the placement of turbines and**
9 **roads in contiguous blocks of grassland. Based on the information**
10 **provided in the Application, did Deuel Harvest address this**
11 **recommendation?**

12 A: Based on reviewing available information, fragmentation of grassland
13 habitats were avoided/minimized in some of the project area through the
14 proposed layout of the infrastructure of the wind farm. Particularly, Deuel
15 Harvest avoided placing wind turbines in large tracts of native prairie and
16 herbaceous cover sites in the east/southeast and southwest portions of
17 the project area (map A-3 in appendix A). This is a result of using existing
18 roads, placing new roads along edges or through cultivated lands, and
19 following existing corridors (roads) for power lines. There are other
20 locations of the project area which currently are void of roads and the
21 placement of service roads to turbines will create some level of
22 fragmentation of smaller grassland blocks (comprised of different
23 grassland cover types: hay, pasture, etc.). Based on the location of the

1 project area and the existing land-use, it will be challenging not to create
2 some additional fragmentation of grassland habitat.

3

4 **Q: If fragmentation of contiguous blocks of grasslands couldn't be**
5 **avoided, the GF&P recommended the impacts should then be**
6 **mitigated. Does the GF&P have any recommendations on adequate**
7 **types of mitigation measures Deuel Harvest should undertake to**
8 **offset any adverse impacts due to fragmentation? Please explain.**

9 A: As stated earlier, the state does not have a mitigation policy, however
10 other resources and approaches exist that could be considered to help
11 minimize the impacts of additional fragmentation.

12

13 **Q: The GF&P recommended that turbines should not be placed in or**
14 **near wetland basins and special care should be made to avoid areas**
15 **with high concentrations of wetlands. Do you believe that Deuel**
16 **Harvest's proposed turbine layout incorporates this**
17 **recommendation?**

18 A: The application mentions under mitigation measures for wildlife that
19 wetlands will be avoided or minimize disturbance of individual wetlands
20 during project construction as well as identifying wetland boundaries by
21 delineating them prior to construction. These are appropriate measures.
22 No turbines are planned in wetland basins. Reviewing the turbine layout
23 and using NWI wetland information for the project area, several turbines

1 appear to be placed in areas of higher concentrations of wetland basins
2 (specifically in the southern portion of the project; see Figure A-6 in
3 Appendix A). It will be challenging to avoid areas of high wetland
4 concentrations because of the number of wetland acres and basins found
5 in this part of state and project area.

6

7 **Q: Are you aware of any other wind farms near this proposed project?**

8 A: Yes. I am aware of projects in the area by reviewing the map of wind
9 projects found on the PUC website indicating projects either in the status
10 of existence, proposed, pending, or under construction.

11

12 **Q: Does the GF&P have any thoughts regarding the potential for**
13 **cumulative impacts the Project may have in relation to other**
14 **projects?**

15 A: Native prairie grasslands continue to decline in eastern South Dakota.
16 Knowing the importance of these native prairie tracts to several grassland
17 dependent species, continued development on these types of lands could
18 result in reduced or limited habitat value, and possibly reduced densities
19 of these species. Placement of turbines in lands currently under
20 cultivation and avoiding, where possible, the different varieties of
21 grassland and wetland habitats will help minimize potential cumulative
22 impacts. Species sensitive to habitat fragmentation may show different

1 responses based on the landscape context (e.g. areas surrounded by
2 grasslands or areas surrounded by cropland or other development).

3

4 Our agency will continue to work with wind developers and provide
5 recommendations that we believe will help minimize cumulative impacts.

6 No different than offered to this project, the focus could include, but not be
7 limited to, recommendations on avoiding grassland habitats, in particular
8 native prairie remnants, avoidance of high density wetland complexes,
9 maximize the use of existing corridors for infrastructure, and pre and post
10 construction surveys to assess the proposed project area.

11

12 **Q: Do any State threatened or endangered species have the potential to**
13 **be impacted by the wind farm?**

14 A: Large bird surveys conducted in 2017 identified two Osprey in the project
15 area (Appendix K). Osprey is considered threatened in South Dakota.
16 Although the project area does not have suitable nesting habitat for
17 Osprey, a chance exists that one may be struck by a wind turbine blade if
18 this species forages in or migrates through the project area. The other
19 state listed species that may be present are the Northern River Otter and
20 the Northern Redbelly Dace. Filing a storm water pollution prevention plan
21 and putting in place practices to reduce or eliminate sedimentation will
22 help negate potential negative impacts to these species.

23

1 **Q: Are there any GF&P lands or other public lands that may be**
2 **impacted by the wind farm?**

3 A: There is one Game Production Areas within the project area boundary and
4 six outside but adjacent to the boundary. There are three walk-in-area
5 parcels within the project area. These properties are privately owned and
6 an agreement with GFP opens them to free public access for hunting.
7 There is one Waterfowl Production Area (owned by USFWS) within the
8 project area boundary and seven other Waterfowl Production Areas within
9 a five-mile radius of the project.

10

11 **Q: Does the GF&P have any recommendations to protect those GF&P**
12 **lands or other public lands?**

13 A: The state does not have an established set-back policy or
14 recommendation for wind turbine placement in proximity to state
15 properties such as Game Production Areas. Set-back policies have been
16 established at local levels by local government entities and in some
17 instances have been suggested as the potential set-back distance from
18 state properties. At this time it is the state's belief that these types of
19 policies be established at the local level and at the discretion of the PUC
20 Commission to impose such set-backs when considering wind energy
21 permits.

22

1 **Q: If the final turbine locations changed from those provided in the**
2 **proposed turbine layout, could the potential terrestrial environment**
3 **impacts change?**

4 A: Yes.

6 **Q: You mentioned the applicant requesting data from the Natural**
7 **Heritage Database. What is the South Dakota Natural Heritage**
8 **database? What type of information does it contain?**

9 A: The South Dakota Natural Heritage database tracks species at risk.
10 Species at risk are those that are listed as threatened or endangered at
11 the state or federal level or those that are rare. Rare species are those
12 found at the periphery of their range, those that have isolated populations
13 or those for which we simply do not have extensive information on.

15 This database houses and maintains data from a variety of sources
16 including site-specific surveys, research projects and incidental reports of
17 species that cover a time period from 1979 to the present. It is important to
18 note that the absence of data from this database does not preclude a
19 species presence in the proposed project area.

1 **Q: In summary, does GF&P offer any specific permit**
2 **recommendations/conditions should the permit be granted?**

3 A: The GF&P recommends two years of post-construction avian and bat
4 mortality monitoring. A similar condition has been ordered by the
5 Commission in past wind farm dockets and if applied for this project would
6 be consistent and addresses our recommendation stated earlier in the
7 testimony. If such a condition is included we would recommend a copy of
8 the report to be shared with the US Fish and Wildlife Service, SD Game,
9 Fish and Parks, and the Commission.

10

11 **Q: Does this conclude your testimony?**

12 A: Yes.

13

14

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BS: Wildlife and Fisheries Sciences, South Dakota State University, May 1993
MS: Wildlife Management, South Dakota State University, May 1996

Certifications:
Certified Wildlife Biologist, The Wildlife Society, July 2000
Level III Career Development Training, SD GF&P, 2007

Experience:

SOUTH DAKOTA GAME, FISH, AND PARKS, Pierre, SD
Wildlife Division Deputy Director (2016 - present) & Chief of Terrestrial Resources (11/08 - present)
Supervisor: Tony Leif, Director, Division of Wildlife, 605-773-4518

- Serve as the Wildlife Division's Deputy Director to assist with the overall management of the Division.
- Coordinate the management and research of game and non-game species statewide.
- Coordinate the management of the Department's habitat programs, including the private lands programs, public lands management, access programs, terrestrial environmental assessments, and programs related to the federal Farm Bill.
- Oversee a staff that includes a Program Administrator for Wildlife, Habitat and Wildlife Damage programs and 23 biologists.
- Serve as the Department's liaison or representative for several state and federal agencies and associated committees.
- Coordinate with non-government organizations, constituency groups, and agricultural groups on resource management programs, projects, and issues.
- Manage an annual budget of approximately \$16M which includes research, direct payments to landowners for habitat, hunting access, and wildlife damage, and contracts to complete surveys, programs, and projects.
- Lead rules promulgation process for respective duties by presenting to the GFP Commission and assisting in writing administrative rules.

SOUTH DAKOTA GAME, FISH, AND PARKS, Pierre, SD
Wildlife Program Administrator, Game Management (12/07 – 11/08)
Supervisor: George Vandel, Assistant Director, Division of Wildlife, retired

- Coordinated the management and research of all game species statewide.
- Coordinated the accumulation and organization of data and regional suggestions in the development of hunting season recommendations.
- Drafted action sheets and present season recommendations to GF&P Commission.
- Assisted with the development and a team member that reviews hunting season applications and the Hunting Handbook.
- Supervised 9 biologists and 1 secretary stationed in five locations across the state.

- Served as department representative on committees (wildlife disease boards and poultry advisory board) and liaison to the SDSU Diagnostic Lab and APHIS Wildlife Services for Avian Influenza monitoring.
- “Press Release” review team member.
- Oversaw the Game Budget, including the contractual research projects with SDSU Wildlife and Fisheries Department and other academic institutions.
- Worked with the media addressing game and related issues, including live interviews, newspaper articles, and the writing of short articles.
- Team member in the development and implementation of the Mentored Hunting Program.
- Presented research and management information at regional meetings, Commission meetings, and to conservation organizations.

SOUTH DAKOTA GAME, FISH, AND PARKS, Huron, SD

Sr. Wildlife Biologist (1/05 – 12/07)

Supervisor: Tony Leif, Director, Division of Wildlife, 605-773-4518

- Oversaw management and research of upland game species statewide.
- Directed internal upland game research, analyses, and reports.
- Part of game staff committee that provided recommendations on all game seasons and license allocations.
- Served as Office Manager at the Huron GF&P District Office: directing day to day activities of Resource Biologist and Secretary within the Upland Game Section.
- Served as field co-leader with waterfowl biologist in the coordination of statewide Avian Influenza (AI) sampling.
- Worked with regional game staff on management, survey, research, and mortality projects.
- Administered the departments Wildlife Partnership Program for two years and provided guidance and direction upon request.
- Assisted with the coordination of meetings and trainings, including serving as chair person of the Prairie Grouse Technical Council (PGTC) meeting in October 2007.
- Served as department representative on several committees such as Midwest Pheasant Study Group, PGTC, Sage Grouse Council, Poultry Advisory Board (AI matters), and the National Wild Turkey Federation Technical Representative.
- Wrote management and scientific reports, as well as magazine and newspaper articles.
- Conducted presentations internally, as well as landowner and sportsmen club meetings.

PHEASANTS FOREVER, INC., St. Paul, MN

Regional Wildlife Biologist

South Dakota & Wyoming (4/00 – 1/05)

Illinois & Indiana (7/95 – 4/00)

Supervisor: Richard Young, VP Field Operations, 877-773-2070

- Established and maintained chapters comprised of grassroots volunteers and guided them in the development of habitat programs, fundraising efforts, and youth programs.
- Worked with chapters to develop wildlife habitat programs designed to fit the needs for both local and regional areas.
- Directed and assisted chapters with annual fund-raising events. Wrote grants to support local and state habitat efforts.
- Built partnerships between Pheasants Forever (both chapters and national) with local, state, and federal conservation agencies. Primary PF representative in developing SD Wildlife Habitat Extension Biologist (WHEB) program with SD GF&P and SD NRCS.
- Developed reporting system, submitted reports to GF&P, NRCS, and PF national, wrote grants, and some supervisory duties related to the WHEB program.
- Served on several state and federal habitat committees (State Technical Committee for both SD and WY, SD CRP sub-committee, WHIP sub-committee for SD and WY, SD School and

Public Lands, Northern Great Plains Joint Venture, Great Lakes and Upper Mississippi Joint Venture, IL Pheasant Fund Committee, IN DNR Gamebird Partnership Committee, IL DNR Conservation Congress).

- Organized and conducted wildlife habitat workshops for chapters, landowners, and other agency personnel.
- Established agenda, budget, and organized annual meeting for subgroup of co-Regional Wildlife Biologists, while serving as Mentor Group Leader.
- Wrote newspaper articles, interviewed for radio and TV shows, conducted presentations, and distributed newsletters.
- Educated volunteers about wildlife biology, habitat, wildlife interactions, and counsel on current, upcoming, and changes to state and federal conservation programs.

SOUTH DAKOTA STATE UNIVERSITY; Brookings, SD
Graduate Research Assistant (4/93 - 7/95; graduated 1996)
Supervisor: Dr. Daniel Hubbard, Professor, retired
Graduate Research Project.

- Research involved the comparison of avian and aquatic invertebrate abundances on conventional, organic, and no-till farming systems.
- Efforts included breeding waterfowl pair counts, waterfowl brood counts, wetland bird surveys, upland bird surveys, and aquatic invertebrate sampling.
- Other duties included surveying aquatic plants and collecting soil seed bank samples.
- Prepared bi-annual reports for USDA and EPA.

SOUTH DAKOTA STATE UNIVERSITY; Brookings, SD
Research Technician (3/92 - 8/92)
Supervisor: Diane Granfors, Graduate Research Assistant
Seasonal position.

- Assisted with wood duck study determining brood habitat and survival.
- Built, repaired, and placed wood duck nesting structures.
- Canded eggs, web tagged ducklings, banded hens, placed radio telemetry collars and acquired locations.

SOUTH DAKOTA STATE UNIVERSITY; Brookings, SD
Research Technician (10/90 - 3/91; 10/91 - 3/92)
Supervisor: Todd Bogenschutz, Graduate Research Assistant
Seasonal position.

- Aided on the research study that evaluated corn and sorghum as a winter food source for the ring-neck pheasant.
- Shared duties to feed pen birds on restricted diets.
- Sampled winter food plots.
- Assisted in extracting intestinal organs and taking anatomical measurements and weights.

SOUTH DAKOTA STATE UNIVERSITY; Brookings, SD
Research Technician (5/91 - 8/91)
Supervisor: John Lott, Graduate Research Assistant
Seasonal position.

- Worked on yellow perch food habit study.

- Used various equipment to sample fish and zooplankton. Aged fish and processed stomach contents. Sorted and tabulated zooplankton samples.

THE NATURE CONSERVANCY, Ordway Prairie, Leola, SD

Intern/Preserve Worker (5/90 - 8/90)

Supervisor: Andy Schollett, Preserve Manager

Seasonal position.

- Monitored grazing leases and rotations, conducted brome and prairie plant surveys, spraying of noxious weeds, fencing and general maintenance.



Management and Conservation

Effect of Wind Energy Development on Breeding Duck Densities in the Prairie Pothole Region

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ABSTRACT Industrial wind energy production is a relatively new phenomenon in the Prairie Pothole Region and given the predicted future development, it has the potential to affect large land areas. The effects of wind energy development on breeding duck pair use of wetlands in proximity to wind turbines were unknown. During springs 2008–2010, we conducted surveys of breeding duck pairs for 5 species of dabbling ducks in 2 wind energy production sites (wind) and 2 paired reference sites (reference) without wind energy development located in the Missouri Coteau of North Dakota and South Dakota, USA. We conducted 10,338 wetland visits and observed 15,760 breeding duck pairs. Estimated densities of duck pairs on wetlands in wind sites were lower for 26 of 30 site, species, and year combinations and of these 16 had 95% credible intervals that did not overlap zero and resulted in a 4–56% reduction in breeding pairs. The negative median displacement observed in this study (21%) may influence the prioritization of grassland and wetland resources for conservation when existing decision support tools based on breeding-pair density are used. However, for the 2 wind study sites, priority was not reduced. We were unable to directly assess the potential for cumulative impacts and recommend long-term, large-scale waterfowl studies to reduce the uncertainty related to effects of broad-scale wind energy development on both abundance and demographic rates of breeding duck populations. In addition, continued dialogue between waterfowl conservation groups and wind energy developers is necessary to develop conservation strategies to mitigate potential negative effects of wind energy development on duck populations. © Published 2012. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS *Anas discors*, *A. platyrhynchos*, blue-winged teal, breeding population, mallard, Prairie Pothole Region, wind energy development, wind turbines.

Millions of glaciated wetlands and expansive grasslands make the Prairie Pothole Region (PPR) the primary breeding area for North America's upland nesting ducks (Batt et al. 1989). Wetland and grassland loss in the PPR due to settlement and agriculture has been extensive (Dahl 1990, Mac et al. 1998),

and conversion to agriculture continues to reduce available habitat for breeding waterfowl and other wetland- and grassland-dependent birds (Oslund et al. 2010, Claassen et al. 2011). During recent years, anthropogenic impacts in the PPR have expanded to include energy development (e.g., wind, oil, natural gas; see Copeland et al. 2011: table 2.1). From 2002 to 2011, industrial wind energy production has increased 1,158% (i.e., 769–9,670 MW), 205% during the past 5 years (United States Department of Energy [USDOE] 2011). Impacts from wind energy development including direct mortality from strikes and avoidance of wind towers and associated infrastructure have been widely documented for many avian species, including raptors, passerines, upland gamebirds, shorebirds, and waterfowl, as well as bats (Drewitt and Langston 2006; Arnett et al. 2007, 2008; Kuvlesky et al. 2007).

Received: 16 March 2012; Accepted: 20 August 2012
Published: 24 December 2012

Additional supporting information may be found in the online version of this article.

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Wetland habitats in the PPR annually attract and support >50% of the breeding waterfowl population in North America (Bellrose 1980). The productivity and subsequent use of prairie wetlands by breeding ducks in the PPR are critical for the maintenance of continental duck populations (Batt et al. 1989, van der Valk 1989). Because of the potential for extensive wind energy development (USDOE 2008, 2011, Kiesecker et al. 2011), understanding the potential effect of wind power development on the use of wetland habitat by breeding duck pairs in the region is critical.

The potential impacts of wind energy development on breeding ducks are similar to other wildlife reviewed in Kuvlesky et al. (2007). Breeding pairs may abandon otherwise suitable wetland habitat, display behavioral avoidance thereby reducing densities of pairs using wetlands near wind turbines, and experience mortality from collision with turbines and associated infrastructure. Additionally, indirect effects on breeding ducks potentially include avoidance of associated grassland by nesting females, increased predation, or reduced reproduction. Wind towers and supporting infrastructure generally do not directly affect the wetlands that provide habitat for breeding ducks. However, ducks are sensitive to many forms of disturbance (Dahlgren and Korschgen 1992, Madsen 1995, Larsen and Madsen 2000). Avoidance related to the presence of towers, movement of blades (e.g., shadow flicker), blade noise (Habib et al. 2007), infrastructure development including roads and transmission lines (Forman and Alexander 1998, Ingelfinger and Anderson 2004, Reijnen and Foppen 2006), and maintenance activities have been documented for other avian species and may similarly affect breeding pairs and reduce the use of wetlands within and adjacent to wind farms.

The presence of wind energy development in high density wetland and breeding pair habitat in the PPR is relatively recent, and previous studies of the effects of land-based wind development on waterfowl (*Anatidae*) have focused primarily on collision mortality (Winkelman 1990, Johnson et al. 2000, Gue 2012) and the effect of wind farms on foraging behavior of wintering and migrating waterfowl (Winkelman 1990, Larsen and Madsen 2000, Drewitt and Langston 2006, Kuvlesky et al. 2007, Stewart et al. 2007). Wind development appears to cause displacement of wintering or migrating Anseriformes, and bird abundance may decrease over time (Stewart et al. 2007). However, habituation has been reported for foraging pink-footed geese (*Anser brachyrhynchos*) during winter (Madsen and Boertmann 2008). Displacement of duck pairs due to wind development could affect population dynamics similar to habitat loss (Drewitt and Langston 2006, Kuvlesky et al. 2007). However, little information exists on how land-based wind development affects the settling patterns, distribution, and density of duck pairs during the breeding season.

The number and distribution of breeding duck pairs in the PPR is related to annual wetland and upland conditions (Johnson et al. 1992; Austin 2002; Reynolds et al. 2006, 2007; U.S. Fish and Wildlife Service [USFWS] 2012). Wetland conditions in the PPR vary both spatially and temporally (Niemuth et al. 2010) and during dry years in

the PPR, waterfowl are displaced to lesser quality habitats farther north (USFWS 2012) where productivity is generally reduced (Bellrose 1980). The long-term sustainability of breeding duck populations is dependent on availability and use of productive wetlands in the PPR that provide local breeding pair habitat when they are wet (Johnson and Grier 1988). Avoidance of wetlands near wind energy development by breeding ducks on otherwise suitable wetland habitat may result in displacement to lesser quality habitats similar to the effect of displacement during dry years. Given the relatively large development footprint (i.e., unit area/GW) for energy produced from wind relative to other energy sources such as coal (e.g., 7.4 times; wind = 72.1 km²/TW-hr/yr, coal = 9.7 km²/TW-hr/yr; McDonald et al. 2009) and the projected growth of the industry (USDOE 2008), a relatively large land area and subsequently a large number of wetlands and associated duck pairs in the PPR can potentially be affected.

We assessed the potential effects of wind energy development and operation on the density of 5 common species of breeding ducks in the PPR of North Dakota and South Dakota: blue-winged teal (*Anas discors*), gadwall (*A. strepera*), mallard (*A. platyrhynchos*), northern pintail (*A. acuta*), and northern shoveler (*A. clypeata*). Our objective was to determine whether the expected density of breeding duck pairs differed between wetlands located within land-based wind energy production sites (hereafter wind sites) and wetlands located within paired sites of similar wetland and upland composition without wind development (hereafter reference sites). We predicted that if disturbance due to wind energy development caused avoidance of wetlands by breeding duck pairs, then expected density of breeding pairs would be lower on wind energy development sites. We interpreted differences in estimated breeding pair densities between paired wind energy development sites and reference sites in the context of the current Prairie Pothole Joint Venture (PPJV) waterfowl conservation strategy for the United States PPR (Ringelman 2005).

STUDY AREA

We selected operational wind energy and paired reference sites as a function of the geographic location, the local wetland community and its potential to attract breeding pairs (i.e., ≥ 40 pairs/km²; Reynolds et al. 2006), and wetland conditions. In 2008, 11 wind farms were operational in the PPR of North and South Dakota, USA. Of those, only 3 were located in areas with the potential to attract relatively large numbers of breeding duck pairs for the 5 species in this study (Loesch et al. 2012, OpenEnergyInfo 2012). We identified 2 existing wind energy production sites in the Missouri Coteau physiographic region (Bluemle 1991) of south-central North Dakota, USA, and north-central South Dakota, USA (Fig. 1). Both wind sites contained wetland communities with the potential to attract an estimated 46 breeding duck pairs/km² (mean density = 8.5 pairs/km² for the PPR; Reynolds et al. 2006, Loesch et al. 2012). The Kulm-Edgeley (KE) wind energy development consisted of 41 towers in a cropland-dominated landscape (e.g., 83% of

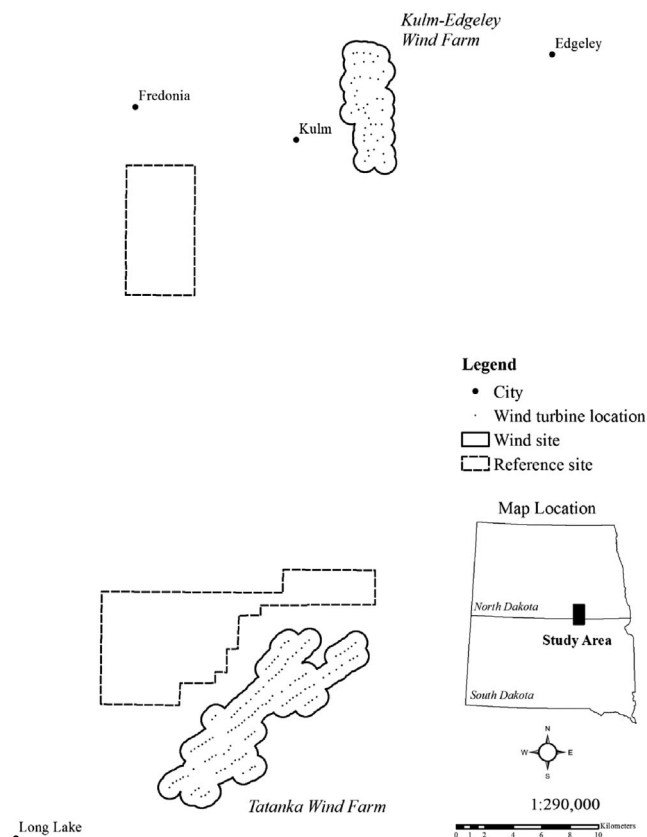


Figure 1. Paired study sites with and without wind energy development surveyed for breeding waterfowl pairs in North Dakota and South Dakota, USA, 2008–2010.

uplands were cropland; Table 1) and was located 3.2 km east of Kulm, North Dakota, USA. The Tatanka (TAT) wind energy development, consisted of 120 towers in a perennial cover-dominated landscape (e.g., 92% of uplands were perennial cover; native grassland, idle planted tame grass, alfalfa hay; Table 1) and was located 9.7 km northeast of Long Lake, South Dakota, USA. The KE site began operation in 2003; approximately 50% of the TAT towers were operational by 28 April 2008 and all were operational by 21 May 2008. Turbine locations were on-screen digitized using

ESRI ArcGIS 9.2 software (ArcGIS Version 9.2, Environmental Systems Research Institute, Redlands, CA) and United States Department of Agriculture National Aerial Imagery Program (NAIP) imagery (ca. 2007).

The potential zone of influence for breeding waterfowl from a wind turbine to a wetland during the breeding season is unknown. The limited research that has been conducted to measure displacement of birds in grassland landscapes has primarily targeted migratory grassland passerines, and has identified relatively short (e.g., 80–400 m) distances (Leddy et al. 1999, Johnson et al. 2000, Shaffer and Johnson 2008, Pearce-Higgins et al. 2009). Compared to grassland passerines, waterfowl have relatively large breeding territories and mallards use multiple wetlands within their home range (e.g., 10.36 km² generalized to a circle based on a 1,608 m radius; Cowardin et al. 1988). Because the objective of this study was to test the potential effects of wind energy development on breeding duck pair density and not to identify a potential zone of influence, we chose a buffer size with the objective to spatially position sample wetlands in proximity to 1 or many turbines where a potential effect of wind energy development would likely be measurable. Consequently, we used the generalized home range of a mallard hen and buffered each wind turbine by 804 m (i.e., half the radius of a circular mallard home range; Cowardin et al. 1988), to ensure overlap of breeding territories with nearby wind turbines. The wind sites contained different numbers of turbines and as a result the sites were not equally sized (KE wind site = 2,893 ha; TAT wind site = 6,875 ha; Fig. 1).

We derived wetland boundaries from digital USFWS National Wetlands Inventory (NWI) data. We post-processed NWI wetlands to a basin classification (Cowardin et al. 1995, Johnson and Higgins 1997) where we combined complex wetlands (i.e., multiple polygons describing a basin) into a single basin and then classified them to the most permanent water regime (Cowardin et al. 1979). Wetlands partially or completely within the buffer areas were considered treatment wetlands.

For each of the 2 wind sites, we employed a rule-based process to select paired sites to control for differences in wetland and landscape characteristics among sites. We first

Table 1. Characteristics of wetland (i.e., number, area [ha], % of total wetland area) and upland (i.e., area [ha], % of total upland area) areas in development (wind) and paired reference sites in North Dakota and South Dakota, USA, where we surveyed wetlands for breeding duck pairs during spring 2008, 2009, and 2010. Sites included Kulm-Edgeley (KE) and Tatanka (TAT) Wind Farms.

Class	KE wind			KE reference			TAT wind			TAT reference		
	Number	Area	%	Number	Area	%	Number	Area	%	Number	Area	%
Wetland												
Temporary	272	41.4	9	283	41.7	7	362	29.9	3	462	97.3	8
Seasonal	372	167.2	37	240	347.3	55	917	253.5	29	815	419.9	36
Semi-permanent	37	239.5	53	37	242.9	38	322	581.7	67	231	636.5	55
Total	681	448.1		560	631.9		1,601	865.0		1,508	1,153.7	
Upland												
Perennial cover ^a		416.3	16		1,324.4	37		5,428.4	92		6,039.7	85
Cropland		2,120.5	83		2,232.8	63		455.3	8		1,064.1	15
Other		6.6	<1		13.4	<1		18.3	<1		11.4	<1
Total		2,543			3,570.6			5,902.1			7,115.2	

^a Includes native grassland, undisturbed grassland, and alfalfa hay landcover classes.

considered physiographic region and proximity to wind sites when identifying potential reference sites. To reduce the potential for environmental variation, especially wetness (Niemuth et al. 2010), between wind and reference sites, we only considered sites <25 km from the nearest turbine and within the Missouri Coteau physiographic region. Additionally, we assumed that wetlands >2.5 km from the nearest turbine were beyond a potential zone of influence. Using the distance and physiographic region criteria, we identified 3 potential reference sites of similar size for each wind site based on upland land use (i.e., proportion of cropland and perennial cover) and wetland density. For the 6 potential sites, we compared the wetland number and area (ha) for each class (i.e., temporary, seasonal, semi-permanent) between each potential reference site and the respective wind site to select the most similar reference site (Table 1). The KE reference site was located 11.3 km west of the KE wind site and the TAT reference site was located 3.2 km northwest of the TAT wind site (Fig. 1).

We identified 5,146 wetland basins encompassing 3,410 ha from NWI data within the wind and reference sites and considered each wetland a potential sample basin. Only temporary, seasonal, and semi-permanent basins were present at the wind sites so we did not survey lake wetlands at reference sites. We did not survey basins that extended >402 m from the boundary of a site to eliminate linear wetlands that potentially extended long distances from the wind and reference sites.

METHODS

Surveys

We surveyed sample wetlands during spring 2008, 2009, and 2010 to count local breeding duck pairs. We used 2 survey periods (i.e., 28 April–18 May, early; and 21 May–7 June, late) to account for differences in settling patterns for the 5 species (Stewart and Kantrud 1973, Cowardin et al. 1995) and to reduce potential bias associated with differences in breeding chronology among species (Dzubin 1969, Higgins et al. 1992, Naugle et al. 2000). We divided the wind and reference sites into 3 crew areas to spatially distribute survey effort across the sites, and crews of 2 observers conducted surveys on each of the 3 crew areas daily. The detection probability of duck pairs was likely not equal among observers (Pagano and Arnold 2009) and we minimized potential confounding of detection, observer, and survey area by rotating observers among crew areas and partners daily. Additionally, our analytical approach was not to compare population estimates for wind and reference sites, which may require development of correction factors (Brasher et al. 2002, Pagano and Arnold 2009), but rather to compare expected rates of pair abundance. Consequently, we assumed non-detection of ducks to be equal among all sites.

We surveyed wetlands within each crew area in a 2.59-km grid pattern based on public land survey sections (PLSS). We used maps with NAIP imagery and wetland basin perimeters from NWI to assist orientation and navigation to survey wetlands. Permission, accessibility, wetness, numbers of wet-

lands, size of wetlands, and numbers of birds affected the rate at which we surveyed PLSS. Surveys began at 0800 hours and continued until 1700 hours and were discontinued during steady rainfall or winds exceeding 48 km/hr. We surveyed most wetlands twice each year, once during each survey period. We visited all sample wetlands during the early survey period. We did not revisit wetlands that were dry during the early survey. Annual changes in access permission and wetland conditions due to precipitation resulted in some basins being surveyed during only 1 of the survey periods.

During the breeding season, waterfowl assemble into various social groupings that are influenced by sex ratios, breeding phenology, and daily activities (Dzubin 1969). We counted social groups of the 5 target species using established survey protocols (Hammond 1969, Higgins et al. 1992, Cowardin et al. 1995, Reynolds et al. 2006) and recorded observations for all sample wetlands that contained surface water regardless of whether birds were present or absent. We summarized field observations into 7 social groupings that we subsequently interpreted to determine the number of indicated breeding pairs for each species, basin, and survey period (Dzubin 1969, Cowardin et al. 1995). On average, the first count period (late April–early May) is regarded as an acceptable approximation of the breeding population for mallard and northern pintail (Cowardin et al. 1995, Reynolds et al. 2006). Consequently, we used observations during the early survey period to determine the number of indicated breeding pairs for mallard and northern pintail. Similarly, the second count period (late May–early June) is generally used to approximate the breeding population of blue-winged teal, gadwall, and northern shoveler (Cowardin et al. 1995, Reynolds et al. 2006) and we used observations during the late survey period to determine the number of indicated breeding pairs for these 3 species. We used indicated breeding pairs as the response variable in our models of estimated duck pairs.

We reduced disturbance during surveys by observing wetlands from 1 or more distant, strategic positions. We approached and surveyed portions of basins that were obscured by terrain or vegetation on foot. We noted birds leaving the wetland because of observer disturbance to minimize recounting on wetlands that we had not yet surveyed. We estimated the proportion of the wetland that was wet by visually comparing the surface water present in the basin relative to the wetland extent displayed on the field map. We recorded basins with no surface water as dry and not surveyed.

We used NAIP (ca. 2009) and on-screen photo-interpretation to develop a categorical variable describing the land-cover of uplands (i.e., cropland, native grassland, idle planted tame grass, alfalfa hayland) adjacent to or surrounding all wetlands on the wind and reference sites. For wetlands touching multiple upland landcover classes, we assigned the class based on the largest wetland perimeter length. The exception was for idle planted tame grass, where we assigned the class if it touched any length of a wetland perimeter because of the limited presence of this class in

the landscape and its positive influence on pair settling densities (Reynolds et al. 2007).

Data Analysis

The objective of our analysis was to compare estimates of expected wetland-level abundance of breeding pairs on the wind and reference sites among years. We used past analyses of breeding duck pairs in the United States PPR and their relationship to wetland and upland parameters to inform the selection of candidate covariates (Cowardin et al. 1988, 1995; Reynolds et al. 1996). Wetland-level covariates included wetland class (i.e., seasonal, semi-permanent, or temporary; Johnson and Higgins 1997), surface area of water in NWI basin (wet area), and square root (sqrt) of wet area to reflect the non-linear response to wetland area demonstrated by breeding ducks in the PPR (Cowardin et al. 1988, 1995; Reynolds et al. 2006). We used a categorical variable for upland landcover (i.e., perennial cover, cropland) adjacent to the wetland for the only upland covariate (Reynolds et al. 2007).

Generalized linear models with Poisson errors provided an appropriate statistical framework for the analysis (McCullagh and Nelder 1989, McDonald et al. 2000). Preliminary summaries of the breeding pair data showed, however, that all 5 species displayed indications of over-dispersion relative to standard Poisson assumptions (i.e., both excess zeros and infrequent large counts; Appendix A, available online at www.onlinelibrary.wiley.com; Zuur et al. 2007). We addressed these challenges, while maintain an approach consistent with past studies by conducting a 2-stage analysis. We began by selecting appropriate models and subsets of the covariates using a likelihood-based approach. Then we used a simulation-based Bayesian approach to estimate parameters of species-specific statistical models, site- and year-level contrasts between wind and reference sites, and lack-of-fit statistics. Our combined approach allowed us to take advantage of the strengths of both approaches (Royle and Dorazio 2008:74–75) to provide a thorough analysis of the data.

We analyzed indicated breeding pairs from counts for each of the 5 study species using separate models. Full Poisson regression models described expected breeding pairs as a log-linear function of site, year, wetland class, landcover, wet area, and sqrt (wet area). We used Akaike's Information Criterion (AIC) differences (Burnham and Anderson 2002) to compare full Poisson models with Zero-Inflated Poisson (ZIP) models. The ZIP models partially accounted for potential excess zeros due to 2 sources: 1) non-detections and 2) unoccupied, but suitable, wetlands. The ZIP models described the data as a mixture of the counts described by the log-linear model and a mass of excess zeros described by a logit-linear model (Zuur et al. 2007). We conducted a comparison of Poisson and ZIP models between the full Poisson model and ZIP model that included a single additional parameter describing the expected probability of a false zero. When AIC differences indicated the ZIP model was more appropriate (i.e., $AIC_{\text{Poisson}} - AIC_{\text{ZIP}} \geq 4$), we used ZIP models for all subsequent analysis. When ZIP models

were selected, the full logit-linear model for excess zeros included covariates describing the upland vegetation cover class associated with each wetland (cover class; Stewart and Kantrud 1973), the area of the NWI basin covered by water (wet area), and the square root of wet area.

We expected that the full models would likely be most appropriate for the study species, as they were parameterized with covariates that have been identified as useful predictors of pair abundance in the Four-Square-Mile Breeding Waterfowl Survey (FSMS) dataset, which has been collected by the USFWS National Wildlife Refuge System since 1987 (Cowardin et al. 1995; Reynolds et al. 2006, 2007). Nonetheless, we sought to efficiently use the information in our less-extensive dataset by ensuring that we had selected a parsimonious subset of the covariates for each species-specific model. We removed a single covariate, or group of covariates in the case of factor variables, from the full model, ran the resulting reduced model, and recorded its AIC value (Chambers 1992, Crawley 2007:327–329). We repeated this procedure for every covariate. This resulted in a vector of AIC values that described, for each covariate, or covariate group, the effect of its removal on the AIC value of the full model. Reduced models for each species contained the set of covariates in the full model or the subset of covariates that resulted in increases in AIC values greater than 2 units per estimated parameter when they were removed from the full model (Arnold 2010).

After selecting a model structure for each species, we estimated the posterior distributions of model parameters with Markov Chain Monte Carlo (MCMC) simulation (Link and Barker 2009) in the Bayesian analysis software WinBUGS 1.4.1 (Spiegelhalter et al., 2003). The structure of the Bayesian ZIP models differed from the maximum likelihood models in 2 ways. The 12 site and year combinations were hierarchically centered and parameterized as normally distributed displacements from a common intercept (Gelman et al. 2004, Congdon 2005), and extra-Poisson variation due to large wetland-level counts was accommodated by a normally distributed error term (Appendix B, available online at www.onlinelibrary.wiley.com).

We conducted all statistical analyses in the R environment (R Development Core Team 2011). We used the generalized linear models capability of base R and the contributed package *pscl* (Jackman 2008) to estimate likelihoods and AIC values for Poisson and ZIP models. When selecting models and subsets of the covariates, we considered AIC differences greater than 4 to provide good evidence in favor of the model with the smaller value (Burnham and Anderson 2002). To generate Bayesian estimates of model parameters, we used the contributed *R2WinBugs* (Sturtz et al. 2005) package to run MCMC simulations in WinBUGS via R. For each model, we ran 2 Markov chains for 500,000 iterations and discarded the first 100,000 iterations from each chain to minimize the influence of starting values and prior distributions. We used minimally informative prior distributions and random starting values for model parameters and random effects. We evaluated convergence to the posterior distribution by examining plots of sequential draws for

each parameter and also by the Gelman–Rubin statistic (Gelman et al. 2004). We estimated the number of uncorrelated samples generated by each Markov Chain by the Effective Sample Size (ESS; Kass et al. 1998, Streftaris and Worton 2008). We required at least 200 uncorrelated samples per chain for inference. We considered a model to have converged when its Gelman–Rubin statistic was <1.1 and the plots of sequential draws indicated that the chains had stabilized and were sampling from a similar space (Gelman et al. 2004). We tested for lack-of-fit of the model using a posterior predictive test (Gelman et al. 2004). Specifically, we compared the variance–mean ratio for the observed data to the variance–mean ratio of simulated data generated from the posterior draws of model parameters. We concluded that the model fit the data if the posterior proportion of simulated variance–mean ratios that exceeded the observed variance–mean ratio was greater than 0.01 and less than 0.99 (Congdon 2005). We then used the CODA (Plummer et al. 2009) package to summarize the posterior distributions of model parameters, convergence diagnostics, and derived quantities like lack-of-fit statistics and back-transformed estimates of abundance. Using the 800,000 posterior simulations from each model, modal values of categorical covariates, and median values of continuous covariates, we calculated species-, site-, and year-specific medians and 95% credible intervals of 1) the estimated posterior distribution of the log-scale model parameters, 2) the estimated posterior distribution of expected pair abundance on wetlands of median area, and 3) the estimated posterior distribution of the back-transformed contrast in expected pair abundance between wind and reference sites in each year. These quantities provided the basis for comparison of pair abundance between wind and reference sites.

We used point estimates of pair density for the median seasonal wetlands size (i.e., 0.2 ha) in grassland to assess the potential effect of wind energy development on breeding duck pair densities. We selected seasonal wetlands because they were the most numerous wetlands in our sample (58%) and because breeding duck pairs use seasonal wetlands at greater rates than other wetland classes (see Reynolds et al. 2006, 2007; Loesch et al. 2012); most pairs (54%) were observed on seasonal wetlands.

We evaluated the potential impact of wind energy development from both a statistical and biological perspective. We compared point estimates of density among sites and within years to either support or reject an effect. We assessed the potential biological impact of breeding pair avoidance of wind sites by calculating the proportional change in the estimated density of pairs between wetlands in wind and reference sites for each species and year. The percent change reflects the potential impact to breeding duck populations in the presence of wind energy development.

RESULTS

As a result of variable wetland conditions both within and among years, and annual changes in access to private land, we surveyed different numbers and area of wetland basins each year. Water levels in wetlands were low during 2008 and 35%

of wetland basins visited during the early count contained water and generally were only partially full (e.g., seasonal regime, mean = 54% full, $n = 684$). Water levels increased in 2009 and 2010 and only 15% of 2,464 and 12% of 3,309 wetland basins, respectively, were dry during the early count. Basins containing water were also more full during 2009 (e.g., seasonal basin mean = 103% full, $n = 1,089$) and 2010 (e.g., seasonal basin mean = 93% full, $n = 1,407$). We conducted 5,339 wetland visits during the early count and 4,999 wetland visits during the late count. During the early count, we observed 5,287 indicated breeding pairs of mallard (3,456 [range = 146–552]) and northern pintail (1,831 [range = 51–310]), and 10,473 indicated breeding pairs of blue-winged teal (5,886 [range = 180–984]), gadwall (2,839 [range = 75–506]), and northern shoveler (1,748 [range = 55–318]) during the late count.

Model Selection and Estimation

Our ZIP models provided a substantially better fit than Poisson models for every species. Differences in AIC ($AIC_{\text{poisson}} - AIC_{\text{zip}}$) were 426 for blue-winged teal, 137 for gadwall, 218 for mallard, 384 for northern pintail, and 78 for northern shoveler. All of the covariates in the full model were retained for mallard, northern pintail, blue-winged teal, and northern shoveler. Wetland class was dropped for gadwall. Differences in AIC between the full model and the nearest reduced model were 11 for blue-winged teal, 3 for gadwall, 26 for mallard, 6 for northern pintail, and 29 for northern shoveler. The MCMC simulations converged for every species-specific model, indicating that the parameter estimates and credible intervals from these models provided a sound basis for inference. The maximum upper 95% credible interval of all R-hat values for any structural parameter was 1.01 for blue-winged teal, 1.01 for gadwall, 1.01 for mallard, 1.02 for northern pintail, and 1.04 for northern shoveler. The posterior predictive test indicated that the models fit the data for every species. The proportion of simulated variance–mean ratios that exceeded the observed variance–mean ratio was 0.52 for blue-winged teal, 0.75 for gadwall, 0.61 for mallard, 0.59 for northern pintail, and 0.72 for northern shoveler. Minimum effective sample sizes were 709 for blue-winged teal, 553 for gadwall, 307 for mallard, 346 for northern pintail, and 612 for northern shoveler.

Estimates

Differences in estimated breeding duck pair densities in a wind site and a reference site varied among site pairs (2), years (3), and species (5), and posterior median values of these 30 contrasts ranged from -0.281 to 0.130 (Table 2). Estimated patterns of contrasts for expected breeding duck pair density between wind and reference sites were similar for all species. Given median wet area and the mode of the categorical covariates, expected, basin-level densities of duck pairs for the 5 species was either statistically indistinguishable (14 of 30) between wind and reference sites or was lower (16 of 30) on wind sites than reference sites depending on site, year, and species (Fig. 2). Regardless of whether 95% credible intervals overlapped zero, density estimates were

Table 2. Log-scale estimated posterior medians and 95% of the estimated posterior distribution from the count portion of a zero-inflated, overdispersed Poisson model of indicated blue-winged teal (*Anas discors* [BWTE]), gadwall (*A. strepera* [GADW]), mallard (*A. platyrhynchos* [MALL]), northern pintail (*A. acuta* [NOPI]), and northern shoveler (*A. clypeata* [NSHO]) pairs on seasonal wetland basins for development (wind) and paired reference sites in North Dakota and South Dakota, USA. Sites are Kulm-Edgely (KE) and Tatanka (TAT) for years 2008 (08), 2009 (09), and 2010 (10).

Species	Site	Year	Reference			Wind		
			Median	2.5%	97.5%	Median	2.5%	97.5%
MALL	KE	08	0.47	0.21	0.73	0.15	-0.13	0.43
	KE	09	-0.49	-0.78	-0.22	-0.90	-1.17	-0.64
	KE	10	-0.42	-0.66	-0.20	-0.77	-1.04	-0.51
	TAT	08	0.29	0.02	0.56	0.41	0.17	0.65
	TAT	09	-0.38	-0.61	-0.14	-0.63	-0.89	-0.38
	TAT	10	-0.33	-0.55	-0.10	-0.47	-0.71	-0.22
BWTE	KE	08	-0.13	-0.25	-0.00	0.22	0.01	0.45
	KE	09	-0.46	-0.66	-0.27	-0.52	-0.74	-0.32
	KE	10	-0.13	-0.30	0.04	-0.58	-0.78	-0.39
	TAT	08	0.25	0.06	0.45	0.18	0.01	0.36
	TAT	09	-0.15	-0.32	0.02	-0.39	-0.58	-0.21
	TAT	10	0.03	-0.12	0.19	-0.19	-0.36	-0.02
NOPI	KE	08	-0.25	-0.61	0.12	-0.80	-1.24	-0.39
	KE	09	-0.80	-1.16	-0.45	-1.54	-1.93	-1.17
	KE	10	-0.72	-1.01	-0.42	-1.20	-1.56	-0.87
	TAT	08	-0.10	-0.46	0.27	0.16	-0.15	0.48
	TAT	09	-0.35	-0.63	-0.06	-0.76	-1.07	-0.44
	TAT	10	-0.15	-0.41	0.13	-0.38	-0.67	-0.07
GADW	KE	08	0.09	-0.17	0.37	-0.13	-0.43	0.18
	KE	09	-0.52	-0.77	-0.28	-0.91	-1.19	-0.64
	KE	10	-0.61	-0.83	-0.38	-1.42	-1.72	-1.14
	TAT	08	0.07	-0.18	0.34	0.17	-0.05	0.41
	TAT	09	-0.46	-0.69	-0.22	-0.55	-0.81	-0.29
	TAT	10	-0.69	-0.92	-0.46	-0.62	-0.86	-0.38
NSHO	KE	08	-0.35	-0.61	-0.08	-0.49	-0.79	-0.18
	KE	09	-0.91	-1.17	-0.67	-1.00	-1.29	-0.73
	KE	10	-0.78	-1.00	-0.57	-1.11	-1.39	-0.85
	TAT	08	-0.23	-0.49	0.00	-0.30	-0.52	-0.08
	TAT	09	-0.59	-0.80	-0.37	-0.99	-1.25	-0.74
	TAT	10	-0.36	-0.55	-0.16	-0.69	-0.90	-0.47

lower on sites with wind development for 26 of the 30 combinations (i.e., mallard and blue-winged teal: 12 combinations, 11 negative [range -6% to -36%], 7 did not overlap zero; gadwall, northern pintail, northern shoveler: 18 combinations, 15 negative [range -5% to -56%], 9 did not overlap zero). The general pattern of results were similar for all species, consequently, we chose a representative early and late arriving species with the largest number of indicated breeding pairs, mallard and blue-winged teal, respectively, for detailed presentation of results.

Mallard and Blue-Winged Teal

Mallard and blue-winged teal comprised 59% of the indicated breeding pair observations (i.e., 3,473 mallard; 5,928 blue-winged teal). Full models were retained for both mallard and blue-winged teal, and the point estimate of density was greatest in 2008 for both KE and TAT sites, but varied among years and sites (mallard: wind median = 0.42 [range = 0.30–1.03], reference median = 0.41 [range = 0.21–0.97]; blue-winged teal: wind median = 0.51 [range = 0.42–0.94], reference median = 0.66 [range = 0.47–0.96]). For mallard, estimated breeding pair densities on seasonal wetlands at wind sites were lower for 5 of the 6 site-year combinations (median = 0.11, range = -0.28 to 0.11) and error bars representing 95% of the posterior distribution of the estimate did not

overlap zero for 4 of the 6 site-year comparisons (Fig. 2A). Similarly, for blue-winged teal in 5 of the 6 site-year combinations, estimated pair densities were lower for seasonal wetlands on wind sites (median = -0.14, range = -0.24 to <0.01) and error bars representing 95% of the posterior distribution of the estimate did not overlap zero for 3 of the 6 site-year comparisons (Fig. 2B). Only 1 site-year combination for each of mallard and blue-winged teal suggested greater pair densities on wind sites, but in both cases 95% confidence intervals overlapped zero.

The estimated proportional change of mallard pair densities for wetlands in wind sites was negative in 5 of 6 site-year combinations (median = -10%, range = 13% [TAT 2008] to -34% [KE 2009]; Fig. 3A). The proportional change for blue-winged teal was also negative in 5 of 6 site-year combinations (Fig. 3B). The median estimate of proportional change for blue-winged teal densities between wind and reference sites was -18% (range 0% [KE 2009] to -36% [KE 2010]).

DISCUSSION

All 5 of our dabbling duck study species demonstrated a negative response to wind energy development and the reduced abundance we observed was consistent with behavioral avoidance. Avoidance of land-based wind energy development has been observed for numerous avian species during

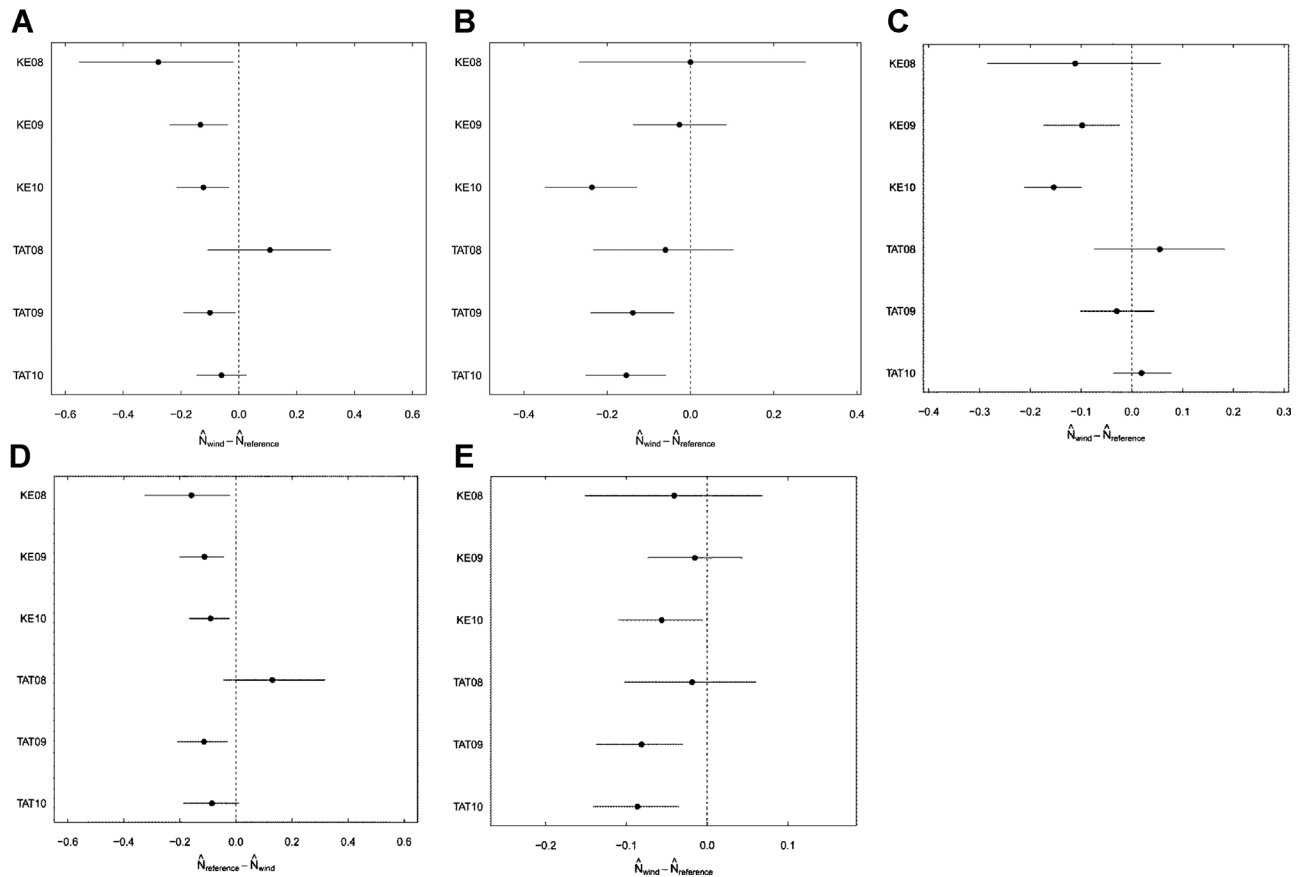


Figure 2. Year-specific estimated differences between estimated posterior median abundance of mallard (*Anas platyrhynchos*; A), blue-winged teal (*A. discors*; B), gadwall (*A. strepera*; C), northern pintail (*A. acuta*; D), and northern shoveler (*A. clypeata*; E) on a seasonal wetland of median area (0.2 ha) embedded in perennial cover on a wind site and its corresponding reference site in North Dakota and South Dakota. Error bars represent 95% of the posterior distribution of the estimate. Site-year combinations are Kulm-Edgely (KE) and Tatanka (TAT) for 2008 (08), 2009 (09), and 2010 (10).

breeding (Leddy et al. 1999, Johnson et al. 2000, Walker et al. 2005, Shaffer and Johnson 2008, see Madders and Whitfield 2006), and does not imply complete abandonment of an area but rather the reduced use of a site (Schneider et al. 2003). This is consistent with our results, where breeding pairs continued to use wetland habitat at the wind sites but at reduced densities.

Our selection of paired wind and reference sites and analytical approach were designed to control for differences in site characteristics and annual variation in habitat conditions, and to use well-understood relationships between breeding duck pairs and wetlands (Cowardin et al. 1995; Reynolds et al. 2006, 2007). Despite the large amount of breeding pair data we collected, discerning if the presence of wind energy development was the ultimate cause of the lower estimated pair abundance on the wind versus reference sites is difficult. However, we did detect a directional effect of wind energy development sites over a 3-year period at the 2 sites that are representative of areas with greater estimated duck densities, and adds to the body of evidence suggesting a negative effect of wind energy development. Reduced wetland use in high density wetland areas with the potential to attract and support relatively greater densities of breeding duck pairs is of concern to waterfowl biologists and managers because when wet, these areas are vital to the sustainability of North

American duck populations. The somewhat limited temporal and geographic scope of our study and confounding between land use and duration of development prevents us from drawing strong conclusions about cumulative effects of wind energy development on breeding ducks (see Krausman 2011). Nonetheless, a 10–18% reduction in addition to other stressors is potentially substantial.

We observed larger negative displacement for most species and years in the KE wind site when compared to the TAT wind site. We found 2 notable differences in the wind sites that may have contributed to these results, the land use and age of development. The KE site was predominantly cropland and older than the grassland-dominated TAT site. The combination of multiple stressors, in this case agriculture and wind energy development, may have resulted in a greater impact to breeding ducks using wetlands in agricultural settings. Differences in estimated pair abundance between the cropland and grassland site suggest that greater habitat quality measured by the percent of grassland area and lack of cropping history in associated wetlands within a site may reduce avoidance of wind development when compared to agricultural landscapes. Breeding waterfowl may occupy wetlands at greater rates in grassland than cropland (Reynolds et al. 2007), nest success is generally greater in grasslands (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al.

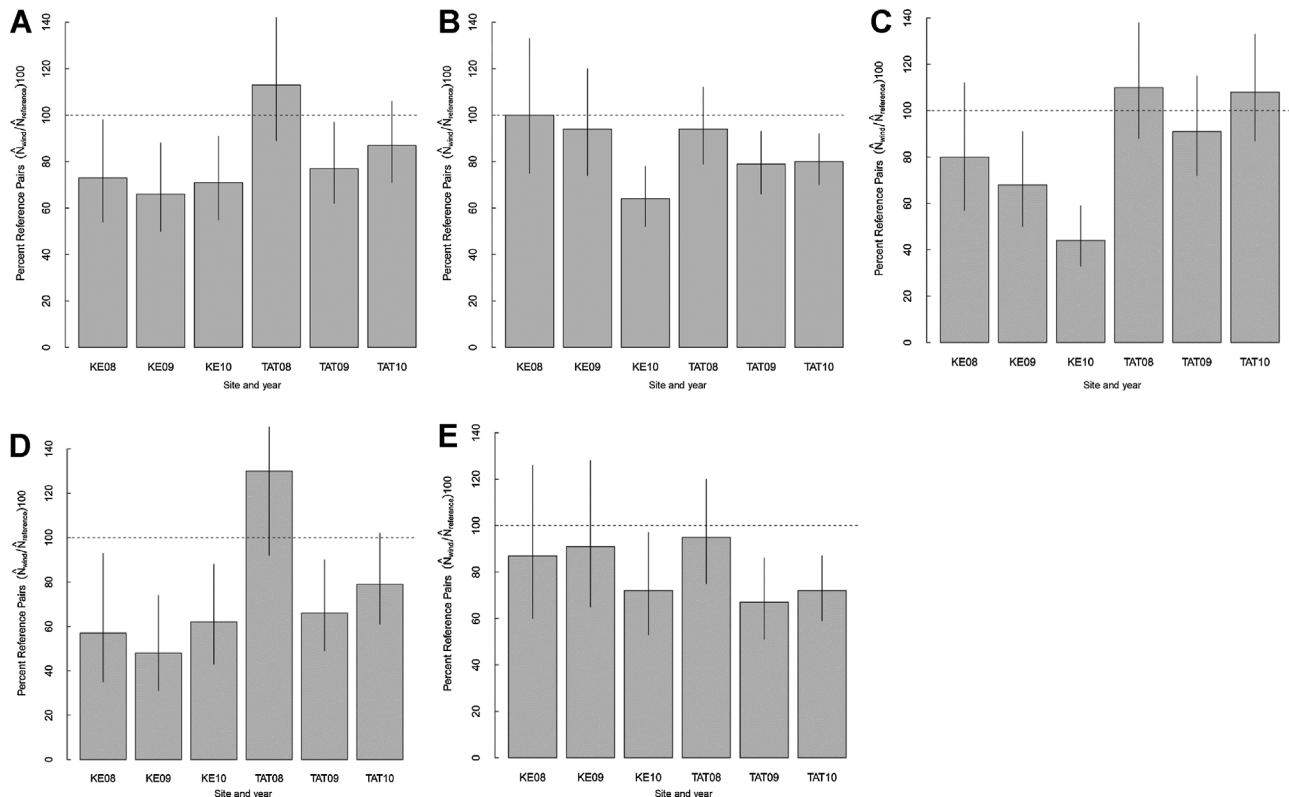


Figure 3. Year-specific estimated number of mallard (*Anas platyrhynchos*; A), blue-winged teal (*A. discors*; B), gadwall (*A. strepera*; C), northern pintail (*A. acuta*; D), and northern shoveler (*A. clypeata*; E) on a seasonal wetland of median area (0.2 ha) embedded in perennial cover on a wind site expressed as a percentage of pairs expected on the same wetland in the corresponding reference site in North Dakota and South Dakota. Error bars represent 95% of the posterior distribution of the estimate. Site-year combinations are Kulm-Edgely (KE) and Tatanka (TAT) for 2008 (08), 2009 (09), and 2010 (10).

2005), and wetlands in grass landscapes have greater occupancy rates by duck broods (Walker 2011), suggesting an overall greater productivity potential for breeding ducks in grassland versus cropland landscapes. The ability of intact habitat to reduce impacts of energy development is supported in current literature. In Wyoming, sage-grouse (*Centrocercus urophasianus*) residing in a fragmented landscape showed a 3 times greater decline in active leks at conventional coal bed methane well densities (1 well per 32 ha) than those in the most contiguous expanses of Wyoming big sagebrush (*Artemisia tridentata*) in North America (Doherty et al. 2010). A similar relationship has been documented for large mammals. In the Boreal forest, woodland caribou (*Rangifer tarandus caribou*) populations could sustain greater levels of industrial development and maintain an increasing population when they resided in large forest tracts that were not fragmented by wildfires (Sorensen et al. 2008).

Our ability to support the hypothesis that habitat quality mitigates impacts could be confounded by time-lags in detecting impacts, as well as the potential for ducks to habituate to wind energy development over time but at a cost to individual fitness (Bejder et al. 2009). The KE wind site was cropland-dominated and began operation in 2003, whereas the TAT wind site was grassland-dominated and began operation in 2008, and was 3 years old during the final field season. Many recent studies for a variety of species and ecosystems have shown time lags between dates of first

construction and full biological impacts. In Wyoming impacts to sage-grouse in some instances doubled 4 years post-development versus the initial year of development (Doherty et al. 2010) and lags varied from 2 to 10 years (Harju et al. 2010). In some instances, full biological impacts may not be apparent for decades. For example, 2 decades passed before impacts of forest logging resulted in woodland caribou population extirpation within 13 km of logging (Vors et al. 2007). In a review paper on the effects of wind farms to birds on 19 globally distributed wind farms using meta-analyses, time lags were important in detecting impacts for their meta-analyses with longer operating times of wind farms resulting in greater declines in abundance of Anseriformes (Stewart et al. 2007). Pink-footed geese foraging during spring appear to have habituated to the presence of wind turbines in Europe (Madsen and Boertmann 2008). We therefore cannot distinguish between these 2 competing hypotheses without additional study.

Wind resources are both abundant and wide-spread in the PPR in the United States (Heimiller and Haymes 2001, Kiesecker et al. 2011), and the development of an additional 37 GW of wind energy capacity in the PPR states is necessary to meet 20% of domestic energy needs by 2030 (USDOE 2008). The projected wind farm footprint in PPR states to support this target is approximately 39,601 km². Even if recommendations for siting energy development outside of intact landscapes suggested by

Kiesecker et al. (2011) are implemented by the wind industry, millions of wetlands occur in agricultural landscapes and our results indicate that wind energy development will likely reduce their use by breeding duck pairs.

Waterfowl conservation partners in the PPR use strategic habitat conservation (Reynolds et al. 1996, 2006; Ringelman 2005; USFWS 2006; Loesch et al. 2012) in an adaptive management framework to target protection, management, and restoration based on biological and landscape information, primarily in response to habitat loss from agricultural activities. From a habitat quality and conservation perspective, wind energy development should be considered as another stressor relative to the cumulative effects of anthropogenic impacts on limiting factors to breeding waterfowl populations.

The protection of remaining, high priority grassland and wetland resources in the United States PPR is the primary focus of waterfowl habitat conservation (Ringelman 2005, Niemuth et al. 2008, Loesch et al. 2012). Population goals and habitat objectives were established to maintain habitat for breeding pairs and the current productivity of the landscape (Ringelman 2005, Government Accounting Office 2007). Spatially explicit decision support tools (Reynolds et al. 1996, Niemuth et al. 2005, Stephens et al. 2008, Loesch et al. 2012) have been used effectively to target and prioritize resources for protection. New stressors such as energy development in the PPR that negatively affect the use of wetland resources have ramifications to breeding waterfowl populations (i.e., potential displacement to lower quality wetland habitat) and their conservation and management. Thus, population and habitat goals, and targeting criteria may need to be revisited if large-scale wind development occurs within continentally important waterfowl conservation areas like the PPR.

MANAGEMENT IMPLICATIONS

Balancing the development of wind energy and current conservation efforts to protect habitat for migratory birds is complex because most conservation and wind energy development in the region occur on private land (USFWS 2011). Given that breeding duck pairs do not completely avoid wetlands in and adjacent to wind energy developments and resource benefits remain, albeit at reduced levels, the grassland and wetland protection prioritization criteria used by conservation partners in the PPR (Ringelman 2005) could be adjusted to account for avoidance using various scenarios of acceptable impact. For example, the wind sites used in our study are in high priority conservation locations (Ringelman 2005, Loesch et al. 2012). After accounting for effects of duck displacement by wind development, their priority was not reduced for either site. Consequently, wind-development does not necessarily preclude these sites from consideration for protection. Additionally, using the measured negative impact of wind energy development and production on breeding duck pairs, opportunities to work with wind energy industry to mitigate the reduced value of wetlands in proximity to wind towers should be investigated. Continued partnership by the wind energy industry and

wildlife conservation groups will be critical for continued research. Further, we suggest expanding our research both spatially and temporally to better address cumulative impacts, zone of influence, impacts on vital rates, potential habituation or tolerance, and/or lag effects of long-term exposure to wind energy development.

ACKNOWLEDGMENTS

We would like to thank the numerous landowners in the project area for granting permission to access their land to conduct breeding duck pair surveys. T. Mitacek, A. Geisler, C. T. Gue, J. Foth, J. Rehar, A. Northrup, B. Hall, D. W. Brant, J. Weiler, H. P., D. Oates, D. LaRochelle, J. Korkos, K. A. Peterson, M. D. McClanahan, M. A. Fellin, and S. W. Cunningham conducted the field surveys and entered the data. Thanks to the U.S. Fish and Wildlife Service, Kulm Wetland Management District Staff, especially R. Holmgren and D. Peterson for logistical support, and Audubon Wetland Management District and Chase Lake Prairie Project for providing logistical support. We would also like to thank NextEra Energy, the U.S. Fish and Wildlife Service, and Ducks Unlimited for financial support of this project. Finally, we thank W. Meeks and K. Doherty for helpful comments on earlier drafts of this paper. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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Associate Editor: Michael Chamberlain.

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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Paper submitted November 21, 2014; revised manuscript accepted May 11, 2015.

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 (Sup-

porting 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

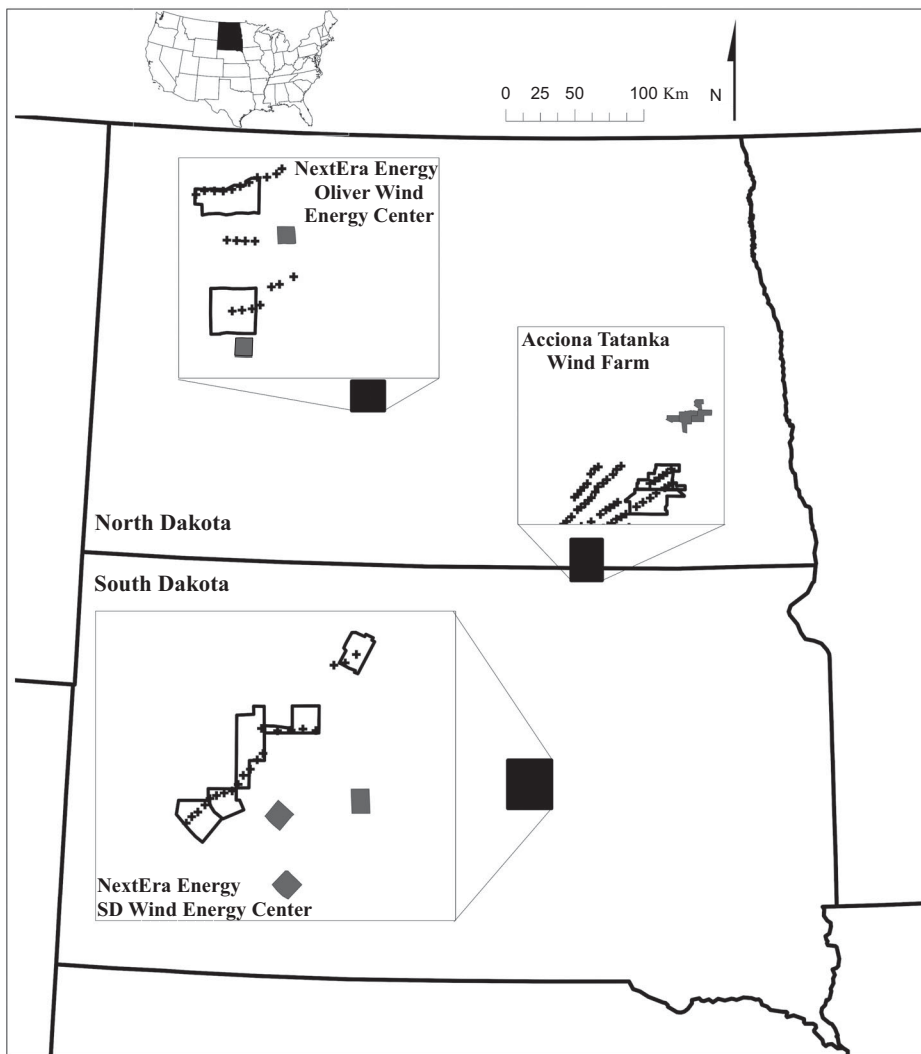


Figure 1. Map of studied wind-energy facilities in North Dakota and South Dakota (U.S.A.) (white polygons, turbine treatment sites; gray polygons, reference sites; plus symbol, turbine locations).

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 ($H_0: [\text{density}_{\text{turbine}, 1\text{yr-post}} - \text{density}_{\text{turbine}, \text{pre}}] - [\text{density}_{\text{reference}, 1\text{yr-post}} - \text{density}_{\text{reference}, \text{pre}}] = 0$) 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 ($H_0: [\text{density}_{\text{turbine}, 2-5\text{yr-post}} - \text{density}_{\text{turbine}, \text{pre}}] - [\text{density}_{\text{reference}, 2-5\text{yr-post}} - \text{density}_{\text{reference}, \text{pre}}] = 0$). 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.

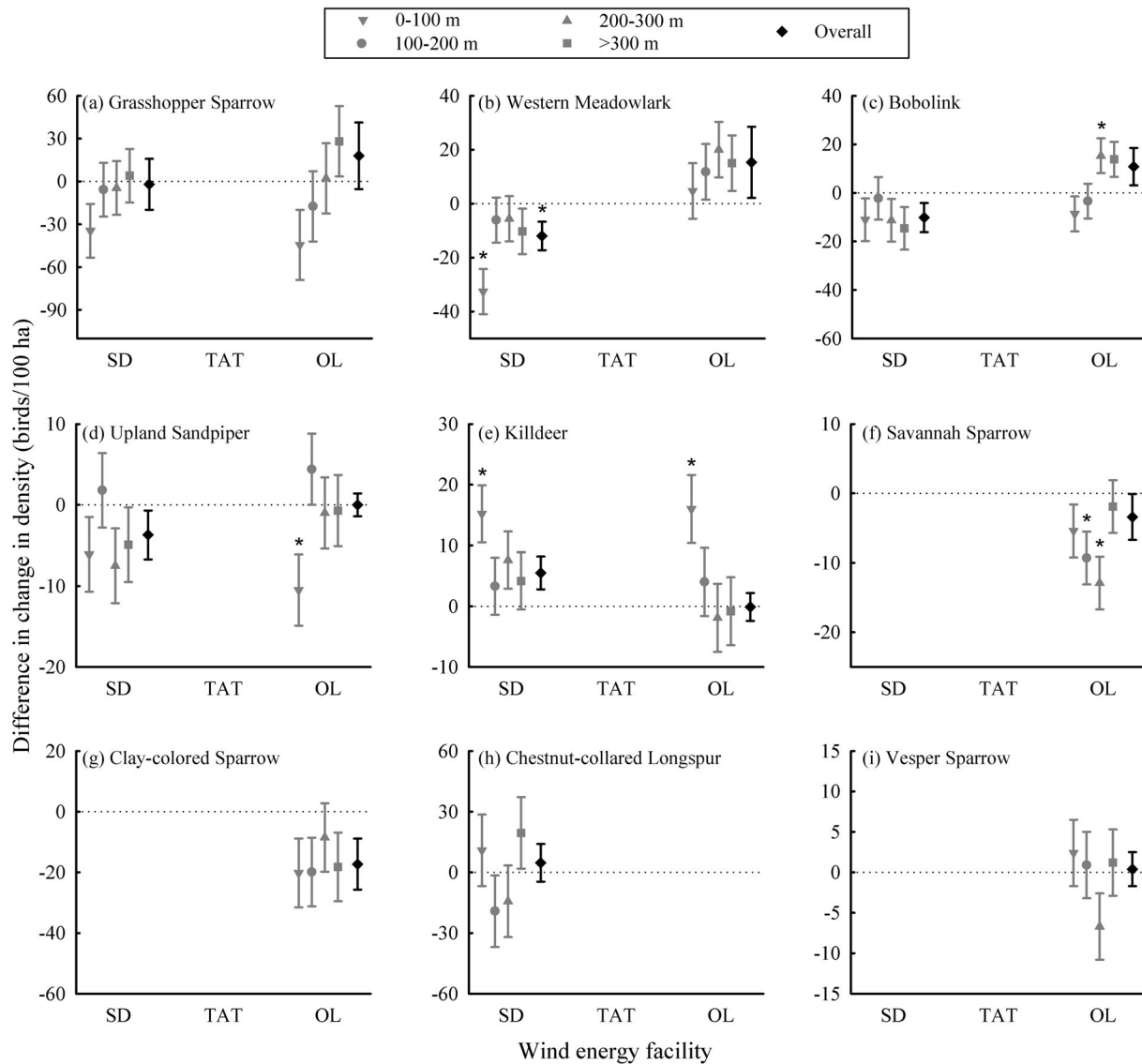


Figure 2. Difference in change in bird density/100 ha between reference and wind turbine sites from pre-treatment year to 1 year post-treatment (immediate effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy 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 = $[density_{turbine, 1yr-post} - density_{turbine, pre}] - [density_{reference, 1yr-post} - density_{reference, pre}]$; 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.

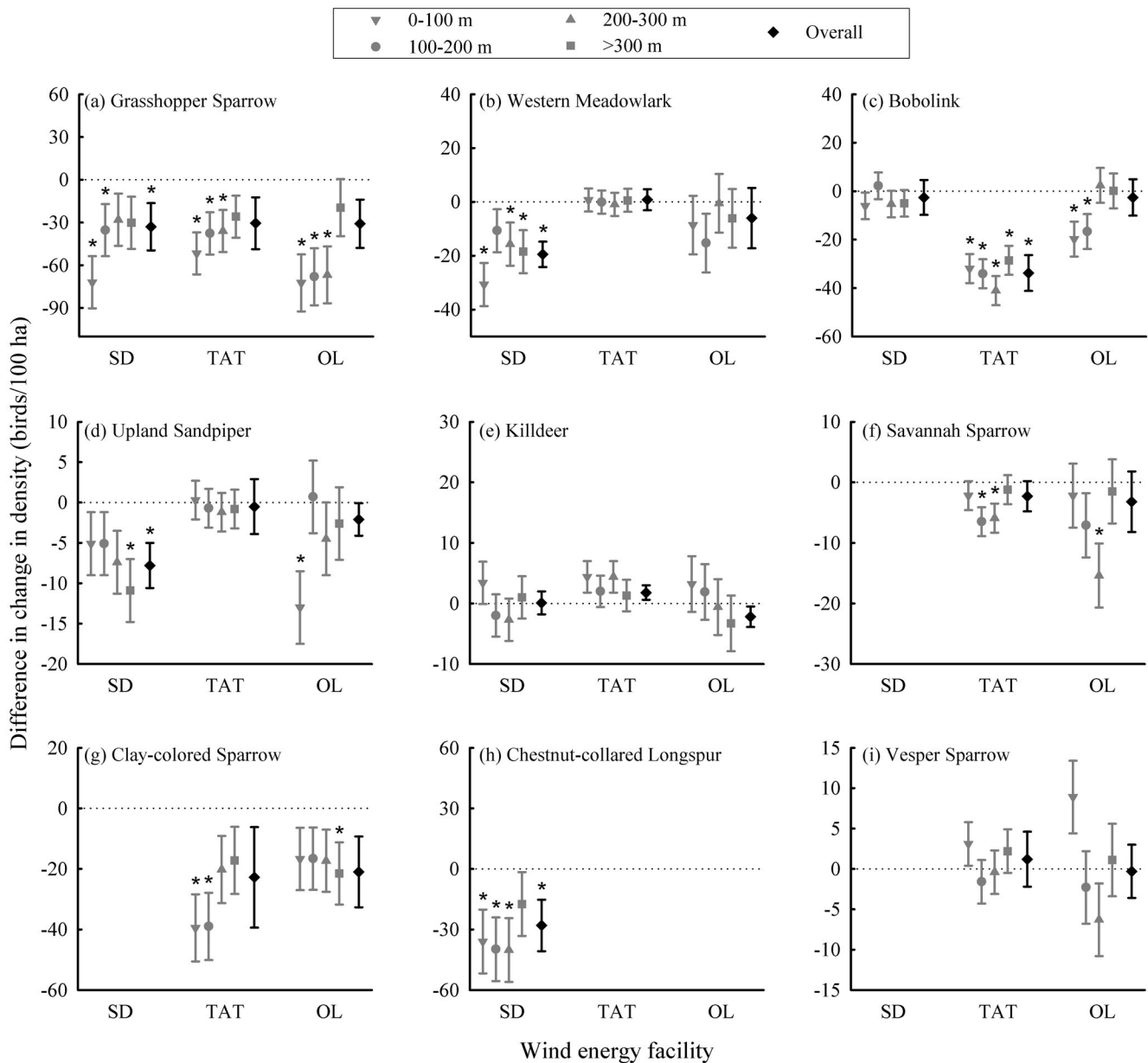


Figure 3. Difference in change in bird density/100 ha between reference and wind turbine site from pre-treatment year to 2–5 years post-treatment (delayed effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy 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 = $[density_{turbine,2-5yr-post} - density_{turbine,pre}] - [density_{reference,2-5yr-post} - density_{reference,pre}]$; 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 aprinaria*); 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 inter-specific 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.

Acknowledgments

This study would not have been possible without the contribution of D. Johnson, who conceptualized the study and its design and provided oversight. The authors acknowledge the opportunity provided to them by his foresight into the need for this study and his ability to secure long-term funding. Funding sources were U.S. Geological

Survey and NEE. We are indebted to field technicians. Land and wind-facility access was permitted by Acciona, NEE, site managers, and landowners. B. Euliss, R. Gleason, W. Newton, and the U.S. Fish and Wildlife Service provided technical and logistical support. Thanks to A. Pearse and 2 anonymous reviewers for insightful suggestions. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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

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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
Rubenstein 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

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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

^aConstruction years were not included.

^bWe 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 <i>Ammodramus savannarum</i>	grassland obligate	-2.5	no
Bobolink <i>Dolichonyx oryzivorus</i>	grassland obligate	-2.1	yes
Western meadowlark <i>Sturnella neglecta</i>	grassland obligate	-1.3	no
Killdeer <i>Charadrius vociferous</i>	generalist	-1.2	no
Upland sandpiper <i>Bartramia longicauda</i>	grassland obligate	0.5	yes
Clay-colored sparrow <i>Spizella pallida</i>	grassland/shrubland	-1.4	no
Vesper sparrow <i>Pooecetes gramineus</i>	grassland obligate	-0.9	no
Savannah sparrow <i>Passerculus sandwichensis</i>	grassland obligate	-1.2	no
Chestnut-collared longspur <i>Calcarius ornatus</i>	grassland obligate	-4.3	yes

^aHabitat classification and concern rankings from NABCI (2014).

^bBreeding 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 *Symphoricarpos 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

^aMost 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)