

BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION

DOCKET NO. EL19-003

**IN THE MATTER OF THE APPLICATION BY CROWNED RIDGE WIND, LLC
FOR A PERMIT OF A WIND ENERGY FACILITY IN GRANT AND CODINGTON
COUNTIES, SOUTH DAKOTA, FOR CROWNED RIDGE WIND FARM**

Direct Testimony of Tom Kirschenmann
On Behalf of the Staff of the South Dakota Public Utilities Commission
May 10, 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

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

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

11

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

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

15

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

18 A: Game, Fish and Parks has no regulatory authority when it comes to
19 permitting wind energy development projects. The agencies role is to
20 consult with developers and provide recommendations and suggestions
21 on how to minimize or remove potential impacts to wildlife and associated
22 habitats or provide available information to make informed decisions as
23 related to natural resources.

1 **Q: Have you reviewed the Application and attachments? How else did**
2 **you learn details around the proposed project?**

3 A: Yes, relevant sections of the application and attachments and also
4 discussed project details with GFP biologists who had more direct
5 communications with the developer.

6

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

10 A: Game, Fish and Parks was initially contacted in October 2007 by
11 TetraTech to request a search of GFP listed threatened or endangered
12 species, and any additional environmental concerns for the project area. A
13 response was sent in December of 2007 by Silka Kempema, wildlife
14 biologist. During this initial contact, information about species of concern
15 and important or sensitive wildlife habitats in the project area were shared
16 with the applicant. Additionally, in November 2007, Doug Backland,
17 wildlife biologist provided a shapefile of threatened, rare, or endangered
18 species present within the project area (natural heritage database review).
19 In December 2009, TetraTech contacted GFP to request an additional
20 natural heritage database review. Game, Fish and Parks provided a list of
21 species occurrences for the project area. In November of 2010, Western
22 Area Power Administration (WAPA) contacted GFP with a scoping notice
23 for the Crowned Ridge Wind Energy Center in Codrington County, South

1 Dakota. GFP replied to the WAPA scoping notice in January 2011 with a
2 letter describing important wildlife habitats (grasslands, wetlands, etc.),
3 information about rare, endangered or threatened species that could occur
4 in the project area as well as general wildlife survey guidelines. In March
5 2014, GFP provided historic grouse lek locations in and around the project
6 boundary. Game, Fish and Parks was contacted by TetraTech in February
7 2015 requesting information regarding ecologically significant areas and
8 listed endangered, threatened or special concern species at a potential
9 wind energy development site in Codington and Grant Counties, South
10 Dakota. Game, Fish and Parks staff replied to their request in March 2015
11 with a letter describing ecologically sensitive areas in the project area and
12 advising an up-to-date Natural Heritage database request, based on the
13 amount of time that passed since the previous request. Information was
14 also included about important wildlife habitats, avoidance of turbine
15 placement in and around public lands, recommendations on transmission
16 line construction and general wildlife survey guidelines for pre and post
17 construction surveys. In March 2017, GFP was first contacted by Nextera,
18 and Ms. Kempema recommended an in-person meeting for the
19 opportunity to review proposed turbine layout and wildlife surveys that had
20 been conducted to-date. In April 2017, a conference call with GFP,
21 USFWS and Nextera was conducted to share a project overview, as well
22 as results from wildlife surveys. During this conference call, Ms. Kempema
23 recommended Nextera avoid placing turbines in untilled grasslands and

1 wetlands, and recommended a 1 mile no-construction buffer around
2 grouse leks. Ms. Kempema also requested a copy of any wildlife survey
3 reports, and recommended a site-visit with GFP and USFWS. In July
4 2017, GFP received a request from SWCA Environmental Consultants to
5 request information regarding ecologically sensitive areas and federally
6 and state listed endangered, threatened or special concern species in the
7 Crowned Ridge project area. Results from a natural heritage database
8 search was provided to SWCA in August 2017. On April 3rd, 2019, SWCA
9 Environmental Consultants requested information regarding ecologically
10 sensitive areas and federally and state listed endangered, threatened or
11 special concern species in the Crowned Ridge project area. Results from
12 a natural heritage database search were provided to SWCA on April 26th
13 2019.

14

15 **Q: Do you agree with the comments and recommendations provided to**
16 **Crowned Ridge by Ms. Kempema? If not, please explain.**

17 A: Yes. These are typical discussion topics and recommendations our
18 Department would share with wind power companies to identify, minimize,
19 or reduce impacts to wildlife and wildlife habitats, especially those projects
20 that are proposed in grassland and wetland habitats.

21

22 **Q: Based on the information provided in the Application, in your opinion**
23 **did Crowned Ridge utilize the proper studies and wildlife surveys**

1 **necessary to identify potential impacts to the terrestrial**
2 **environment?**

3 A: Pre-construction wildlife survey data usually incorporates a small snap-
4 shot in time (ex. monthly large bird counts) but is used to assess risks for
5 the life of a project (~30 years) therefore, it is important to perform surveys
6 with a high degree of scientific rigor. The US Fish and Wildlife Service
7 (USFWS) Land-Based Wind Energy Guidelines (hereafter referred to as
8 USFWS guidelines) are intended to encourage scientifically rigorous
9 survey, monitoring, assessment and research designs, produce potentially
10 comparable data across the nation, and improve the ability to predict and
11 resolve effects of wind energy development locally, regionally and
12 nationally. These guidelines, along with GF&P siting guidelines
13 (https://gfp.sd.gov/userdocs/docs/SDSitingGuides_2018-10-17.pdf) are
14 voluntary suggestions (USFWS 2012).

15
16 Survey methods used by Crowned Ridge followed the USFWS guidelines,
17 and were reasonable and appropriate. Crowned Ridge conducted aerial
18 raptor nest surveys, avian use surveys, large bird use surveys, grouse lek
19 surveys, bat acoustic surveys, bat habitat assessments and an
20 endangered butterfly habitat assessment.

21
22 Q: **What are the potential impacts to wildlife as a result of the**
23 **construction of a wind project?**

1 A: Direct; birds and bats can be killed by turbines due to direct strikes.
2 Indirect; some species may be displaced from otherwise suitable habitat
3 around turbines and roads. A research project on the effects of wind
4 energy on breeding grassland bird densities in North and South Dakota
5 showed seven of nine species of grassland birds had reduced densities
6 around wind turbines over time (Shaffer and Buhl 2016).

7
8 **Q: What potential impacts to wildlife habitat can result from a wind
9 project?**

10 A: Permanent loss; habitat is permanently converted to turbine pads, roads
11 or buildings. This is often a small percent of the total project acreage (area
12 define by wind easements or otherwise defined project boundary).
13 Temporary loss; habitat is disturbed for a time during construction (e.g.
14 widened roads, crane paths) but is restored. Fragmentation; habitat
15 fragmentation is the division of a block of habitat into smaller, and at times
16 into isolated patches. Habitat fragmentation can decrease the overall
17 value of the remaining habitat.

18
19 **Q: Can you suggest methods to address temporary and permanent
20 changes to habitat?**

21 A: Temporary impacts to habitat resulting from construction activities likely
22 can be reclaimed by restoring impacted areas by grading and reseeded.
23 Disturbed areas should be restored using native seed sources to reduce

1 the introduction of new or discourage encroachment of already present
2 exotic and/or invasive species.

3

4 For those areas that are permanently changed, lost grassland or wetland
5 acres could be addressed through consideration of mitigation options.

6 Disturbed areas again should be restored using native seed sources to
7 reduce the introduction of new or discourage encroachment of already
8 present exotic and/or invasive species. It would also be recommended
9 that if lost acres are replaced to carry out these replacement activities in
10 the closest possible proximity of the project.

11

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

14 A: Indirect habitat impacts are also a consideration. Potential indirect impacts
15 created by wind turbines and associated infrastructure raise concerns with
16 habitat fragmentation and potential displacement, especially with regards
17 to breeding grassland and wetland species. Research into the effects of
18 wind energy on habitat avoidance has shown that some species will not
19 use grassland or wetland habitat within a certain distance of a wind turbine
20 (Loesch et al. 2013, Shaffer and Buhl 2016).

21

22 **Q: Did GFP have any wildlife or habitat concerns regarding the**
23 **proposed Crowned Ridge project? If yes, what are they?**

1 A: Yes. The area of primary interest is the potential impacts to the various
2 grassland habitats and associated wildlife.

3

4 Q: **Did GFP provide any recommendations to avoid wildlife and habitat
5 impacts from Crowned Ridge? If yes, what were they?**

6 A: Yes. The primary recommendations were to site turbines and associated
7 infrastructure in cropland, minimize fragmentation, utilize existing
8 infrastructure and avoid siting turbines in grasslands, and completion of
9 post-construction surveys for bat and bird mortality which could be used in
10 assisting with operational adjustments in the future.

11

12 Q: **Are there different types of grasslands?**

13 A: Yes.

14

15 Q: **Please describe the following: native prairie, hayland, pasture, CRP,
16 and cropland.**

17 A: Grasslands are areas that contain plants species such as graminoids and
18 commonly used for grazing or set aside for conservation purposes. They
19 can also be areas which are planted to a mixture of grasses and legumes
20 for livestock grazing or feed. Native prairie is grassland upon which the
21 soil has not undergone a mechanical disturbance associated with
22 agriculture or any other type of development. Hayland is grassland that is
23 managed by frequent mowing and often contains non-native plant species

1 either intentionally or by encroachment. Pasture is grassland that may
2 contain non-native plant species either intentionally or by encroachment
3 and is managed by through grazing. In some instances hayland and
4 pasture could be native prairie; in other situations hayland and pasture in
5 particular could be land once cultivated and restored to grassland habitat.
6 Conservation Reserve Program acres (CRP) is grassland that occurs on
7 land that was once tilled and used for crop production and has now been
8 seeded to herbaceous cover to address soil loss, water quality, and
9 provide wildlife habitat. Cropland could be described as agricultural lands
10 cultivated and used to grow crops such as corn, soybeans, small grains,
11 and others.

12

13 **Q: Are there any areas of native prairie in the proposed project?**

14 **A:** Yes. Spatial analysis conducted by Bauman et al. (2016) has identified
15 potentially undisturbed lands within the proposed project boundary. This
16 is one of the best available spatial data sets representing the location of
17 untilled native grasslands. The applicant also identified within the
18 application an estimated 17,889 acres of untilled grassland within the
19 project area (pg. 49).

20

21 **Q: Do grasslands other than native prairie have conservation value?**

1 A: Yes. Given the loss of native prairie, working grasslands like pasture,
2 hayland, and conservation grassland plantings serve as surrogates for
3 native grasslands.

4

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

6 A: Yes.

7

8 **Q: Do grazed grasslands have any conservation value and what is the**
9 **impact to grassland wildlife?**

10 A: All grasslands have a conservation value, including those managed
11 through grazing. Grassland birds require a diversity of grassland types
12 and structure to complete life-cycle requirements. Studies have shown
13 that grassland birds respond primarily not to variation in plant species
14 composition but to the structure that these plants provide. Grassland birds
15 have evolved with a gradation of grazing intensities. Grassland wildlife
16 diversity can be maximized by creating a heterogeneous landscape
17 comprised of short, medium and tall vegetation structures. Grazing
18 (haying and burning) management can provide this variation in vegetative
19 structure. Changes in land management and annual precipitation levels
20 can alter plant species composition and vegetation structure of grassland
21 within a short timeframe.

22

1 **Q: One of the GF&P's recommendations was that efforts should be**
2 **made to avoid placement of turbines and new roads in grasslands,**
3 **especially untilled native prairie. Based on the information in the**
4 **Application and the proposed turbine layout, did Crowned Ridge**
5 **demonstrate efforts to address this recommendation? Please**
6 **explain.**

7 A: Data from the application indicates that 17,889 acres of the 53,186 acre
8 project area is native prairie habitat. From reviewing the available maps,
9 resources, and other information available there were efforts to avoid
10 placement of turbines on untilled native prairie as approximately 19 of the
11 planned 130 turbines appear to be positioned in native prairie. A continued
12 recommendation for wind development is to avoid untilled native prairie
13 habitat to the greatest extent possible. It appears that multiple turbines are
14 being planned in cultivated land (disturbed) which from a wildlife
15 perspective is a positive siting approach. Some turbines will likely be
16 placed on other types of grassland habitats (hay and pasture) within the
17 project area. Avoidance of all grassland habitat will be challenging in this
18 part of the state and in the project area as a high proportion of the total
19 area is some type of grassland/herbaceous habitat as demonstrated by
20 the application indicating that project construction easement is 26%
21 grass/pasture (page 47).

22

1 **Q: One of GF&P's concerns around wind farm development is the**
2 **fragmentation of contiguous blocks of grasslands. Why is**
3 **fragmentation a concern?**

4 A: Fragmentation results in the direct loss of habitat and diminishes the value
5 of remaining habitat. Habitat fragmentation is the division of large
6 contiguous blocks of habitat into smaller, and in some instances isolated
7 patches. Identification of contiguous blocks of habitat, especially in
8 predominantly non-habitat landscapes is an important component of
9 grassland and wetland bird conservation.

10

11 **Q: Are there any areas of contiguous grassland habitat in the proposed**
12 **project?**

13 A: Yes. The northeastern portion, central portion and northwestern portion of
14 the proposed project area have the highest level of contiguous blocks of
15 grassland habitat.

16

17 **Q: Based on the information available does the GF&P have concerns**
18 **over the placement of turbines and roads in contiguous blocks of**
19 **grassland?**

20 A: Based on reviewing available information, fragmentation of grassland
21 habitats were avoided/minimized in some of the project area through the
22 proposed layout of the infrastructure of the wind farm. This is a result of
23 primarily utilizing tilled agricultural fields for turbine locations. There are

1 other locations of the project area which the placement of turbines will
2 likely create some level of fragmentation of smaller grassland blocks
3 (comprised of different grassland cover types: hay, pasture, etc.). Based
4 on the location of the project area and the existing land-use, it will be
5 challenging not to create some additional fragmentation of grassland
6 habitat, and in some situations larger contiguous blocks comprised of
7 different grassland cover types.

8

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

12 A. At the current time South Dakota does not have a state mitigation policy
13 that can be provided to wind energy developers. However, there are
14 resources available which can provide guidance and suggestions that can
15 be considered as well as self-imposed actions or activities that can
16 minimize natural resource impacts.

17

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

19 A: Mitigation can take multiple forms and accomplished in a multitude of
20 ways. It could be an approach which implements an applied management
21 activity/strategy on impacted lands which elevates these lands to a more
22 productive state or higher ecological state (example – grazing
23 management) to an approach which is more sophisticated and detailed

1 using tools developed to calculate acres of habitat to be restored or
2 created based on impacted acres and other relevant research data
3 (example – decision support tool). Two examples that are available
4 specifically for wind energy projects is a decision support tool based off
5 the research conducted by Loesch et al. (2013) that considers breeding
6 waterfowl and another which focuses on breeding grassland songbirds
7 resulting from research findings of Shaffer and Buhl (2016). As stated
8 earlier South Dakota does not have a state mitigation policy nor does the
9 state endorse either study and resulting products, however it is worthy of
10 mentioning these tools demonstrating resources available to developers
11 and managers.

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 Crowned**
16 **Ridge’s proposed turbine layout incorporates this recommendation?**

17 A: The application mentions under mitigation measures for wildlife that
18 wetlands will be avoided or minimize disturbance of individual wetlands
19 during project construction. These are appropriate measures. No
20 turbines are planned in wetland basins. Reviewing the turbine layout and
21 using NWI wetland information for the project area, some turbines appear
22 to be placed in areas of higher concentrations of wetland basins
23 (specifically in the central and eastern portions of the project). It will be

1 challenging to avoid areas of wetland concentrations because of the
2 number of wetland acres and basins found in this part of the state and
3 project area. Recommendations to avoid areas of higher concentrations of
4 wetlands is supported by findings from Loesch et al. (2013).

5
6 **Q: Are you aware of any other wind farms near this proposed project?**

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

10

11 **Q: Does the GF&P have any thoughts regarding the potential for
12 cumulative impacts the Project may have?**

13 A: As projects are completed and based on location and proximity to other
14 projects, the question of cumulative impacts will become more apparent.
15 Knowing the importance of native prairie tracts and other forms of
16 grassland habitat to several grassland dependent species, continued
17 development on these types of lands could result in reduced or limited
18 habitat value. Placement of turbines in lands currently under cultivation
19 and avoiding where possible the different varieties of grassland and
20 wetland habitats will help minimize potential cumulative impacts.

21

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

1 No different than offered to this project, the focus could include, but not
2 limited to, recommendations on avoiding grassland habitats, in particular
3 native prairie remnants, avoidance of high wetland complex areas,
4 maximize the use of existing corridors for infrastructure, and pre and post
5 construction surveys to assess the proposed project area that may assist
6 in operational decisions.

7

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

10 A: There are two records of the state threatened Northern River Otter
11 adjacent to the project boundary. Filing a storm water pollution prevention
12 plan and putting in place practices to reduce or eliminate sedimentation
13 will help negate potential negative impacts to Northern River Otters that
14 may be in or near the project area.

15

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

18 A: It does not appear any Game Production Areas within the project area will
19 be impacted by the project. There are six walk-in-area parcels within the
20 project area; three turbines are planned on these properties. These
21 properties are privately owned and an agreement with GFP opens them to
22 free public access for hunting. Should a Walk-In Area be temporarily
23 disrupted for construction, GFP would ask we are involved with those

1 discussions to determine whether any action required from our agency to
2 notify the public.

3
4 For clarification, Game Production Areas and Waterfowl Production Areas
5 are not private land leased by GFP. Game Production Areas are owned by
6 the State of South Dakota and managed by GFP. Waterfowl Production
7 Areas are publicly owned and managed by the US Fish and Wildlife
8 Service.

9

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

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

21

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.

5
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.

14
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.

20
21 **Q: In summary, does GF&P offer any specific permit recommendations**
22 **should the permit be granted?**

1 A: Game, Fish & Parks would suggest performing post-construction avian
2 and bat mortality monitoring for at least two years; one year of post-
3 construction surveys is currently proposed by the developer in the PUC
4 application to confirm operational trends are consistent with previously
5 observed trends for other projects in the region. That consistency would
6 have more assurance with two years of data.

7 Additionally, GFP recommends post-construction grouse lek monitoring of
8 confirmed leks less than 1 mile from proposed turbines. This data could be
9 useful information for future discussions around cumulative effects of wind
10 energy development on prairie grouse. We also recommend consultation
11 between the developers, GFP and the US Fish and Wildlife Service on
12 proposed survey methodology for post-construction lek monitoring. GFP
13 would request a copy of any future report to be shared with the US Fish
14 and Wildlife Service and GFP.

15

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

17 A: Yes.

18

19 Bauman, P., B. L. Carlson, and T. Butler. 2016. Quantifying undisturbed (native)
20 lands in eastern South Dakota: 2013. South Dakota State University.

21 Loesch, C. R., J. A. Walker, R. E. Reynolds, J. S. Gleason, N. D. Niemuth, S. E.
22 Stephens, and M. A. Erickson. 2013. Effect of wind energy development

1 on breeding duck densities in the Prairie Pothole Region. *The Journal of*
2 *Wildlife Management* 77:587-598.

3 Shaffer, J. A., and D. A. Buhl. 2016. Effects of wind-energy facilities on breeding
4 grassland bird distributions. *Conservation Biology* 30:59-71.

5

Thomas R. Kirschenmann
2206 Stratford Place
Pierre, SD 57501
(605) 773-4192 (w) (605) 494-0241 (h)
Tom.Kirschenmann@state.sd.us (work)
kirsch@pie.midco.net (home)

Education: Eureka High School, Eureka, SD, 1989
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 Vandell, 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

CHARLES R. LOESCH,¹ *Habitat and Population Evaluation Team, U.S. Fish and Wildlife Service, 3425 Miriam Avenue, Bismarck, ND 58501, USA*

JOHANN A. WALKER, *Great Plains Regional Office, Ducks Unlimited, 2525 River Road, Bismarck, ND 58503, USA*

RONALD E. REYNOLDS,² *Habitat and Population Evaluation Team, U.S. Fish and Wildlife Service, 3425 Miriam Avenue, Bismarck, ND 58501, USA*

JEFFREY S. GLEASON,³ *Kulm Wetland Management District, U.S. Fish and Wildlife Service, 1 First Street SW, Kulm, ND 58546, USA*

NEAL D. NIEMUTH, *Habitat and Population Evaluation Team, U.S. Fish and Wildlife Service, 3425 Miriam Avenue, Bismarck, ND 58501, USA*

SCOTT E. STEPHENS,⁴ *Great Plains Regional Office, Ducks Unlimited, 2525 River Road, Bismarck, ND 58503, USA*

MICHAEL A. ERICKSON, *Kulm Wetland Management District, U.S. Fish and Wildlife Service, 1 First Street SW, Kulm, ND 58546, USA*

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.

¹E-mail: chuck_loesch@fws.gov

²Present address: Retired, 14622 246th Avenue Northwest, Zimmerman, MN 55389, USA.

³Present address: P.O. Box 808, Folsom, LA 70437, USA.

⁴Present address: Ducks Unlimited Canada, Oak Hammock Marsh Conservation Centre, P.O. Box 1160, Stonewall, Manitoba, Canada R0C 2Z0.

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

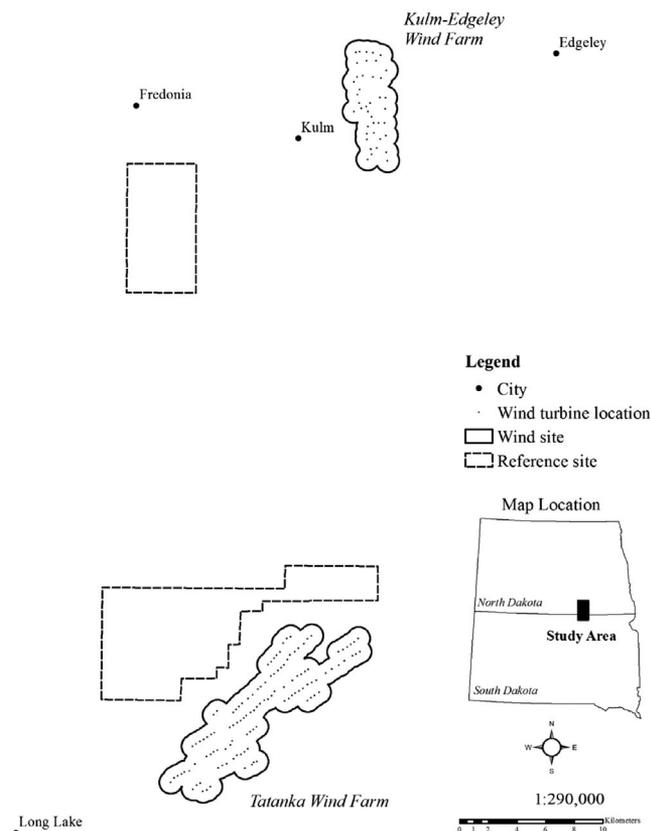


Figure 1. Paired study sites with and without wind energy development surveyed for breeding waterfowl pairs in North Dakota and South Dakota, USA, 2008–2010.

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 overdispersion 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, Strefataris 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

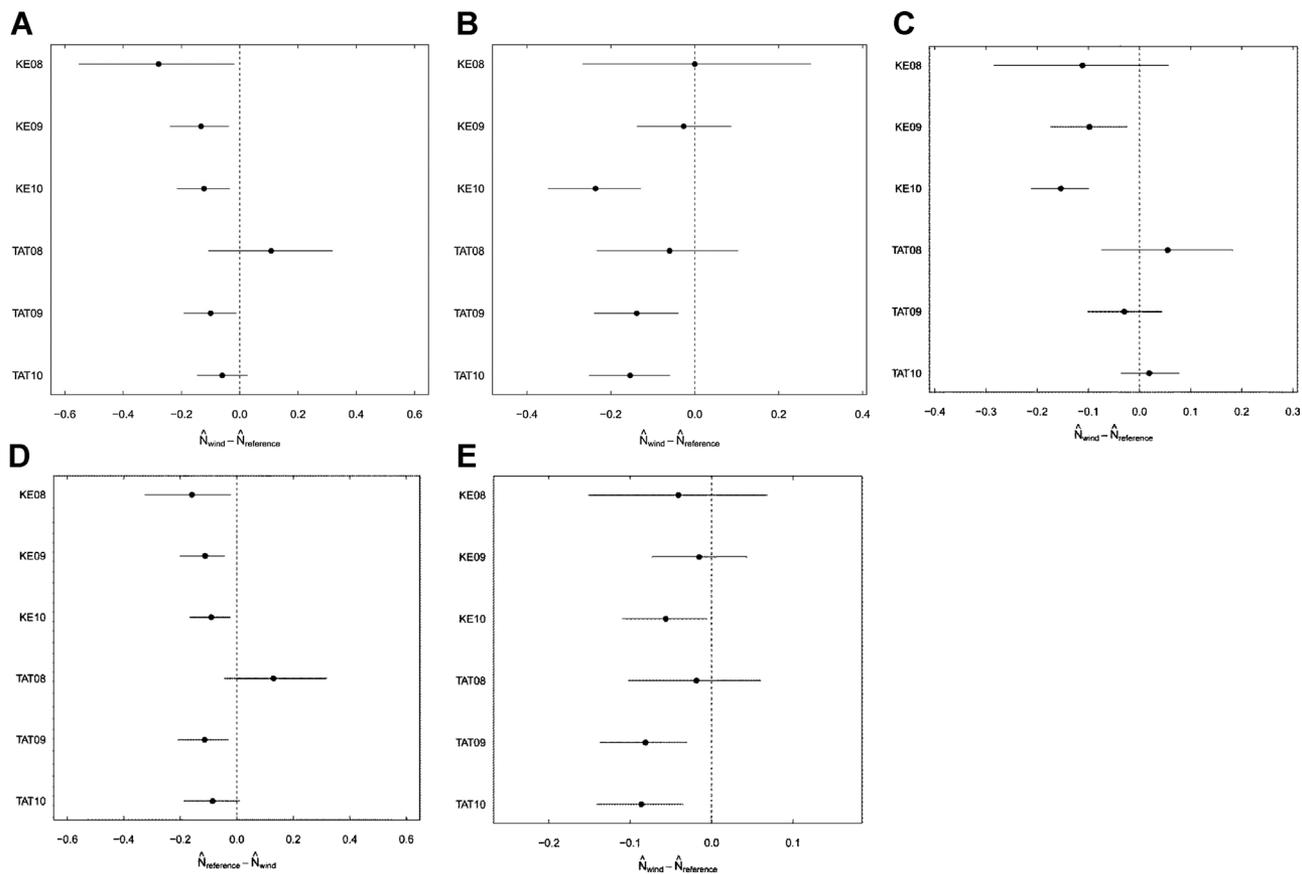


Figure 2. Year-specific estimated differences between estimated posterior median abundance of mallard (*Anas platyrhynchos*; A), blue-winged teal (*A. discors*; B), gadwall (*A. strepera*; C), northern pintail (*A. acuta*; D), and northern shoveler (*A. clypeata*; E) on a seasonal wetland of median area (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.

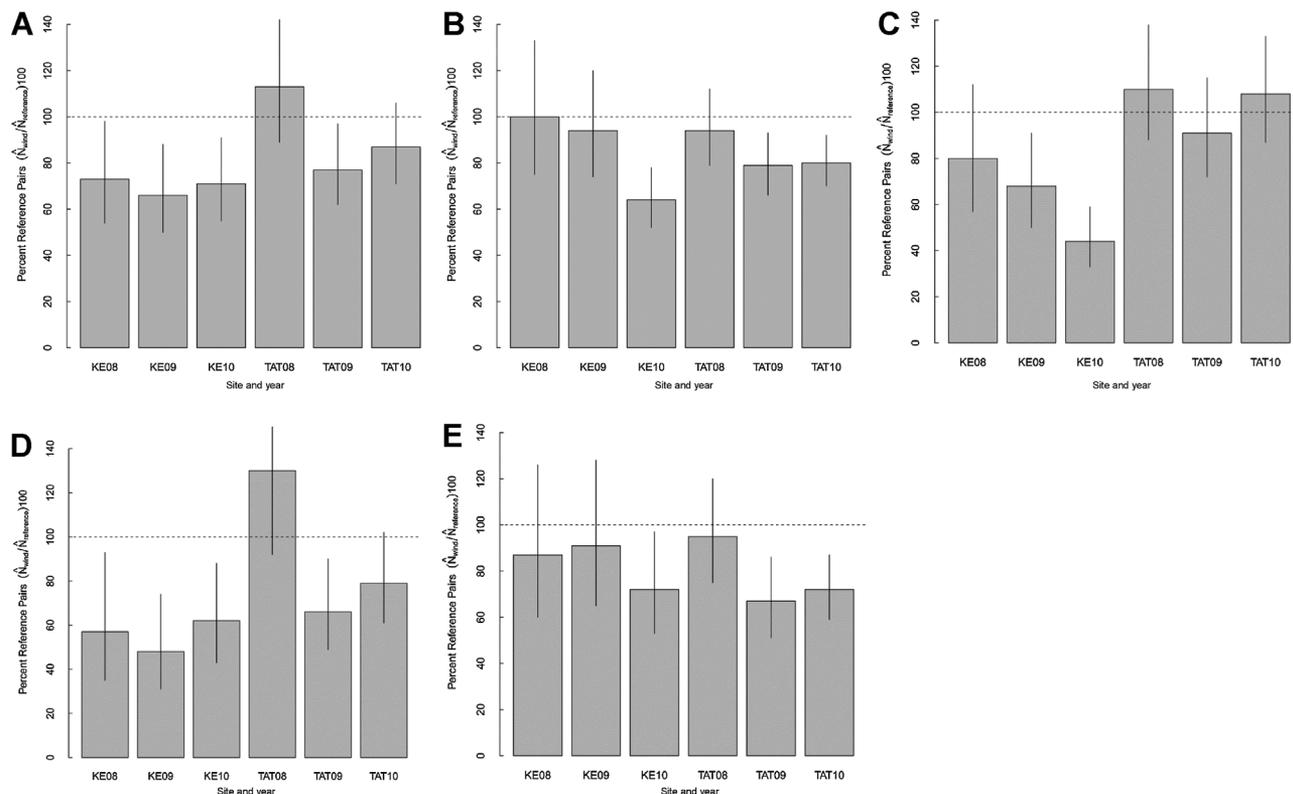


Figure 3. Year-specific estimated number of mallard (*Anas platyrhynchos*; A), blue-winged teal (*A. discors*; B), gadwall (*A. strepera*; C), northern pintail (*A. acuta*; D), and northern shoveler (*A. clypeata*; E) on a seasonal wetland of median area (0.2 ha) embedded in perennial cover on a wind 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.

LITERATURE CITED

- Arnett, E. B., W. K. Brown, W. P. Erickson, J. K. Fielder, B. L. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley. 2008. Patterns of bat fatalities at wind energy facilities in North America. *Journal of Wildlife Management* 72:61–78.
- Arnett, E. B., D. B. Inkley, D. H. Johnson, R. P. Larkin, S. Manes, A. M. Manville, J. R. Mason, M. L. Morrison, M. D. Strickland, and R. Thresher. 2007. Impacts of wind energy facilities on wildlife and wildlife habitat. *Wildlife Society Technical Review 07-2*. The Wildlife Society, Bethesda, Maryland, USA.
- Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. *Journal of Wildlife Management* 74:1175–1178.
- Austin, J. E. 2002. Responses of dabbling ducks to wetland conditions in the Prairie Pothole Region. *Waterbirds* 25:465–473.
- Batt, B. D. J., M. G. Anderson, C. D. Anderson, and F. D. Caswell. 1989. The use of prairie potholes by North American ducks. Pages 204–227 in A. van der Valk, editor. *Northern prairie wetlands*. Iowa State University Press, Ames, USA.
- Bejder, L., A. Samuels, H. Whitehead, H. Finn, and S. Allen. 2009. Impact assessment research: use and misuse of habituation, sensitization and tolerance in describing wildlife responses to anthropogenic stimuli. *Marine Ecology Progress Series* 395:177–185.
- Bellrose, F. C. 1980. Ducks, geese, and swans of North America. Second Edition. Stackpole Books, Harrisburg, Pennsylvania, USA.
- Bluemle, J. P. 1991. The face of North Dakota. North Dakota Geological Survey, Educational Series 21, Bismarck, USA.
- Brasher, M. G., R. M. Kaminski, and L. W. Burger, Jr. 2002. Evaluation of indicated breeding pair criteria to estimate mallard breeding populations. *Journal of Wildlife Management* 66:985–992.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Chambers, J. M. 1992. Linear models. Pages 99–116 in J. M. Chambers and T. J. Hastie, editors. *Statistical models*. S. Wadsworth & Brooks/Cole, Belmont, California, USA.

- Claassen, R., F. Carraizo, J. C. Cooper, D. Hellerstein, and K. Ueda. 2011. Grassland to cropland conversion in the Northern Plains: the role of crop insurance, commodity, and disaster programs. U.S. Department of Agriculture Economic Research Service Economic Research Report 120, Washington, D.C., USA.
- Congdon, P. 2005. Bayesian models for categorical data. John Wiley and Sons, Chichester, West Sussex, England.
- Copeland, H. E., A. Pocewicz, and J. M. Kiesecker. 2011. Geography of energy development in western North America: potential impacts on terrestrial ecosystems. Pages 7–25 in D. E. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington D.C., USA.
- Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Science-79/31, Washington, D.C., USA.
- Cowardin, L. M., D. H. Johnson, T. L. Shaffer, and D. W. Sparling. 1988. Applications of a simulation model to decisions in mallard management. U.S. Department of the Interior Fish and Wildlife Service Technical Report 17, Washington, D.C., USA.
- Cowardin, L. M., T. L. Shaffer, and P. M. Arnold. 1995. Evaluations of duck habitat and estimation of duck population sizes with a remote-sensing-based approach. Biological Science Report No. 2. U.S. Department of the Interior, Washington, D.C., USA.
- Crawley, M. J. 2007. The R book. John Wiley and Sons, Chichester, West Sussex, England.
- Dahl, T. E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.
- Dahlgren, R. B., and C. E. Korschgen. 1992. Human disturbances of waterfowl: an annotated bibliography. U.S. Fish and Wildlife Service Resource Publication 188, Washington, D.C., USA.
- Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting habitat: the importance of managing at multiple scales. Journal of Wildlife Management 74:1544–1553.
- Drewitt, A. L., and R. H. W. Langston. 2006. Assessing the impacts of wind farms on birds. Ibis 148:29–42.
- Dzubin, A. 1969. Assessing breeding populations of ducks by ground counts. Pages 178–230 in Saskatchewan Wetlands Seminar. Canadian Wildlife Service Report 6, Ottawa, Canada.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207–231.
- Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. Second Edition. Chapman and Hall/CRC Press, Boca Raton, Florida, USA.
- Government Accounting Office. 2007. Prairie Pothole Region: at the current pace of acquisitions, the U.S. Fish and Wildlife Service is unlikely to achieve its habitat protection goals for migratory birds. Report to the Subcommittee on Interior, Environment, and Related Agencies, Committee on Appropriations, House of Representatives. United States Government Accountability Office. 07-1093, Washington, D.C., USA.
- Greenwood, R. J., A. B. Sargeant, D. H. Johnson, L. M. Cowardin, and T. L. Shaffer. 1995. Factors associated with duck nest success in the Prairie Pothole Region of Canada. Wildlife Monographs 128.
- Gue, C. T. 2012. Effects of a large-scale wind farm in the Prairie Pothole Region of North and South Dakota on survival and habitat use of breeding female mallards (*Anas platyrhynchos*) and blue-winged teal (*A. discors*). Thesis, University of North Dakota, Grand Forks, USA.
- Habib, L., E. M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. Journal of Applied Ecology 44:176–184.
- Hammond, M. C. 1969. Notes on conducting waterfowl breeding population surveys in the north central states. Pages 238–254 in Saskatchewan Wetlands Seminar. Canadian Wildlife Service Report 6, Ottawa, Canada.
- Harju, S. M., M. R. Dzialak, R. C. Taylor, L. D. Hayden-Wing, and J. B. Winstead. 2010. Thresholds and time lags in effects of energy development on greater sage-grouse populations. Journal of Wildlife Management 74:437–448.
- Heimiller, D. M., and S. R. Haymes. 2001. Geographic information systems in support of wind energy activities at NREL. National Renewable Energy Laboratory, Golden, Colorado, USA.
- Higgins, K. F., L. M. Kirsch, A. T. Klett, and H. W. Miller. 1992. Waterfowl production on the Woodworth Station in south-central North Dakota, 1965–1981. U.S. Fish and Wildlife Service, Resource Publication 180, Washington, D.C., USA.
- Ingelfinger, F., and S. Anderson. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64:385–395.
- Jackman, S. 2008. pscl: classes and methods for R developed in the Political Science Computational Laboratory, Stanford University. Department of Political Science, Stanford University, Stanford, California, USA.
- Johnson, D. H., and J. W. Grier. 1988. Determinants of breeding distributions of ducks. Wildlife Monographs 100.
- Johnson, D. H., J. D. Nichols, and M. D. Schwartz. 1992. Population dynamics of breeding waterfowl. Pages 446–485 in B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis, USA.
- Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepard, and D. A. Shepard. 2000. Avian monitoring studies at the Buffalo Ridge, Minnesota wind resource area: results of a 4-year study. Final report. West Ecosystems Technology, Inc., Cheyenne, Wyoming, USA.
- Johnson, R. R., and K. F. Higgins. 1997. Wetland resources of eastern South Dakota. South Dakota State University, Brookings, USA.
- Kass, R. E., B. P. Carlin, A. Gelman, and R. M. Neal. 1998. Markov chain Monte Carlo in practice: a roundtable discussion. American Statistician 52:93–100.
- Kiesecker, J. M., J. S. Evans, J. Fargione, K. Doherty, K. R. Foresman, T. H. Kunz, D. Naugle, N. P. Nibbelink, and N. D. Niemuth. 2011. Win-win for wind and wildlife: a vision to facilitate sustainable development. PLoS ONE 6:e17566.
- Krausman, P. R. 2011. Quantifying cumulative effects. Pages 47–64 in P. R. Krausman and L. K. Harris, editors. Cumulative effects in wildlife management—impact mitigation. CRC Press, Boca Raton, Florida, USA.
- Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard, and F. C. Bryant. 2007. Wind energy development and wildlife conservation: challenges and opportunities. Journal of Wildlife Management 71:2487–2498.
- Larsen, J. K., and J. Madsen. 2000. Effects of wind turbines and other physical elements on field utilization by pink-footed geese (*Anser brachyrhynchus*): a landscape perspective. Landscape Ecology 15:755–764.
- Leddy, K. L., K. F. Higgins, and D. E. Naugle. 1999. Effects of wind turbines on upland nesting birds in Conservation Research Program grasslands. Wilson Bulletin 111:100–104.
- Link, W. A., and R. J. Barker. 2009. Bayesian inference with ecological applications. Academic Press, Burlington, Massachusetts, USA.
- Loesch, C. R., R. E. Reynolds, and L. T. Hansen. 2012. An assessment of re-directing breeding waterfowl conservation relative to predictions of climate change. Journal of Fish and Wildlife Management 3:1–22.
- Mac, M. J., P. A. Opler, C. E. Puckett Haecker, and P. D. Doran. 1998. Status and trends of the nation's biological resources. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia, USA.
- Madders, M., and D. P. Whitfield. 2006. Upland raptors and the assessment of wind farm impacts. Ibis 148:43–56.
- Madsen, J. 1995. Impacts of disturbance on migratory waterfowl. Ibis 137:S67–S74.
- Madsen, J., and D. Boertmann. 2008. Animal behavioral adaptation to changing landscapes: spring staging geese habituate to wind farms. Landscape Ecology 23:1007–1011.
- McCullagh, P., and J. A. Nelder. 1989. Generalized linear models (Monographs on statistics and applied probability 37). Chapman Hall, London, England.
- McDonald, R. I., J. Fargione, J. Kiesecker, W. M. Miller, and J. Powell. 2009. Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America. PLoS ONE 4(8):e6802.
- McDonald, T. L., W. P. Erickson, and L. L. McDonald. 2000. Analysis of count data from before-after control-impact studies. Journal of Agricultural, Biological, and Environmental Statistics 5:262–279.
- Naugle, D. E., R. R. Johnson, T. R. Cooper, M. M. Holland, and K. F. Higgins. 2000. Temporal distribution of waterfowl in eastern South Dakota: implications for aerial surveys. Wetlands 20:177–183.
- Niemuth, N. D., G. W. Beyersbergen, and M. R. Norton. 2005. Waterbird conservation planning in the northern prairie and parkland region: inte-

- gration across borders and with other bird conservation initiatives. Pages 184–189 in J. C. Ralph and T. D. Rich, editors. Bird conservation implementation and integration in the Americas: proceedings of the third international partners in flight conference. Volume 1 General Technical Report PSW-GTR-191. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, USA.
- Niemuth, N. D., R. E. Reynolds, D. A. Granfors, R. R. Johnson, B. Wangler, and M. E. Estey, 2008. Landscape-level planning for conservation of wetland birds in the U.S. Prairie Pothole Region. Pages 533–560 in J. J. Millsbaugh and F. R. Thompson, III, editors. Models for planning wildlife conservation in large landscapes. Elsevier Science: Burlington, Massachusetts, USA.
- Niemuth N. D., B. Wangler, and R. E. Reynolds. 2010. Spatial and temporal variation in wet area of wetlands in the Prairie Pothole Region of North Dakota and South Dakota. *Wetlands* 30:1053–1064.
- OpenEnergyInfo. 2012. Openenergyinfo homepage. <<http://en.openei.org>>. Accessed 6 Aug 2012.
- Oslund, F. T., R. R. Johnson, and D. R. Hertel. 2010. Assessing wetland changes in the Prairie Pothole Region of Minnesota from 1980 to 2007. *Journal of Fish and Wildlife Management* 1:131–135.
- Pagano, A. M., and T. W. Arnold. 2009. Detection probabilities for ground-based breeding waterfowl surveys. *Journal of Wildlife Management* 73:392–398.
- Pearce-Higgins, J. W., S. Leigh, R. H. W. Langston, I. P. Bainbridge, and R. Bullman. 2009. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* 46:1323–1331.
- Plummer, M., N. Best, K. Cowles, and K. Vines. 2009. coda: output analysis and diagnostics for MCMC. Version 0.13-4. R Development Core Team, Vienna, Austria.
- R Development Core Team. 2011. R: a language and environment for statistical computing. Version 2.13.1. R Development Core Team, Vienna, Austria.
- Reijnen, R., and R. Foppen. 2006. Impact of road traffic on breeding bird populations. Pages 255–274 in J. Davenport and J. L. Davenport, editors. The ecology of transportation: managing mobility for the environment. *Environmental Pollution* volume 10. Springer, Dordrecht, The Netherlands.
- Reynolds, R. E., D. R. Cohan, and M. A. Johnson. 1996. Using landscape information approaches to increase duck recruitment in the Prairie Pothole Region. *Transactions of the North American Wildlife and Natural Resources Conference* 61:86–93.
- Reynolds, R. E., C. R. Loesch, B. Wangler, and T. L. Shaffer. 2007. Waterfowl response to the Conservation Reserve Program and Swampbuster Provisions in the Prairie Pothole Region, 1992–2004. U.S. Department of Agriculture RFA 05-IA-04000000-N34, Bismarck, North Dakota, USA.
- Reynolds, R. E., T. L. Shaffer, C. R. Loesch, and R. R. Cox, Jr., 2006. The Farm Bill and duck production in the Prairie Pothole Region: increasing the benefits. *Wildlife Society Bulletin* 34:963–974.
- Reynolds, R. E., T. L. Shaffer, R. W. Renner, W. E. Newton, and B. D. J. Batt. 2001. Impact of the Conservation Reserve Program on duck recruitment in the U.S. Prairie Pothole Region. *Journal of Wildlife Management* 65:765–780.
- Ringelman, J. K., editor. 2005. Prairie Pothole Joint Venture 2005 implementation plan. U.S. Fish and Wildlife Service, Denver, Colorado, USA.
- Royle, J. A., and R. M. Dorazio. 2008. Hierarchical modeling and inference in ecology: the analysis of data from populations, metapopulations and communities. Academic Press, Burlington, Massachusetts, USA.
- Schneider, R. R., J. B. Stelfox, S. Boutin, and S. Wasel. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: a modeling approach. *Conservation Ecology* 7:8.
- Shaffer, J. A., and D. H. Johnson. 2008. Displacement effects of wind developments on grassland birds in the northern Great Plains. Pages 57–61 in Proceedings of wind wildlife research meeting VII. National Wind Coordinating Collaborative, Washington, D.C., USA.
- Sorensen, T., P. D. McLoughlin, D. Hervieux, E. Dzus, J. Nolan, B. Wynes, and S. Boutin. 2008. Determining sustainable levels of cumulative effects for boreal caribou. *Journal of Wildlife Management* 72:900–905.
- Spiegelhalter, D., A. Thomas, N. Best, and D. Lunn. 2003. WinBUGS user manual, version 1.4. Cambridge: MRC Biostatistics Unit, Cambridge, United Kingdom.
- Stephens, S. E., J. J. Rotella, M. S. Lindberg, M. L. Taper, and J. K. Ringelman. 2005. Duck nest survival in the Missouri Coteau of North Dakota: landscape effects at multiple spatial scales. *Ecological Applications* 15:2137–2149.
- Stephens, S. E., J. A. Walker, D. R. Blunck, A. Jayaraman, D. E. Naugle, J. K. Ringelman, and A. J. Smith. 2008. Predicting risk of habitat conversion in native temperate grasslands. *Conservation Biology* 22:1320–1330.
- Stewart, G. B., A. S. Pullin, and C. F. Coles. 2007. Poor evidence-base for assessment of windfarm impacts on birds. *Environmental Conservation* 34:1–11.
- Stewart, R. E., and H. A. Kantrud. 1973. Ecological distribution of breeding waterfowl populations in North Dakota. *Journal of Wildlife Management* 37:39–50.
- Streftaris, G., and B. J. Worton. 2008. Efficient and accurate approximate Bayesian inference with an application to insurance data. *Computational Statistics and Data Analysis* 52:2604–2622.
- Sturtz, S., U. Ligges, and A. Gelman. 2005. R2WinBUGS: a package for running WinBUGS from R. *Journal of Statistical Software* 12: 1–16.
- United States Department of Energy [USDOE]. 2008. 20% wind energy by 2030 increasing wind energy's contribution to U.S. electricity supply. Department of Energy, Office of Scientific and Technical Information, Oak Ridge, Tennessee, USA.
- United States Department of Energy [USDOE]. 2011. Wind Power America homepage. <<http://www.windpoweringamerica.gov>>. Accessed 6 Aug 2012.
- U.S. Fish and Wildlife Service [USFWS]. 2006. Strategic habitat conservation plan: final report of the National Ecological Assessment Team. Department of the Interior, Washington, D.C., USA.
- U.S. Fish and Wildlife Service [USFWS]. 2011. Annual report of lands under the control of the U.S. Fish and Wildlife Service. Department of the Interior, U.S. Fish and Wildlife Service Division of Realty, Washington D.C., USA.
- U.S. Fish and Wildlife Service [USFWS]. 2012. Waterfowl population status, 2012. U.S. Department of the Interior, Washington, D.C., USA.
- van der Valk, A. G., editor. 1989. Northern prairie wetlands. Iowa State University Press, Ames, USA.
- Vors, L. S., J. A. Schaefer, B. A. Pond, A. R. Rodgers, and B. R. Patterson. 2007. Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management* 71:1249–1256.
- Walker, D., M. McGrady, A. McCluskie, M. Madders, and D. R. A. McLeod. 2005. Resident golden eagle ranging behaviour before and after construction of a wind farm in Argyll. *Scottish Birds* 25:24–40.
- Walker, J. A. 2011. Survival of duck nests, distribution of duck broods, and habitat conservation targeting in the Prairie Pothole Region. Dissertation, University of Alaska Fairbanks, USA.
- Winkelman, J. E. 1990. Impact of the wind park near Urk, Netherlands, on birds: bird collision victims and disturbance of wintering fowl. *International Ornithological Congress* 20:402–403.
- Zuur, A. F., E. N. Ieno, and G. M. Smith. 2007. Analysing ecological data. Springer Verlag, New York, New York, USA.

Associate Editor: Michael Chamberlain.



Effects of wind-energy facilities on breeding grassland bird distributions

Jill A. Shaffer and Deborah A. Buhl

U.S. Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, U.S.A.

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*

Address correspondence to Jill A. Shaffer, U.S. Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, U.S.A., email: jsbaffer@usgs.gov

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

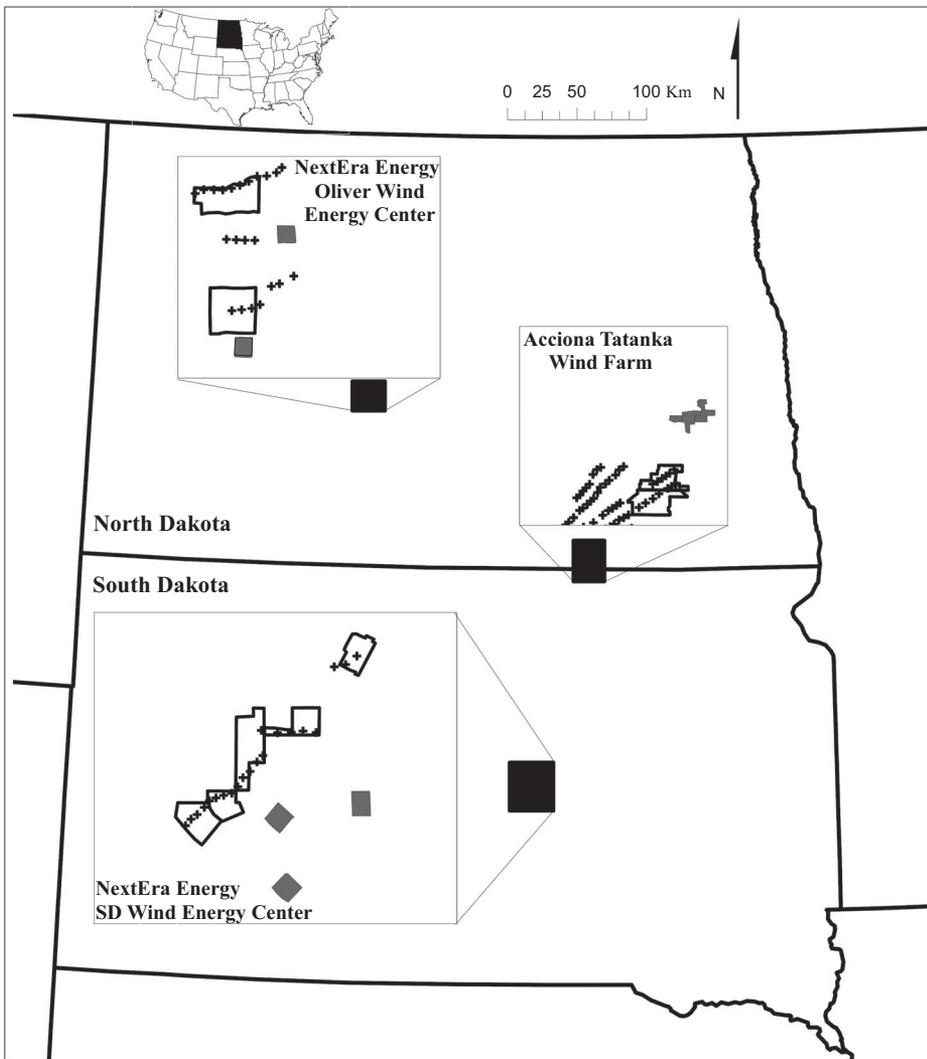


Figure 1. Map of studied wind-energy facilities in North Dakota and South Dakota (U.S.A.) (white polygons, turbine treatment sites; gray polygons, reference sites; plus symbol, turbine locations).

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

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

| Location and distance from turbines (m) | Grasshopper Sparrow | Western Meadowlark | Bobolink | Upland Sandpiper | Killdeer | Savannah Sparrow | Clay-colored Sparrow | Chestnut-collared Longspur | Vesper Sparrow |
|---|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| SD | | | | | | | | | |
| 0-100 | $t_{76} = -1.84$, $p = 0.07$ | $t_{77} = -3.90$, $p < 0.01$ | $t_{57} = -1.25$, $p = 0.22$ | $t_{83} = -1.33$, $p = 0.19$ | $t_{92} = 3.21$, $p < 0.01$ | | | $t_{69} = 0.62$, $p = 0.54$ | |
| 100-200 | $t_{76} = -0.31$, $p = 0.76$ | $t_{77} = -0.75$, $p = 0.47$ | $t_{57} = -0.26$, $p = 0.80$ | $t_{83} = 0.38$, $p = 0.70$ | $t_{92} = 0.70$, $p = 0.49$ | | | $t_{69} = -1.09$, $p = 0.28$ | |
| 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.

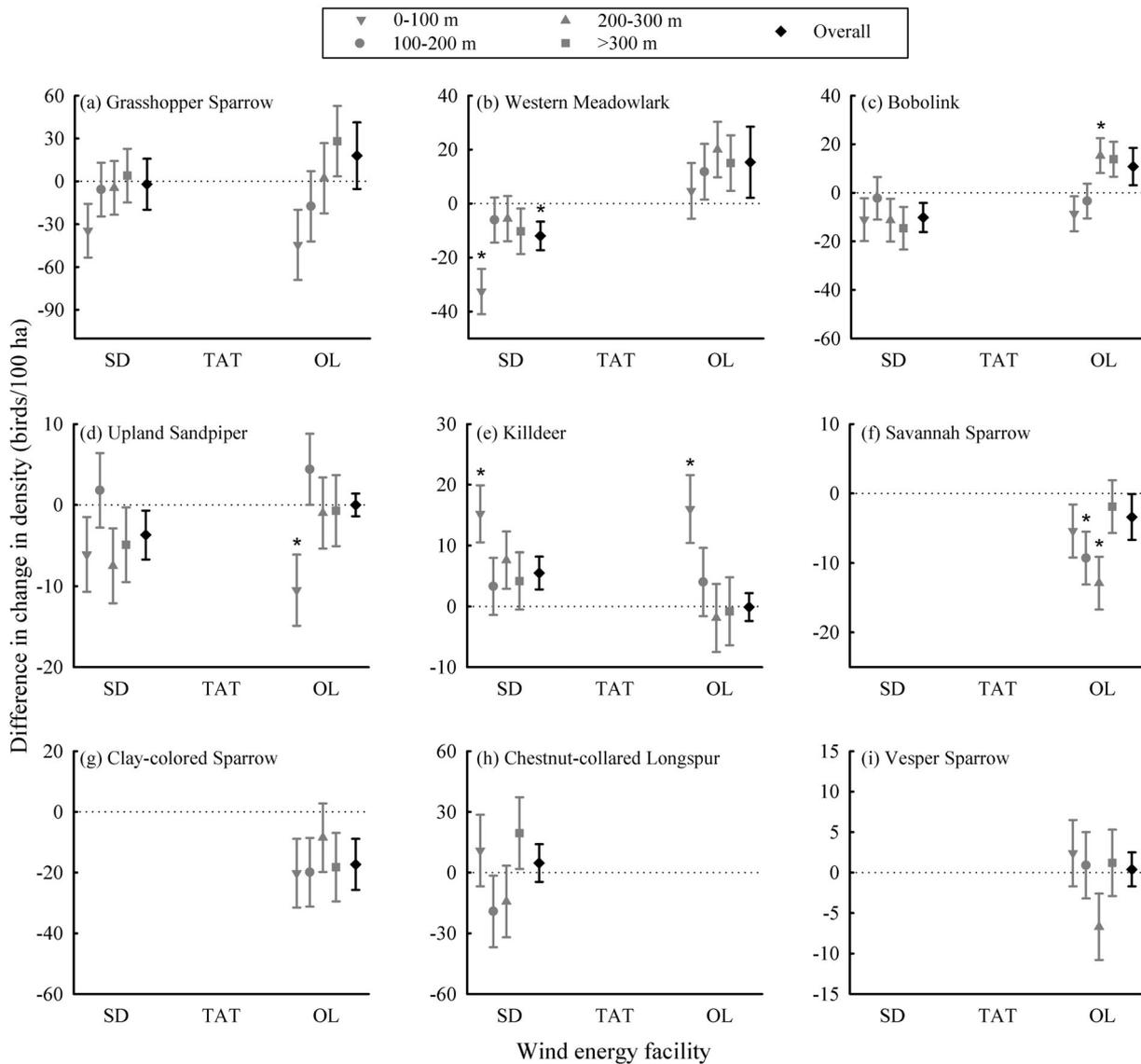


Figure 2. Difference in change in bird density/100 ha between reference and wind turbine sites from pre-treatment year to 1 year post-treatment (immediate effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy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

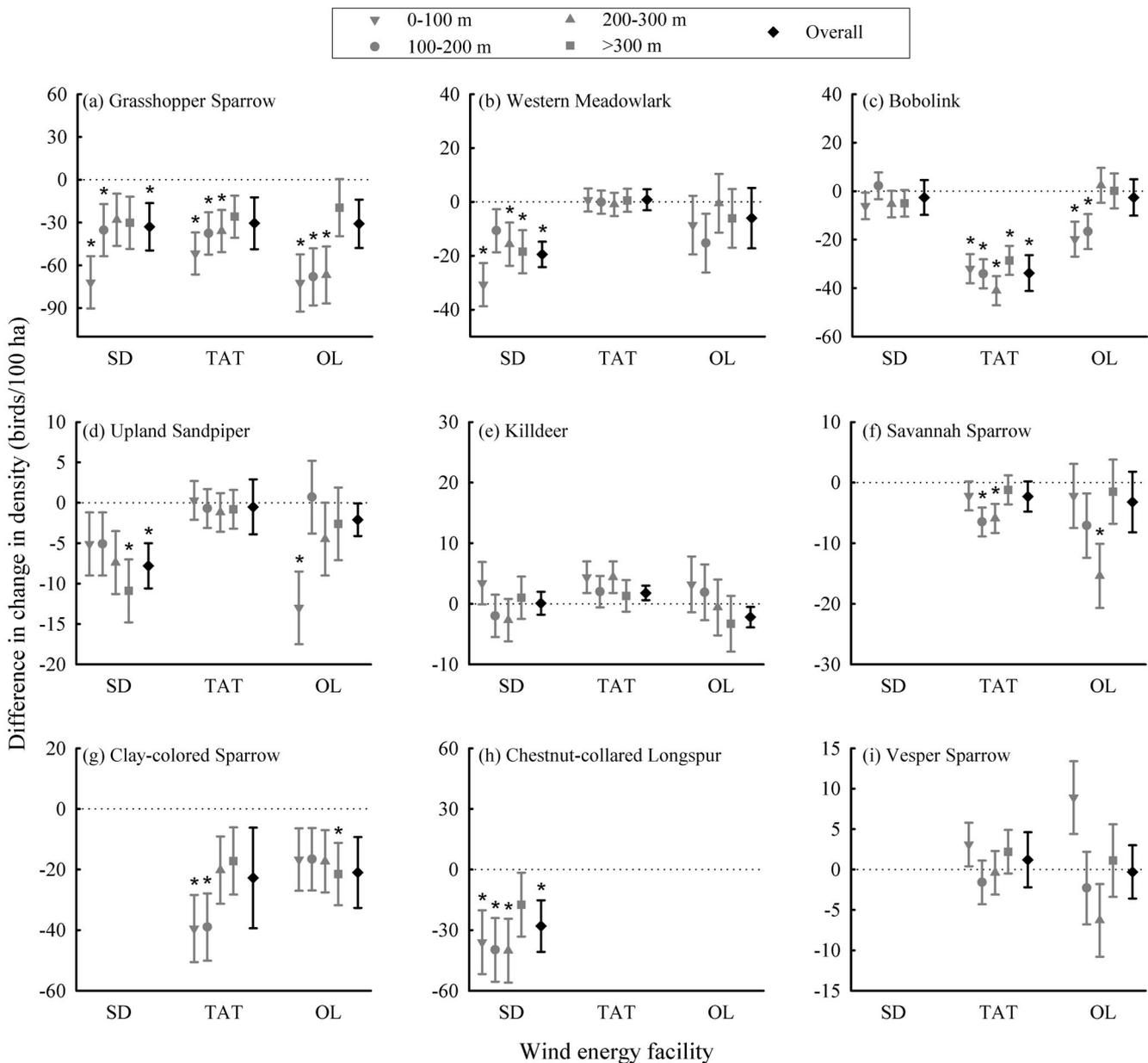


Figure 3. Difference in change in bird density/100 ha between reference and wind turbine site from pre-treatment year to 2–5 years post-treatment (delayed effect) in South Dakota (NextEra Energy [NEE] SD Wind Energy Center [SD]) and North Dakota (Acciona Tatanka Wind Farm [TAT] and NEE Oliver Wind Energy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

Literature Cited

- Arnett EB, Inkley DB, Johnson DH, Larkin RP, Manes S, Manville AM, Mason JR, Morrison ML, Strickland MD, Thresher R. 2007. Impacts of wind energy facilities on wildlife and wildlife habitat. Wildlife Society technical review 07-2. The Wildlife Society, Bethesda, MD.
- Berman GM. 2007. Nesting success of grassland birds in fragmented and unfragmented landscapes of north central South Dakota. M.S. thesis. South Dakota State University, Brookings, South Dakota.
- Bluemle JP. 1991. The face of North Dakota. Educational series 11. North Dakota Geological Survey, Bismarck, North Dakota. Available from http://www.dmr.nd.gov/ndgs/documents/Publication_List/pdf/EducationSeries/ED-11.pdf (accessed April 2015).
- Doherty KE, Ryba AJ, Stenler CL, Niemuth ND, Meeks WA. 2013. Conservation planning in an era of change: state of the U.S. Prairie Pothole Region. *Wildlife Society Bulletin* 37:546–563.
- Douglas DJT, Bellamy PE, Pearce-Higgins JW. 2011. Changes in the abundance and distribution of upland breeding birds at an operational wind farm. *Bird Study* 58:37–43.
- Drewitt A, Langston RHW. 2006. Assessing the impacts of wind farms on birds. In: wind, fire and water: renewable energy and birds. *Ibis* 148:76–89.
- Erickson WP, Jeffrey J, Kronner K, Bay K. 2004. Stateline Wind Project wildlife monitoring final report July 2001–December 2003. Western EcoSystems Technology, Cheyenne, Wyoming, and Northwest Wildlife Consultants, Pendleton, Oregon.
- Evans PGH. 2008. Offshore wind farms and marine mammals: impacts and methodologies for assessing impacts. ECS special publication series 49. European Cetacean Society. Available from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.232.302&rep=rep1&type=pdf> (accessed April 2015).
- Fajardo N, Strong AM, Perlut NG, Buckley NJ. 2009. Natal and breeding dispersal of Bobolinks (*Dolichonyx oryzivorus*) and Savannah Sparrows (*Passerculus sandwichensis*) in an agricultural landscape. *Auk* 126:310–318.

- Grant TA, Knapton RW. 2012. Clay-colored Sparrow (*Spizella pallida*). Number 120 in Poole A, editor. The birds of North America online, Cornell Lab of Ornithology, Ithaca, New York. Available from <http://www.bna.birds.cornell.edu/bna/species/120> (accessed April 2015).
- Grant TA, Madden E, Berkey GB. 2004. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. *Wildlife Society Bulletin* 32:807–818.
- Green RH. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York.
- Greer MJ. 2009. An evaluation of habitat use and requirements for grassland bird species of greatest conservation need in central and western South Dakota. M.S. thesis. South Dakota State University, Brookings, South Dakota.
- Gue CT, Walker JA, Mehl KR, Gleason JS, Stephens SE, Loesch CR, Reynolds RE, Goodwin BJ. 2013. The effects of a large-scale wind farm on breeding season survival of female Mallards and Blue-winged Teal in the Prairie Pothole Region. *Journal of Wildlife Management* 77:1360–1371.
- Helldin JO, Jung J, Neumann W, Olsson M, Skarin A, Widemo F. 2012. The impacts of wind power on terrestrial mammals: a synthesis. Swedish Environmental Protection Agency, Bromma. Available from <http://www.naturvardsverket.se/Om-Naturvardsverket/Publicationer/ISBN/6500/978-91-620-6510-2> (accessed April 2015).
- Hill DP, Gould LK. 1997. Chestnut-collared Longspur (*Calcarius ornatus*). Number 288 in Poole A, editor. The birds of North America online, Cornell Lab of Ornithology, Ithaca, New York. Available from <http://bna.birds.cornell.edu/bna/species/288> (accessed April 2015).
- IPCC (Intergovernmental Panel on Climate Change). 2011. Summary for policymakers. IPCC special report on renewable energy sources and climate change mitigation. Cambridge University Press, New York.
- IPCC (Intergovernmental Panel on Climate Change). 2012. IPCC special report on renewable energy sources and climate change mitigation. Cambridge University Press, New York.
- Irons DB, Kendall SJ, Erickson WP, McDonald LL, Lance BK. 2000. Nine years after the Exxon Valdez oil spill: effects on marine bird populations in Prince William Sound, Alaska. *Condor* 102:723–737.
- Jackson BJ, Jackson JA. 2000. Killdeer (*Charadrius vociferus*). Number 517 in Poole A, editor. The birds of North America online, Cornell Lab of Ornithology, Ithaca, New York. Available from <http://bna.birds.cornell.edu/bna/species/517> (accessed April 2015).
- Jenkins D, Watson A, Miller GR. 1963. Population studies on Red Grouse, *Lagopus lagopus scoticus* (Lath.) in north-east Scotland. *Journal of Animal Ecology* 32:317–376.
- Johnson DH, Igl LD. 2001. Area requirements of grassland birds: a regional perspective. *Auk* 118:24–34.
- Johnson GD, Erickson WP, Strickland MD, Shepherd MF, Shepherd DA. 2000. Avian monitoring studies at the Buffalo Ridge Wind Resource Area, Minnesota: results of a four-year study. Technical report prepared for Northern States Power Co., Minneapolis, Minnesota. Western EcoSystems Technology, Inc., Cheyenne, Wyoming.
- Johnson GD, Stephens SE. 2011. Wind power and biofuels: a green dilemma for wildlife conservation. Pages 131–155 in Naugle DE, editor. Energy facilities and wildlife conservation in western North America. Island Press, Washington, D.C.
- Johnston A, Cook ASCP, Wright LJ, Humphreys EM, Burton NHK. 2013. Modelling flight heights of marine birds to more accurately assess collision risk with offshore wind facilities. *Journal of Applied Ecology* 51:31–41.
- Jones SL, Cornely JE. 2002. Vesper Sparrow (*Pooecetes gramineus*). Number 624 in Poole A, editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, New York. Available from <http://bna.birds.cornell.edu/bna/species/624> (accessed April 2015).
- Jones SL, Dieni JS, Green MT, Gouse PJ. 2007. Annual return rates of breeding grassland songbirds. *Wilson Journal of Ornithology* 119:89–94.
- Kiesecker JM, Evans JS, Fargione J, Doherty K, Foresman KR, Kunz TH, Naugle D, Nibbelink NP, Niemuth ND. 2011. Win-win for wind and wildlife: a vision to facilitate sustainable development. *PLOS ONE* 6:e17566 DOI: 10.1371/journal.pone.0017566.
- Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O. 2006. SAS for mixed models. 2nd edition. SAS Institute, Cary, NC.
- Loesch CR, Walker JA, Reynolds RE, Gleason JS, Niemuth ND, Stephens SE, Erickson MA. 2013. Effect of wind energy facilities on breeding duck densities in the Prairie Pothole Region. *Journal of Wildlife Management* 77:587–598.
- Manly BFJ. 2001. Statistics for environmental science and management. Chapman and Hall/CRC, Boca Raton, FL.
- Martin SG, Gavin TA. 1995. Bobolink (*Dolichonyx oryzivorus*). Number 176 in Poole A, editor. The birds of North America online, Cornell Lab of Ornithology, Ithaca, New York. Available from <http://bna.birds.cornell.edu/bna/species/176> (accessed April 2015).
- McDonald RI, Fargione J, Kiesecker J, Miller WM, Powell J. 2009. Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America. *PLOS ONE* 4:e6802 DOI: 10.1371/journal.pone.0006802.
- McDonald TL, Erickson WP, McDonald LL. 2000. Analysis of count data from before-after control-impact studies. *Journal of Agricultural, Biological, and Environmental Statistics* 5:262–279.
- McLaughlin ME, Janousek WM, McCarty JP, Wolfenbarger LL. 2014. Effects of urbanization on site occupancy and density of grassland birds in tallgrass prairie fragments. *Journal of Field Ornithology* 85:258–273.
- Milliken GA, Johnson DE. 2009. Analysis of messy data, volume I: designed experiments, 2nd edition. Chapman and Hall/CRC, New York.
- Niemuth ND, Walker JA, Gleason JS, Loesch CR, Reynolds RE, Stephens SE, Erickson MA. 2013. Influence of wind turbines on presence of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on wetlands in the Prairie Pothole Region of North Dakota and South Dakota. *Waterbirds* 36:263–276.
- NOAA (National Oceanic and Atmospheric Administration). 2015. Historical Palmer Drought indices. National Climatic Data Center, Asheville, North Carolina. Available from <http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/psi/200303-201208> (accessed April 2015).
- Parr R. 1980. Population study of Golden Plover *Pluvialis apricaria* using marked birds. *Ornis Scandinavica* 11:179–189.
- Pearce-Higgins JW, Stephen L, Douse A, Langston RHW. 2012. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. *Journal of Applied Ecology* 49:386–394.
- Pearce-Higgins JW, Stephen L, Langston RHW, Bainbridge IP, Bullman R. 2009. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* 46:1323–1331.
- Péron, G, Hines JE, Nichols JD, Kendall WL, Peters KA, Mizrahi DS. 2013. Estimation of bird and bat mortality at wind-power farms with superpopulation models. *Journal of Applied Ecology* 50:902–911.
- Rashford BS, Walker JA, Bastian CT. 2011. Economics of grassland conversion to cropland in the Prairie Pothole Region. *Conservation Biology* 25:276–284.
- Ribic CA, Koford RR, Herkert JR, Johnson DH, Niemuth ND, Naugle DE, Bakker KK, Sample DW, Renfrew RB. 2009. Area sensitivity in North American grassland birds: patterns and processes. *Auk* 126:233–244.
- SAS Institute. 2012. SAS/STAT 12.1 user's guide. SAS Institute, Cary, North Carolina.

- Shaffer JA, Thiele JP. 2013. Distribution of Burrowing Owls in east-central South Dakota. *Prairie Naturalist* **45**:60-64.
- Smucker KM, Hutto RL, Steele BM. 2005. Changes in bird abundance after wildfire: importance of fire severity and time since fire. *Ecological Applications* **15**:1535-1549.
- Stephens SE, Walker JA, Blunck DR, Jayaraman A, Naugle DE, Ringelman JK, Smith AJ. 2008. Predicting risk of habitat conversion in native temperate grasslands. *Conservation Biology* **22**:1320-1330.
- Stevens TK, Hale AM, Karsten KB, Bennett VJ. 2013. An analysis of displacement from wind turbines in a grassland bird community. *Biodiversity & Conservation* **22**:1755-1767.
- Stewart GB, Pullin AS, Coles CF. 2007. Poor evidence-base for assessment of windfarm impacts on birds. *Environmental Conservation* **34**:1-11.
- Stewart RE, Kantrud HA. 1972. Population estimates of breeding birds in North Dakota. *Auk* **89**:766-788.
- Strickland MD, Arnett EB, Erickson WP, Johnson DH, Johnson GD, Morrison ML, Shaffer JA, Warren-Hicks W. 2011. Comprehensive guide to studying wind energy / wildlife interactions. National Wind Coordinating Collaborative, Washington, D.C. Available from <http://www.nationalwind.org/research/publications/comprehensive-guide> (accessed April 2015).
- Underwood AJ. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology* **161**:145-178.
- USDOE (U.S. Department of Energy). 2013. 2012 wind technologies market report. DOE/GO-102013-3948. Energy efficiency and renewable energy. U.S. Department of Energy, Washington, D.C. Available from http://www1.eere.energy.gov/wind/pdfs/2012_wind_technologies_market_report.pdf (accessed April 2015).
- Verbeke G, Molenberghs G. 2000. Linear mixed models for longitudinal data. Springer-Verlag, New York.
- Winkelman JE. 1992. De invloed van de Sep-proefwindcentrale te Oosterbierum (Fr.) op vogels, 4: verstoring (The impact of the Sep Wind Park near Oosterbierum 4: disturbance). DLO-Instituut voor Bos-en Natuuronderzoek, Arnhem, The Netherlands.
- Wright CK, Wimberly MC. 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. *Proceedings of the National Academy of Sciences* **110**:4134-4139.

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 |

Shaffer & Buhl. Wind facility effects on grassland birds. *Conservation Biology*, Supporting Information Appendix S1.

| | | | | | | | | |
|----------------------------|---------|-------------------------------|-----------------------------|--------------------|----|--------|---|-----|
| 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 |

Shaffer & Buhl. Wind facility effects on grassland birds. *Conservation Biology*, Supporting Information Appendix S1.

| | | | | | | | | |
|------------------------------|-----|---------------------|-------------------------|------------|---|--------|---|------------------|
| 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.

Literature Cited

- Barrios L, Rodriguez A. 2004. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. *Journal of Applied Ecology* **41**:72-81.
- Bennett VJ, Hale AM, Karsten KB, Gordon CE, Suson BJ. 2014. Effect of wind turbine proximity on nesting success in shrub-nesting birds. *American Midland-Naturalist* **172**:317-328.
- de Lucas M, Janss GFE, Ferrer M. 2004. The effects of a wind farm on birds in a migration point: the Strait of Gibraltar. *Biodiversity and Conservation* **13**:395-407.
- de Lucas M, Janss GFE, Ferrer M. 2005. A bird and small mammal BACI and IG design studies in a wind farm in Malpica (Spain). *Biodiversity and Conservation* **14**:3289-3303.
- Devereux CL, Denny MJH, Whittingham MJ. 2008. Minimal effects of wind turbines on the distribution of wintering farmland birds. *Journal of Applied Ecology* **45**:1689-1694.
- Douglas DJT, Bellamy PE, Pearce-Higgins JW. 2011. Changes in the abundance and distribution of upland breeding birds at an operational wind farm. *Bird Study* **58**:37-43.
- Erickson WP, Jeffrey J, Kronner K, Bay K. 2004. Stateline Wind Project Wildlife Monitoring Final Report July 2001–December 2003. Technical report for FPL Energy, Stateline Technical Advisory Committee, and Oregon Energy Siting Council, by Western EcoSystems Technology, Inc., Cheyenne, Wyoming, and Northwest Wildlife Consultants, Pendleton, Oregon.
- Garvin JC, Jennelle CS, Drake D, Grodsky SM. 2011. Response of raptors to a windfarm. *Journal of Applied Ecology* **48**:199-209.
- Hatchett ES, Hale AM, Bennett VJ, Karsten KB. 2013. Wind turbines do not negatively affect nest success in the Dickcissel (*Spiza americana*). *Auk* **130**:520-528.
- Jain AA, Koford RR, Hancock AW, Zenner GG. 2011. Bat mortality and activity at a Northern Iowa wind resource area. *American Midland Naturalist* **165**:185-200.
- Johnson GD, Erickson WP, Strickland MD, Shepherd MF, Shepherd DA. 2000a. Avian monitoring studies at the Buffalo Ridge Wind Resource Area, Minnesota: results of a four-year study. Technical report prepared for Northern States Power Co., Minneapolis, Minnesota. Western EcoSystems Technology, Inc., Cheyenne, Wyoming.
- Johnson GD, Young, Jr. DP, Derby CE, Erickson WP, Strickland MD, Kern J. 2000b. Wildlife monitoring studies, SeaWest Windpower Plant, Carbon County, Wyoming, 1995-1999. Technical report prepared by WEST for SeaWest Energy Corporation and Bureau of Land Management. Western EcoSystems Technology, Inc., Cheyenne, Wyoming.

- Larsen JK, Madsen J. 2000. Effects of wind turbines and other physical elements on field utilization by Pink-footed Geese (*Anser brachyrhynchus*): a landscape perspective. *Landscape Ecology* **15**:766-764.
- LeBeau CW, Beck JL, Johnson GD, Holloran MJ. 2014. Short-term impacts of wind energy development on Greater Sage-Grouse fitness. *Journal of Wildlife Management* **78**:522-530.
- Leddy KL, Higgins KF, Naugle DE. 1999. Effects of wind turbines on upland nesting birds in conservation reserve program grasslands. *Wilson Bulletin* **111**:100-104.
- Loesch CR, Walker JA, Reynolds RE, Gleason JS, Niemuth ND, Stephens SE, Erickson MA. 2013. Effect of wind energy facilities on breeding duck densities in in the Prairie Pothole Region. *Journal of Wildlife Management* **77**:587–598.
- Madsen J, Boertmann D. 2008. Animal behavioural adaptation to changing landscapes: spring-staging geese habituate to wind farms. *Landscape Ecology* **23**:1007-1011.
- Manly BFJ. 2001. *Statistics for environmental science and management*. Chapman and Hall/CRC, Boca Raton, Florida.
- McNew LB, Hunt LM, Gregory AJ, Wisely SM, Sandercock BK. 2014. Effects of wind energy development on nesting ecology of Greater Prairie-Chickens in fragmented grasslands. *Conservation Biology* **28**:1089-1099.
- Niemuth ND, Walker JA, Gleason JS, Loesch CR, Reynolds RE, Stephens SE, Erickson MA. 2013. Influence of wind turbines on presence of Willet, Marbled Godwit, Wilson’s Phalarope and Black Tern on wetlands in the Prairie Pothole Region of North Dakota and South Dakota. *Waterbirds* **36**:263–276.
- Osborn RG, Dieter CD, Higgins KF, Usgaard RE. 1998. Bird flight characteristics near wind turbines in Minnesota. *American Midland Naturalist* **139**:29-38.
- Pearce-Higgins JW, Stephen L, Douse A, Langston RHW. 2012. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. *Journal of Applied Ecology* **49**:386–394.
- Pearce-Higgins JW, Stephen L, Langston RHW, Bainbridge IP, Bullman R. 2009. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* **46**:1323–1331.
- Rabin LA, Coss RG, Owings DH. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biological Conservation* **131**:410-420.
- Rubenstein TG, Hale AM, Karsten KB. 2012. Nesting success of Scissor-tailed Flycatchers (*Tyrannus forficatus*) at a wind farm in northern Texas. *Southwestern Naturalist* **57**:189-194.

Stevens TK, Hale AM, Karsten KB, Bennett VJ. 2013. An analysis of displacement from wind turbines in a grassland bird community. *Biodiversity and Conservation* **22**:1755–1767.

Walter WD, Leslie, Jr. DM, Jenks JA. 2006. Response of Rocky Mountain Elk (*Cervus elaphus*) to wind-power development. *American Midland Naturalist* **156**:363-375.

Winder VL, McNew LB, Gregory AJ, Hunt LM, Wisely SM, Sandercock BK. 2014a. Effects of wind energy development on survival of female Greater Prairie-Chickens. *Journal of Applied Ecology* **51**:395-405.

Winder VL, McNew LB, Gregory AJ, Hunt LM, Wisely SM, Sandercock BK. 2014b. Space use by female Greater Prairie-Chickens in response to wind energy development. *Ecosphere* **5**:art3. <http://www.esajournals.org/doi/abs/10.1890/ES13-00206.1>.

Winkelman JE. 1992. De invloed van de Sep-proefwindcentrale te Oosterbierum (Fr.) op vogels, 4: verstoring (The impact of the Sep Wind Park near Oosterbierum 4: disturbance). DLO-Instituut voor Bos-en Natuuronderzoek, Arnhem, The Netherlands.

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).

Literature Cited

NABCI (North American Bird Conservation Initiative). 2014. The state of the birds 2014 report. U.S. Department of Interior, Washington, D.C. <http://www.stateofthebirds.org> (accessed April 2015).

Sauer JR, Link WA, Fallon JE, Pardieck KL, Ziolkowski Jr. DJ. 2013. The North American breeding bird survey 1966–2011: summary analysis and species accounts. *North American Fauna* **79**:DOI: 10.3996/nafa.79.0001.

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.

Literature Cited

Hill DP, Gould LK. 1997. Chestnut-collared Longspur (*Calcarius ornatus*). Number 288 in Poole A, editor. The birds of North America online, Cornell Lab of Ornithology, Ithaca, New York. Available from <http://www.bna.birds.cornell.edu/bna/species/288> (accessed November 2014).

Owensby CE. 1973. Modified step-point system for botanical composition and basal cover estimates. *Journal of Range Management* **26**:302–303.

3 Shaffer & Buhl. Wind facility effects on grassland birds. *Conservation Biology*, Supporting Information Appendix S3.

Robel RJ, Briggs JN, Dayton AD, Hulbert LC. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management* **23**:295–297.

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) |