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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)

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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*)

by

C. Tanner Gue
Bachelor of Science, Jamestown College, 2007

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
May
2012

This thesis, submitted by C. Tanner Gue in partial fulfillment of the requirements for the Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for the appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dr. Wayne Swisher
Dean of the Graduate School

April 16, 2012
Date

PERMISSION

Title	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*)
Department	Biology
Degree	Master of Science

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Date April 16, 2012

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ABSTRACT

The Prairie Pothole Region (PPR) is the most important breeding habitat for North American ducks. However, much of the PPR is suitable for large-scale wind energy development and conflicts for waterfowl populations may occur if wind energy alters habitat in a way that reduces survival or productivity. Adult survival of breeding female ducks has a disproportionately large effect on population growth. Thus, populations might be particularly sensitive to increased mortality in this cohort because of direct collisions with wind turbines. Additionally, large home ranges are energetically taxing. If females avoid resources near wind turbines during breeding season activities, females may allocate less energy to reproduction and more energy to visiting distant foraging sites. Thus, wind energy development may indirectly impact duck production. Lastly, wind energy may be a source of indirect habitat loss if females avoid wind turbines when selecting nest sites. To assess these direct and indirect impacts of wind energy on breeding waterfowl, we radio-marked and monitored female mallards (*Anas platyrhynchos*) and blue-winged teal (*A. discors*) during the 2009 and 2010 breeding seasons at the Tatanka Wind Farm (TWF) near Kulm, North Dakota and an adjacent reference site without wind turbines (REF).

A single radio-marked female mallard and no blue-winged teal collided with wind turbines. Most mortalities, irrespective of species and site, were caused by predators (78.3%; 36/46). For mallards, the best-approximating survival model indicated that breeding season survival depended on year and site such that survival in 2009 was high at TWF (S = 0.90, 95% CI = 0.61 – 0.98) relative to survival at REF (S = 0.83, 95% CI = 0.48 – 0.95) but survival in 2010 was low at TWF (S = 0.62, 95% CI = 0.31 – 0.80) relative to survival at REF (S = 0.84, 95% CI = 0.57 – 0.94). The most competitive model for blue-winged teal including the effect of wind turbines indicated that breeding season survival at TWF (S = 0.71, 95% CI = 0.57 – 0.81) was lower than survival at REF (S = 0.81, 95% CI = 0.65 – 0.90). There was a positive association between the presence of wind turbines and home range size for female mallards (β = 0.0154, SE = 0.0711) and a negative association between the presence of wind turbines and home range size for blue-winged teal (β = -0.0892, SE = 0.1650), but we obtained no support for this effect on mallard home range size and moderate support for this effect on blue-winged teal home range size. Female mallards and blue-winged teal did not appear to avoid wind turbines when selecting nest sites. Our results suggest that females breeding in wind-developed landscapes rarely collide with wind turbines and probably do not avoid wind turbines during breeding season activities. Thus, waterfowl management strategies in the PPR that include acquiring wetland and grassland easements in wind-developed landscapes may be appropriate. However, differences in survival between TWF and REF for both species may reflect potential indirect effects of wind development activity on female survival and further study may be required given the scope and scale of projected wind energy development in the PPR.

CHAPTER I

GENERAL INTRODUCTION

Wind is not a novel source of energy, but the demand for energy and growing concerns about the impacts of anthropogenic climate change have caused increased interest in wind energy development (Arnett et al. 2007, Meseguer 2007). Wind energy is the fastest growing source of alternative energy and exponential growth of the industry continues, with an average annual growth rate in the United States of 39% (2005-2009; AWEA 2010). Similar to traditional energy development projects (coal, Anderson 1978; coal-bed natural gas, Walker et al. 2007; natural gas and oil, Gilbert and Chalfoun 2011), wind energy may also create conflicts for wildlife populations if it alters habitat in a way that reduces survival, productivity, or both. For example, recent studies have confirmed that wind turbines are an additional source of anthropogenic mortality for some bird and bat populations because of collision of individuals with wind turbine blades or associated infrastructure (Erickson et al. 2001, Arnett et al. 2008). Wind turbines are also a source of indirect habitat loss because of behavioral avoidance of individuals to wind turbines (Leddy et al. 1999, Masden et al. 2009). Although common themes persist, our understanding of these effects remains primarily site specific (Drewitt and Langston 2006, De Lucas et al. 2008). Given the rate at which wind energy is expanding and an incomplete understanding about the potential impacts of wind energy on wildlife, concern exists about the effect of large-scale wind energy developments on wildlife populations (J.S. Gleason, U.S. Fish and Wildlife Service, unpublished report).

Upland-nesting ducks that breed in the Prairie Pothole Region (PPR) of the Northern Great Plains rely on the expansive grasslands and high densities of wetland basins that characterize it (Stewart and Kantrud 1971, Batt et al. 1989). In fact, the PPR is the most productive area for waterfowl in North America, providing breeding habitat for more than 50% of the continent's population of dabbling duck species (Smith et al. 1964, Bellrose 1980, Kaminski and Weller 1992). Two major physiographic sub-regions make up the PPR: the Drift Prairie and the Missouri Coteau (hereafter, Coteau). The Coteau's rocky soil and topographic relief (Bluemle 1991) have slowed agricultural conversion in this sub-region. As a result, the Coteau is an area where comparatively large expanses of grasslands remain intact. This area supports some of the highest densities of breeding duck pairs in the PPR (Reynolds et al. 2006). Protection of wetland and grassland habitat in the Coteau and throughout the PPR was recognized as the highest priority for waterfowl conservation in the North American Waterfowl Management Plan (NAWMP; North American Waterfowl Management Plan Committee 1986). Waterfowl conservation programs in the PPR have focused heavily on the purchase of conservation easements (i.e., wetland and grassland easements) on private lands (Ringleman 2005). The U.S. Fish and Wildlife Service (USFWS), as part of the National Wildlife Refuge System, manages the bulk of these easements. Easements, which are retained in private ownership, are intended to prevent the conversion of native grassland and wetland habitat to cropland, thereby maintaining the intrinsic value of these habitats to breeding waterfowl and other migratory birds. The easement program is the primary method for translating habitat and population goals of NAWMP to the landscape of the PPR, but the easement program was created prior to the introduction of large-scale wind energy development.

Wind resources are particularly abundant in the PPR, and most of the Coteau is considered excellent for large-scale wind energy development (NREL 2010). Much of PPR and Coteau lie within North and South Dakota. These states currently rank among the top 15 wind producing states, having 1,424 and 784 Megawatts (MW) of installed wind capacity, respectively (AWEA 2011*a*). Furthermore, North Dakota ranks fourth and South Dakota ranks fifth in wind energy potential (AWEA 2011b, c). This creates an evident overlap between an area of high wind energy potential and an area of primary conservation concern. Potential conflicts between wind energy development and conservation efforts in the PPR are also of concern given recent conversion of native grasslands to cropland (reviewed by Johnson and Stephens 2011). For example, between 1982 and 1997, approximately 93,000 km^2 of grasslands in the United States were lost to agricultural conversion (Samson et al. 2004). From 1989 to 2003, 36,540 ha of native grasslands in the PPR of North and South Dakota were converted to cropland and recent increases in prices of commodities have probably increased the rate of grassland conversion (Stephens et al. 2008). Wind energy development on remaining grasslands might represent an additional negative effect on waterfowl populations in the PPR and although wind energy development in the PPR is expanding rapidly, the effect of wind development on waterfowl is uncertain (Stewart et al. 2007).

Consistent with uncertainties, the USFWS questions the appropriateness of acquiring easements in wind-developed landscapes and currently takes a precautionary approach in sanctioning wind-development on private lands already enrolled in the easement program (Manville 2009). The USFWS has issued voluntary recommendations for reducing potential ecological consequences of wind energy and is working with the wind industry to formulate siting guidelines for wind turbines (USFWS 2011*a*, *b*). However, there is high interest in wind energy development by private landowners because of financial benefits and private landowners may be unwilling to sell the cropping rights to a tract of land if they cannot participate in wind development. Taken together with the importance of grassland habitat for breeding waterfowl (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005), there is great interest among members of the waterfowl management community in ultimately understanding if wind development is compatible with the goals of the easement program.

Recent research has confirmed that migrating birds may avoid wind turbines, as documented for common eiders (*Somateria mollissima*; Desholm and Kahlert 2005, Masden et al. 2009). Waterfowl migrating through the PPR in the spring may exhibit one or more patterns of settling behavior depending on habitat conditions (Johnson and Grier 1988). If migrating waterfowl avoid wetlands in grassland dominated habitats with wind turbines that traditionally support high breeding duck densities, this would represent a loss of carrying capacity and an overall decrease in the conservation value of that habitat for breeding ducks. In May 2008, the USFWS Region 6 Habitat and Population Evaluation Team (HAPET) and Ducks Unlimited, Inc. (DU) began a three-year study of breeding pairs on wetlands at wind energy developments in the PPR with the goal of understanding if breeding pair density is influenced by presence and proximity of wind turbines. This information about carrying capacity is critical, but the need for additional research regarding the potential conflict between conservation goals in the PPR and wind energy development has been recognized.

Of particular and immediate interest is the potential for wind turbines to cause increased mortality of breeding females through collision with wind turbines. Survival of adult female mallards, and presumably other upland nesting ducks, during the breeding season is one of the most limiting factors on population growth (Hoekman et al. 2002). Female dabbling ducks suffer greater mortality during the breeding season than any other period of their annual life-cycle because of inherent dangers of ground-nesting life history strategies (Johnson and Sargeant 1977, Sargeant et al. 1984, Sargeant and Raveling 1992). Wind turbines might introduce a novel source of mortality that could reduce the level of productivity and thus reduce the conservation value of grassland dominated landscapes of the PPR. In Chapter 2, we examine whether breeding female mallards and blue-winged teal collided with wind turbines and assessed differences in survival of these species in an area with wind turbines and an area without wind turbines.

Wind turbines and associated infrastructure, such as turbine maintenance roads, will undoubtedly introduce a unique source of fragmentation to grassland habitat in the PPR (Bureau of Land Management, 2005). However, recent research has confirmed that some avian grassland species may lose habitat indirectly by behaviorally avoiding anthropogenic features, such as wind turbines (passerines, Leddy et al. 1999, Shaffer and

Johnson 2008; galliformes, Pruett et al. 2009). Additionally, some birds avoid nesting in habitat near anthropogenic features, as documented for lesser prairie-chickens (*Tympanuchus pallidicinctus*; Pitman et al. 2005) and greater prairie-chickens (*T. cupido*; McNew 2010). If waterfowl avoid habitat directly adjacent to wind turbines when selecting nest sites or during other normal diurnal activities, this would represent an indirect source of habitat loss and also a decline in habitat suitability. In Chapter 3, we examine whether breeding female mallards and blue-winged teal avoid wind turbines by estimating female home ranges and by assessing nest locations in relation to wind turbines and other anthropogenic features.

Chapters 2 and 3 are formatted for publication. I have had the privilege to collaborate with many individuals and coauthors during this research effort. Thus, I have used plural pronouns throughout this thesis. Even so, I accept full responsibility for its content.

CHAPTER II

BREEDING-SEASON SURVIVAL OF FEMALE MALLARDS AND BLUE-WINGED TEAL AT A LARGE-SCALE WIND FARM IN THE PRAIRIE POTHOLE REGION

Abstract

The Prairie Pothole Region (PPR) is the most important breeding habitat for North American ducks. Adult survival of breeding female mallards (*Anas platyrhynchos*), and presumably other upland nesting ducks, is one of the most limiting factors on population growth. However, much of the PPR is suitable for large-scale wind energy development and collisions of breeding females with wind turbines may be a novel source of mortality. We assessed impacts of wind energy on breeding female mallard and blue-winged teal (*A. discors*) survival by monitoring 77 radio-marked mallards and 88 blue-winged teal during the 2009 and 2010 breeding seasons at the Tatanka Wind Farm (TWF) near Kulm, North Dakota. During the same period, we monitored 70 female mallards and 75 blue-winged teal at an adjacent reference site without wind turbines (REF). We used an information-theoretic approach to investigate relationships between female survival and site (TWF vs. REF), year (2009 vs. 2010), and date (DATE). We estimated female mallard survival probability during the 93-day period following arrival and female blue-winged teal survival probability during the 71-day period following nest initiation. Collision mortalities were uncommon. A single radio-marked female mallard and no blue-winged teal collided with wind turbines. Most mortalities were caused by predators (78.3%; 36/46), irrespective of species and site. For mallards, the best-approximating model indicated that breeding season survival was (1) lowest when a high proportion of radio-marked females were nesting, and (2) depended on year and site such that survival in 2009 was high at TWF (S = 0.90, 95% CI = 0.61 – 0.98) relative to survival at REF (S = 0.83, 95% CI = 0.48 – 0.95) but survival in 2010 was low at TWF (S = 0.62, 95% CI = 0.31 – 0.80) relative to survival at REF (S = 0.84, 95% CI = 0.57 – 0.94). For blue-winged teal, the constant model was the best-approximating model and indicated that female survival was 0.75 (95% CI = 0.65 – 0.83). The most competitive model for blue-winged teal including the effect of wind turbines indicated that breeding season survival at TWF (S = 0.71, 95% CI = 0.57 – 0.81) was lower than survival at REF (S = 0.81, 95% CI = 0.65 – 0.90). The limited number of collisions observed for female mallards and blue-winged teal nesting at TWF suggests that wind turbines had no significant direct impact on female survival. Based on these findings alone, waterfowl management efforts to conserve wetland and grassland habitat in the PPR even in the presence of wind energy development may be appropriate. However, differences in survival between TWF and REF for both species may reflect potential indirect effects of wind development activity on female survival and further study may be required given the scope and scale of projected wind energy development in the PPR.

Introduction

The demand for energy and growing concern about impacts of anthropogenic climate change have caused increased interest in alternative energy sources (Arnett et al. 2007, Meseguer 2007). Wind energy is the fastest growing source of alternative energy, with an average annual capacity growth rate in the United States of 39% (2005-2009; AWEA 2010). Similar to more traditional energy development projects (coal, Anderson 1978; coal-bed natural gas, Walker et al. 2007; natural gas and oil, Gilbert and Chalfoun 2011), wind energy may also create conflicts for wildlife populations when it alters habitat in a way that reduces survival, productivity, or both. For example, recent studies have confirmed additional mortality in bird (primarily raptors and passerines) and bat populations because of direct collision with wind turbines or associated infrastructure (Erickson et al. 2001, Arnett et al. 2008) . However, collision risk varies and may depend on landscape characteristics near the wind turbines, the spatial arrangement of the wind turbines themselves, and specific behavioral characteristics of the species present (Drewitt and Langston 2006, De Lucas et al. 2008). Given the rate at which wind energy is expanding and an incomplete understanding about the potential impacts of wind energy on wildlife, concern exists about the effect of large-scale wind energy developments on wildlife populations (J.S. Gleason, U.S. Fish and Wildlife Service, unpublished report).

Upland nesting waterfowl that breed in the Prairie Pothole Region (PPR) of the Northern Great Plains rely on the abundant grasslands and high wetland densities that characterize it (Stewart and Kantrud 1971, Batt et al. 1989). The PPR provides critical breeding habitat for more than 50% of the continent's population of dabbling duck species (Smith et al. 1964, Bellrose 1980, Kaminski and Weller 1992). As a result, the PPR was identified as the highest priority for waterfowl conservation by the North American Waterfowl Management Plan (NAWMP; North American Waterfowl Management Plan Committee 1986). The Missouri Coteau physiographic region (hereafter, Coteau) within the PPR is an area where comparatively abundant wetlands and large expanses of grasslands still remain after agricultural advancement. The Coteau supports some of the highest densities of breeding waterfowl pairs in the PPR (Reynolds et al. 2006). Waterfowl conservation programs in the PPR and Coteau have focused heavily on the purchase of conservation easements on private lands (Ringleman 2005). The U.S. Fish and Wildlife Service (USFWS) manages and administers most of these easements. Easements, which are retained in private ownership, are intended to prevent the conversion of native grassland and wetland habitat to cropland, thereby maintaining the intrinsic value of these habitats to breeding waterfowl and other migratory birds. However, the easement program was created prior to the introduction of large-scale wind energy development.

Wind resources are particularly abundant in the PPR, and most of the Coteau is considered excellent for large-scale wind energy development (NREL 2010). Both North and South Dakota currently rank among the top 15 wind producing states, having 1,424 and 784 Megawatts (MW) of installed wind capacity, respectively (AWEA 2011*a*). North Dakota ranks fourth and South Dakota ranks fifth in wind energy potential (AWEA 2011b, c). This creates an evident overlap between an area of high wind energy potential and an area of primary conservation concern. Although wind energy development in the PPR is expanding rapidly, the effect of wind development on waterfowl populations, particularly in North America, is unknown (Stewart et al. 2007).

One of the greatest concerns regarding wind energy in the PPR is decreased survival of breeding females because of potential collisions with wind turbines. Breeding season survival of female mallards, and presumably other upland nesting ducks, is one of the most limiting factors on population growth (Hoekman et al. 2002). Female dabbling ducks suffer greater mortality during this time than any other period of their annual life-cycle because of increased vulnerability to predation (Johnson and Sargeant 1977, Sargeant et al. 1984), but collision of ducks with turbine blades or other associated infrastructure may represent a novel source of breeding season mortality (Johnson et al. 2002).

We predicted that if breeding females are susceptible to collision with wind turbines, the probability of survival for females choosing to nest in landscapes near wind turbines will be lower than for females nesting in similar landscapes without wind turbines. Siegfried (1972) hypothesized that male dabbling ducks may be susceptible to collisions with anthropogenic structures during pursuit flights because of a potential decrease in their awareness of such features. We predicted that female ducks may also be particularly susceptible to collision with wind turbines during pre-nesting courtship flights shortly after arrival at the breeding grounds (Titman 1983), as opposed to other periods (e.g., incubation) when females are less active (Afton and Paulus 1992). Further, because of increased fragmentation of grassland dominated habitat at wind farms in the PPR (Bureau of Land Management 2005), predators might be more efficient at locating duck nests and depredating nesting females in wind-developed landscapes (Cowardin et al. 1983, Sargeant et al. 1993). To test these predictions, we used an impact-reference study design (Morrison et al. 2008). We radio-marked and monitored breeding female ducks from April to August in 2009 and 2010 in a recently developed wind farm and an adjacent reference site with similar landscape characteristics but no wind turbines.

To our knowledge, our study was the first attempt to investigate potential effects of wind energy development on the survival of breeding female ducks. The primary focus of our study was to assess the risk of collision for breeding females. Our goals were to: 1) assess support for our predictions about survival of female ducks during breeding in wind developments; and 2) provide managers with useful information about relationships between survival probability of breeding females and wind energy development in grassland and wetland dominated landscapes of the PPR.

Study Area

In 2009 and 2010 we studied adult female mallards and blue-winged teal at the Tatanka Wind Farm (Tatanka, Acciona Energy Company, North America; hereafter TWF) and an adjacent reference site without wind turbines (hereafter REF; Fig. 2.1). TWF is located 40 km south of Kulm, North Dakota (46°56'23"N, 99°00'20"W) and extends approximately 16.5 km on the Missouri Coteau physiographic region in Dickey County, North Dakota and McPherson County, South Dakota. REF is located in Dickey and McIntosh counties in North Dakota. TWF has 120 operational wind turbines located on private lands in cropland or grassland habitat. Turbine operation at TWF commenced in May 2008. Each turbine (model AW-77/1500) has three 37 m blades (76 meter rotor diameter) atop an 80 m tower. The turbines operate at wind speeds between 3.5 and 25 m/s and are capable of producing 1.5 MW/day.

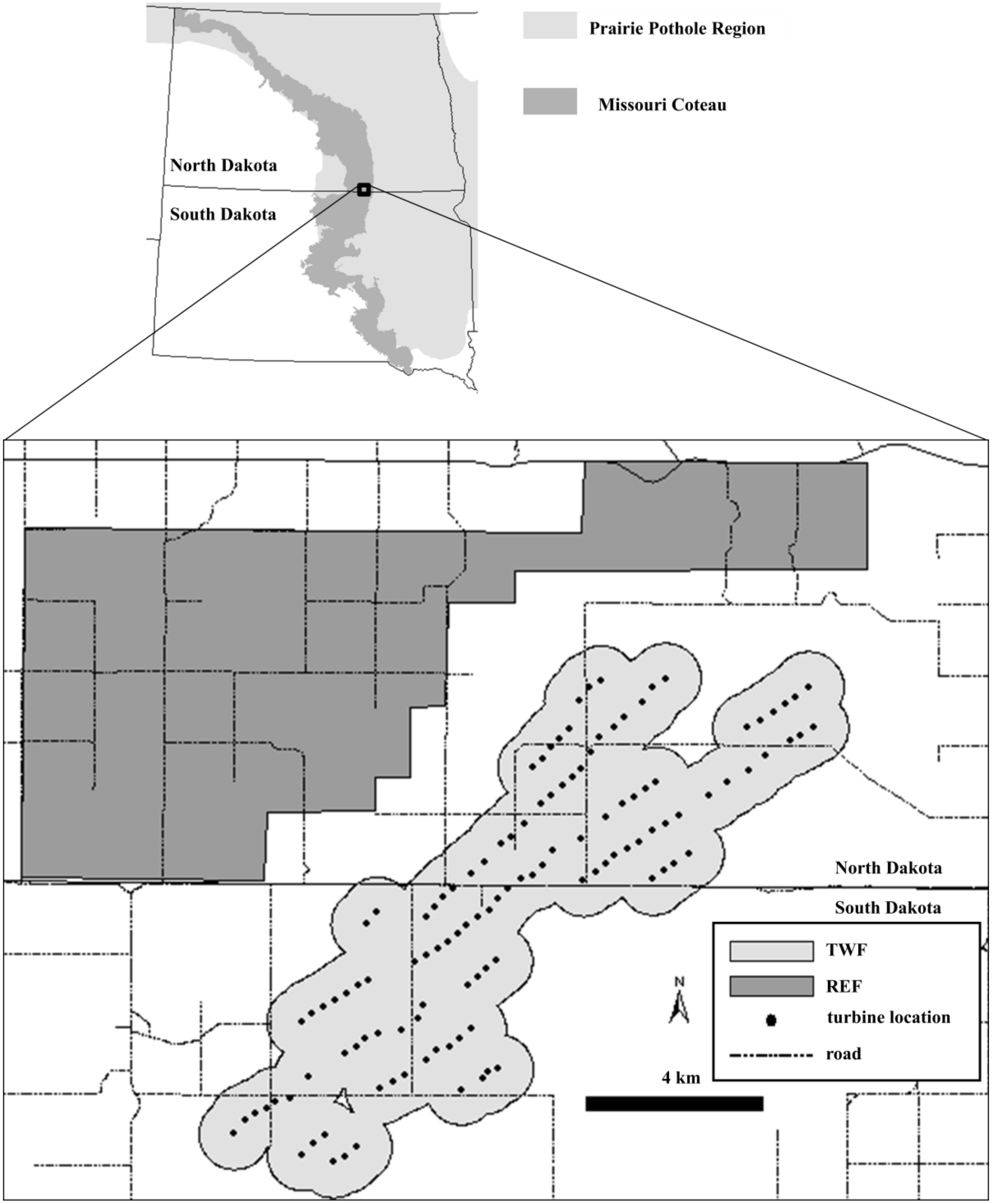


Figure 2.1: Location of the Tatanka Wind Farm (TWF) and the adjacent reference site (REF) on the Missouri Coteau of the Prairie Pothole Region in North and South Dakota. A 0.8-km buffer around each wind turbine (black circles) describes the extent of TWF (6,915 ha). REF (8,768 ha) was selected based on area and similarities in landscape characteristics with TWF.

Both sites are typical of the glaciated PPR landscape and are characterized by moderately sloped topography (Bluemle 1979) and many temporary, seasonal and semipermanent wetlands (Stewart and Kantrud 1971). Agricultural practices at both sites consisted primarily of livestock grazing and annually cultivated small grains and row crops. Habitat composition at TWF was 73.0 % native grassland, 14.6% wetland, 6.6% cropland, 5.4% undisturbed grassland, 0.3% forest, and 0.1% hayland. Habitat composition at REF was 51.7% native grassland, 18.9% wetland, 17.0% undisturbed grassland, 12.1% cropland, 0.2% hayland, and 0.1% forest (see Appendix for habitat definitions). Wetlands were abundant at both sites (TWF: 23.4 basins/km^2, REF: 17.3 basins/km^2). Temporary, seasonal, and semipermanent wetlands occupied 33.6, 33.7, and 32.7% of the wetland area at REF, respectfully, and 33.3, 33.4, and 33.3% of the wetland area at TWF, respectfully.

The climate at TWF and REF is continental. Average monthly temperature during our study ranged between 4.83°C – 21.4°C (U.S. Dep. Commer. 2009*a*, 2010*a*). Annual precipitation at the study site averages 49.6 cm (U.S. Dep. Commer. 2002). Between June and December 2008, the study sites received 54.9 cm of precipitation (U.S. Dep. Commer. 2008). Taken together with above average precipitation in 2009 (64.5 cm) and 2010 (53.0 cm), conditions were exceptionally wet during both years our study (U.S. Dep. Commer. 2009*b*, 2010*b*).

Methods

Study Area Definition

Breeding female mallards in the PPR have home range sizes as large as 4.7 km^2 (Krapu et al. 1983). Blue-winged teal have comparatively small home range sizes (Dzubin 1955, Evans and Black 1956). However, female mallards and blue-winged teal use a considerably small fraction of their entire home range during the egg laying and incubation period (Gilmer et al. 1975, Dwyer et al. 1979, Stewart and Titman 1980). Therefore, we conservatively assumed that if a female spent ≥50% of the breeding season within 0.8 km of a wind turbine, it adequately represented a duck that could be influenced by the presence of wind turbines. Consequently, we described the extent of TWF as all habitats within 0.8 km of each wind turbine. REF and its boundaries were selected based on the land area, landscape characteristics, and wetland communities of TWF.

Capture, Radio Attachment, and Monitoring

When mallards arrived on the study area in mid April, we placed decoy traps in temporary, seasonal, and semipermanent wetlands where we observed territorial pairs (Sharp and Lokemoen 1987, Krapu et al. 1997). We checked decoy traps each morning and afternoon. We relocated traps frequently and dispersed them throughout TWF and REF to capture a representative sample of the local mallard population. Decoy trapping continued for approximately 4 weeks in 2009 and 2010.

Beginning in early May of 2009 and 2010, we nest-searched approximately 1,000 ha at TWF and REF using an all-terrain vehicle chain-drag technique (Higgins et al. 1969, Klett et al. 1986). We conducted searches between 0800 and 1400 (Gloutney et al.

1993), but we postponed or cancelled searches during periods of rainfall. We captured nesting mallards and blue-winged teal with walk-in nest traps (Dietz et al. 1994) or mist nets (Bacon and Evrard 1990) during egg-laying or early in incubation.

We marked decoy and nest-trapped females with a standard USFWS leg band and a 9-g prong-and-suture VHF transmitter equipped with mortality sensor (Model A4430, Advanced Telemetry Systems, Isanti, MN). We attached transmitters dorsally using a subcutaneous anchor and 3 sterile monofilament polypropylene sutures (DemeTech Corporation, Miami, FL; 0 metric, 40 mm reverse cutting) following local anesthetic application (1cc bupivacaine) as described by Pietz et al. (1994). We weighed captured females using a Pesola spring scale (± 10g) prior to transmitter attachment to ensure that the transmitters did not exceed 3% of the females total body weight (Cochran 1980, Barron et al. 2010). In the event that a breeding pair was captured in a decoy trap, we secured the male in a ventilated enclosure until the procedure was complete, at which time both members of the pair were released simultaneously. We manually disoriented nest-trapped females post-procedure and replaced them on their nest to reduce nest abandonment. Total handling time of radio-marked females averaged 22.15 min (±0.33 min SE). Trapping, banding, and collection was conducted under USFWS special permit (06824 and 64570) and NDGF license (GNF02601675). All female capture and marking procedures were sanctioned by Institutional Animal Care and Use Committee of the University of North Dakota (protocol no. 0907-4c).

We began monitoring radio-marked females as soon as 24 hours after radio attachment. For mallards, we included data in our analysis for the subsequent 92- and 94-

day sampling period after the initiation of marking in 2009 and 2010, respectively. For blue-winged teal, we included data in our analysis for the subsequent 70- and 72-day sampling period after the initiation of marking in 2009 and 2010, respectively. We used vehicle-mounted null-peak receiving systems equipped with Location of a Signal triangulation software (LOAS, version 4.0, Ecological Software Solutions LLC, Hegymagas, Hungary) or handheld antennas and standard triangulation techniques (White and Garrott 1990) to locate radio-marked females. We generally located females between 0700 and 2100. When a female's nest was destroyed, we increased efforts to locate individuals between 0800 and 1400, a time when females are most likely to be on their nest (Gloutney et al. 1993). We located each female within every 48-hour period between capture and termination of the sampling period unless the female was assumed to have emigrated and was right-censored or the female died. When females were missing during daily tracking, we searched via road searches and aerial telemetry flights over our study area and the surrounding area within approximately 3 km of the study area boundaries. In 2009, we searched for missing birds with one telemetry flight on 2 July. In 2010, we searched for missing birds with 5 telemetry flights on a tri-weekly interval. We right-censored data from females that we assumed to have either left the study area, shed their transmitter before monitoring ended, or became entangled in their transmitter. These encounter histories were censored at the time of their last known live encounter. We assumed that transmitters were shed when there was no evidence of predation. We censored individuals that emitted a mortality signal on private land that we could not gain access. To avoid bias associated with potential harmful effects of capture, handling, or radio-marking during periods immediately following transmitter attachment (Cox and Afton 1998, Iverson et al. 2006), we censored individuals that were monitored ≤ 1 week (White and Garrott 1990).

Cause of Mortality

We recovered dead females as quickly as possible. Upon visual confirmation of mortality, we recorded the time, location, and cause of death. We considered carcass location (e.g., in a fox or mink den, below a raptor perch, below a wind turbine) and transmitter condition (e.g., apparent tooth or claw marks in transmitter molding, crimped antenna) when assigning the possible cause of mortality. We took photographs and collected the female for further inspection. When the cause of death could not be determined in the field, carcasses were frozen and submitted to the National Wildlife Health Center (University of Wisconsin, Madison) for necropsy.

We categorized cause of death into 3 mortality factors: predation (mammal or raptor), collision (with wind turbine), and other. Collision mortalities were identified based on proximity to wind turbine and carcass condition (e.g., visible appearance of trauma). We listed the cause of death as “other” if it was a rare occurrence for our sample, the carcass disclosed no clear information regarding the cause of death during immediate observation in the field, or necropsy reports were inconclusive. For example, one female was killed by a hay swather while attending her nest. This was a rare occurrence. For another female, we could not determine the cause of death in the field, but necropsy reports suggested that the female drowned. This was also a rare occurrence.

On 3 occasions, the cause of death could not be determined in the field and necropsy reports were inconclusive. We categorized these mortalities as “other”.

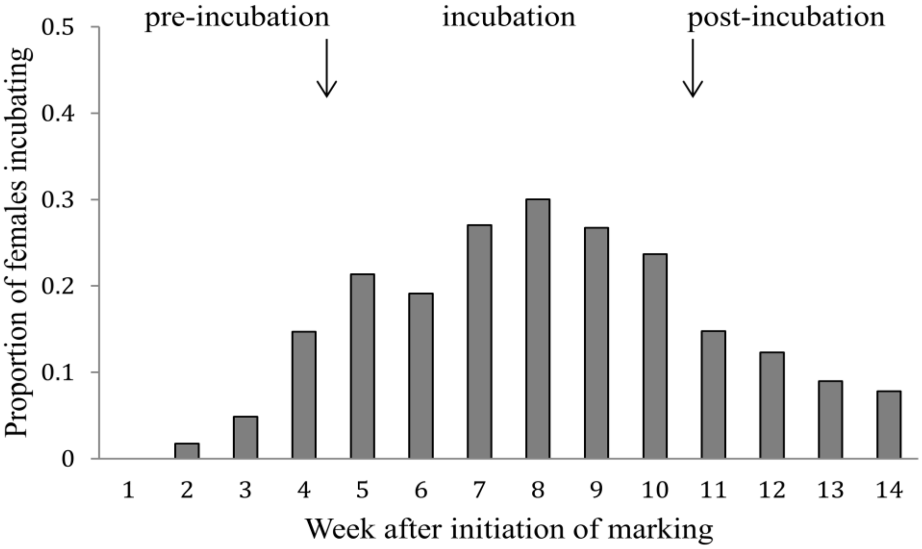
We were initially concerned that any females that struck turbines may be scavenged by predators, causing us to misclassify the mortality factor (Smallwood et al. 2010). During 2009 we used a transmitter equipped with a precise event mortality sensor (precise event transmitter: PET) to determine the time of death to nearest 30 min (Advanced Telemetry Systems, Isanti, MN). However, when the PET tilt switch did not detect a considerable amount of movement (i.e., flight) for a period of 8 hours, the transmitter locked into mortality signal for 5 days. Mortality signals occurred frequently when females were in later stages of incubation and consequently caused additional investigator disturbance to nesting females during the 2009 study period. Thus, in 2010 we chose to use a simple tilt switch mortality sensor that did not record time since death and did not lock into mortality signal. We determined the median retrieval time in 2010 using the interval between the last live encounter and the day of carcass discovery.

Statistical Analyses

We used an information-theoretic approach (Burnham and Anderson 2002) to assess the relative support for potential relationships between survival probability of breeding females and site, year, and date. We created a set of candidate models that described the potential effect of wind turbines on adult female survival given variation between years and within each breeding season. Every female in the analysis was described by 2 binary variables: SITE (TWF or REF) to account for the presence of wind turbines, and YEAR (2009 or 2010) to account for commonly noted annual variation in female survival (Nichols et al. 1982, Blohm et al. 1987, Johnson et al. 1992).

To test our prediction that females may be susceptible to collision prior to incubation, an ideal covariate would describe each female as either pre-incubating, incubating or post-incubating. Similar to Devries et al. (2003) and Hoekman et al. (2006), we initially classified the behavioral phase of females based on within-season nesting effort of all monitored female mallards and blue-winged teal (Fig. 2.2). However, we detected either very few or no mortalities for some groups of females. Therefore, we used date of the season (DATE), a continuous variable to account for potential within-season trends in DSR. This time trend was linear and may not have accurately reflected realistic patterns of adult survival. Thus, we included a quadratic time trend (DATE^2) in our analysis, which allowed daily survival to follow a curvilinear pattern. We predicted that if females were susceptible to collision prior to incubation, this may be reflected by support for a positive linear relationship between DSR and DATE or a concave non-linear relationship between DSR, DATE, and DATE^2. Alternatively, we may have observed support for a convex non-linear relationship between DSR, DATE, and DATE^2 if females were more susceptible to predation during incubation (Johnson and Sargeant 1977, Sargeant et al. 1984). We did not consider more complex non-linear models (Burnham and Anderson 2002: 32-35). Importantly, we were not interested in the survival of females on a particular day. Rather, we were interested in the trend of survival between different behavioral phases and within the breeding season. Given our data, quadratic

a)



b)

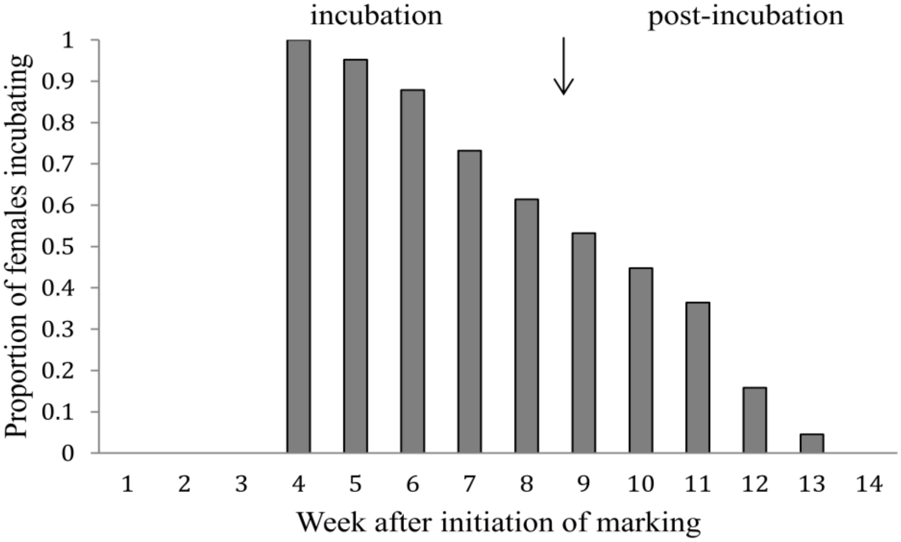


Figure 2.2: Proportion of radio-marked female mallards (a) and blue-winged teal (b) known to be incubating for each week of the 14-week study period (mid-April – mid-July) in 2009 and 2010 following the initiation of marking for REF and TWF combined. For mallards, we defined pre-incubation, incubation, and post-incubation as weeks 1-4, 5-10, and 11-14, respectfully. For blue-winged teal, we defined incubation as weeks 4-8 and post-incubation as weeks 9-14.

time trend models served as the most appropriate way to interpret general trends in survival between different behavioral periods.

We used Program MARK (White and Burnham 1999) to assess survival trends and evaluate relative support for candidate models. We used generalized linear models (McCullagh and Nelder 1989), logit link function, and assumed a binomial error distribution to obtain maximum-likelihood estimates of regression coefficients and sampling variances. The most parsimonious model(s) were chosen using Akaike's Information Criterion adjusted for small sample size (AIC_c: Burnham and Anderson 2002). Because encounter histories were of unequal length (ragged), we used the nest survival data format and nest survival module in program MARK (Dinsmore et al. 2002) to compare survival of females at TWF and REF. This method, unlike the known-fate method, enabled data of radio-marked females with uneven intervals between resightings to be included in the analysis.

To accurately estimate DSR, this model used for female survival required fulfillment of 4 general assumptions: 1) female fates were known with certainty, 2) investigator activity did not influence female fate, 3) female fates were not correlated, and 4) there was not heterogeneity of survival among females (Dinsmore et al. 2002, Williams et al. 2002). We specifically targeted females missing during daily tracking during extensive road searches and telemetry flights at and surrounding TWF and REF. However, as with many telemetry studies, it is possible that females with unknown fates were included in our analysis (White and Garrott 1990). In this case, our survival estimates would be biased high. To reduce potential effects of investigator disturbance on female survival, we 1) flushed radio-marked females as infrequently as possible and 2) spent as little time at radio-marked female's nests as possible. However, we used a PET in 2009 which may have increased the potential for nest abandonment from increased investigator disturbance of nesting females late in incubation during that year. Because incubating females are more susceptible to predation (Cowardin et al. 1985, Kirby and Cowardin 1986, Devries et al. 2003), survival may be biased high in 2009.

We could not be sure that assumptions 3 and 4 were satisfied. Nest fates may be spatially dependent (Larivière and Messier 1998). Although we distributed decoy traps and nest traps throughout REF and TWF, survival of nest-trapped females may have been correlated. Additionally, we did not know each radio-marked female's age or nesting experience, but these factors could have led to heterogeneity among female fates (Reynolds et al. 1995). To investigate possible violations of assumption 3 and 4, we explored impacts of potential overdispersion on model selection. An unbiased goodness-of-fit test is not available for nest survival models (Dinsmore et al. 2002, Rotella et al. 2007), so we used Program MARK to adjust the variance inflation factor (c) from 1 (no overdispersion) to 3 (extreme overdispersion) in increments of 0.5 and examined the effect of this change on resulting model selection output.

Results

During our 2-year study, we marked a total of 81 and 85 female mallards at REF and TWF, respectively (Fig. 2.3). We censored 11 and 8 female mallards at REF and TWF, respectfully, because they were either monitored ≤ 1 week (*n* = 16), their transmitter failed (*n* =1), or their transmitter emitted a mortality signal on land which we could not gain access (*n* = 2). Thus we analyzed 3,555 exposure days for 70 females at REF and 3,693 exposure days for 77 female mallards at TWF (Table 2.1). Approximately half (75/147) of the female mallards included in the survival analysis were decoy-trapped. We nest-trapped all blue-winged teal. We marked a total of 79 and 94 female blue-winged teal at REF and TWF respectfully (Fig. 2.3). We censored 4 blue-winged teal at REF and 6 blue-winged teal at TWF because they were monitored ≤ 1 week. Thus we analyzed 2,651.5 exposure days for 75 females at REF and 3,130.5 exposure days for 88 females at TWF (Table 2.1). The number of females included in the analyses varied for both species throughout the sampling interval (Fig. 2.4). Of the 310 female mallards and blue-winged teal included in analyses, 128 were monitored for the duration of the study period, 136 were right censored and 46 were found dead (Table 2.2). We right censored data from females that we assumed to have either left the study area (*n*=94), shed their transmitter before monitoring ended (*n*=36), or became entangled in their transmitter (*n*=6).

Table 2.1: Number of females and exposure days (in parentheses) included in the survival analysis by species (MALL = mallard, BWTE = blue-winged teal), site (Tatanka Wind Farm [TWF] or reference [REF]), and year (2009 or 2010).

	2009		2010		
	REF	TWF	REF	TWF	**Total**
MALL	25 (1293.5)	33 (1567.5)	45 (2261.5)	44 (2125.5)	**147** **(7248)**
BWTE	29 (851.5)	40 (1376.5)	46 (1800.0)	48 (1754.0)	**163** **(5782)**
Total	**54** **(2145)**	**73** **(2944)**	**91** **(4061.5)**	**92** **(3879.5)**	**310** **(13030)**

Cause of Mortality

Median retrieval time of all dead birds and shed transmitters in 2009 was 49 hrs (*IQR*=42, *n*=35) with a minimum and maximum of 8 and 127.5 hrs, respectively. In 2010, the median retrieval time was 48 hrs (*IQR*=36, *n*=47) with a minimum and maximum of 24 and 505 hours, respectively. Median retreival time of all carcasses and shed transmitters in both years at REF was 47.5 hrs (*IQR* = 36.5, *n* = 32) with a minimum and maximum of 8.0 and 216.0 hrs, respectively. We recovered carcasses and shed transmitters in both years at TWF similarly with the exception of 1 female (see discussion); median retrieval time was 48.0 hrs (*IQR*=44.5, *n* = 50) with a minimum and maximum of 8.0 and 505.0 hrs, respectively.

Although we detected few mallard mortalities at REF and TWF in 2009 (Fig. 2.5), predation was the most common cause of mortality for mallards at both sites in 2009 and 2010 (TWF: 8/15, REF: 5/8; Table 2.2). We detected similar numbers of blue-winged teal mortalities at both sites in 2009 and 2010. Predation was the only cause of mortality for blue-winged teal at both sites (TWF: 15/15, REF: 8/8; Table 2.2). Among all recorded mortalities across species, predation accounted for 78.3% (*n* = 36/46) of deaths. We observed 8 mallard deaths in which we either could not determine the cause of death in the field, necropsy reports were inconclusive, or the cause of death was rare for our sample (e. g., one nesting female was killed by a hay swather and another may have drowned).

At TWF, wind turbine collision contributed to 1 of 15 mallard deaths (Table 2.2). We observed 1 additional mallard collision mortality at TWF, but multiple obstructions in the immediate area confounded the cause of mortality (e.g., wind turbine, barbed-wire fence, power line). We observed no blue-winged teal collision mortalities (Table 2.2).

We detected very few mallard mortalities prior to periods when a high proportion of radio-marked female mallards were incubating (i.e., pre-incubating). In fact, we detected no mallard mortalities during this period at TWF in both years. We generally detected more blue-winged teal mortalities after periods when a high proportion of female blue-winged teal were incubating (i.e., post-incubating). Regardless, we detected either very few or no mortalities for some groups of females according to this covariate scheme (Table 2.3). Thus, we used quadratic time trend models in our statistical analysis to interpret general trends in survival between different behavioral periods.

Table 2.2: Number of female mortalities by species (MALL = mallard, BWTE = blue-winged teal), site (Tatanka Wind Farm [TWF] or reference [REF]), year (2009 or 2010) and mortality factor. 1* female mallard collision in 2009 could not confidently be attributed to wind turbines. There were other obstructions in the immediate area of her carcass (e.g., barb-wire fence, power line). Mortalities caused by raptors or mammals are included as predator mortalities. Females in which the cause of death was rare or could not be determined in the field and necropsy reports were inconclusive were categorized as other mortalities.

			COLLISION	PREDATOR	OTHER	**TOTAL**
2009	REF	MALL	0	2	1	**3**
		BWTE	0	3	0	**3**
	TWF	MALL	1*	1	0	**2**
		BWTE	0	8	0	**8**
2010	REF	MALL	0	3	2	**5**
		BWTE	0	5	0	**5**
	TWF	MALL	1	7	5	**13**
		BWTE	0	7	0	**7**
		TOTAL	**2**	**36**	**8**	**46**

Table 2.3: Number of mortalities observed during the 3 behavioral periods by species (MALL = mallard, BWTE = blue-winged teal), site (Tatanka Wind Farm [TWF] or reference [REF]), and year (2009 or 2010). Pre-incubation, incubation, and post-incubation was defined for mallards as weeks 1-4, 5-10, and 11-14, respectfully. All blue-winged teal were nest trapped. We defined the incubating and post-incubating periods as weeks 4-8 and 9-14, respectfully.

			pre-incubating	incubating	post-incubating
2009	REF	MALL	1	2	0
		BWTE	NA	2	1
	TWF	MALL	0	2	0
		BWTE	NA	3	5
2010	REF	MALL	2	2	1
		BWTE	NA	1	4
	TWF	MALL	0	13	0
		BWTE	NA	1	6

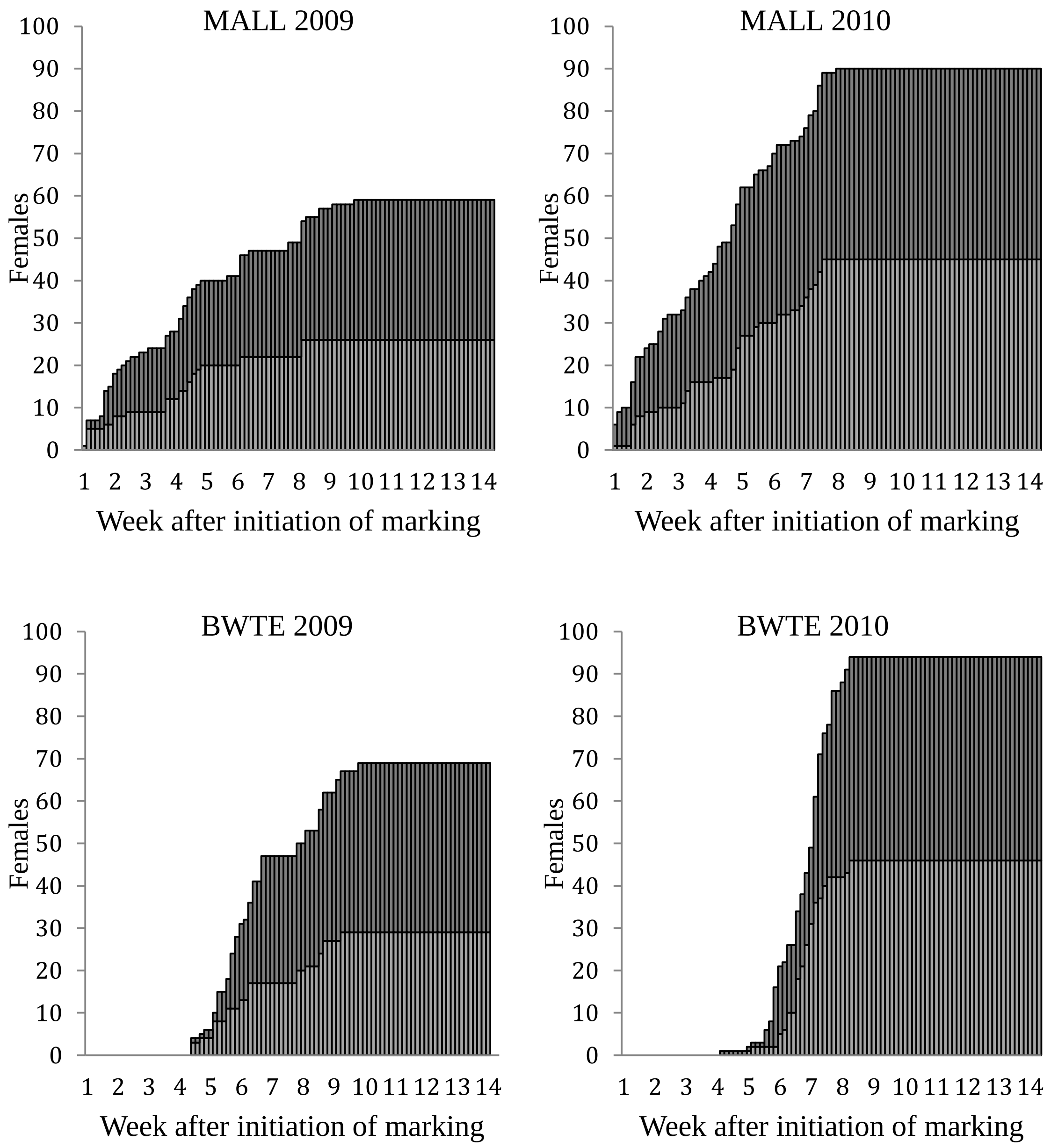


Figure 2.3: Total number of females radio-marked for each day of the 14-week study period (mid-April – mid-July) following the initiation of marking. The light portion of each bar represents females marked at REF. The dark portion of each bar represents females marked at TWF. MALL is the acronym for mallards and BWTE is the acronym for blue-winged teal.

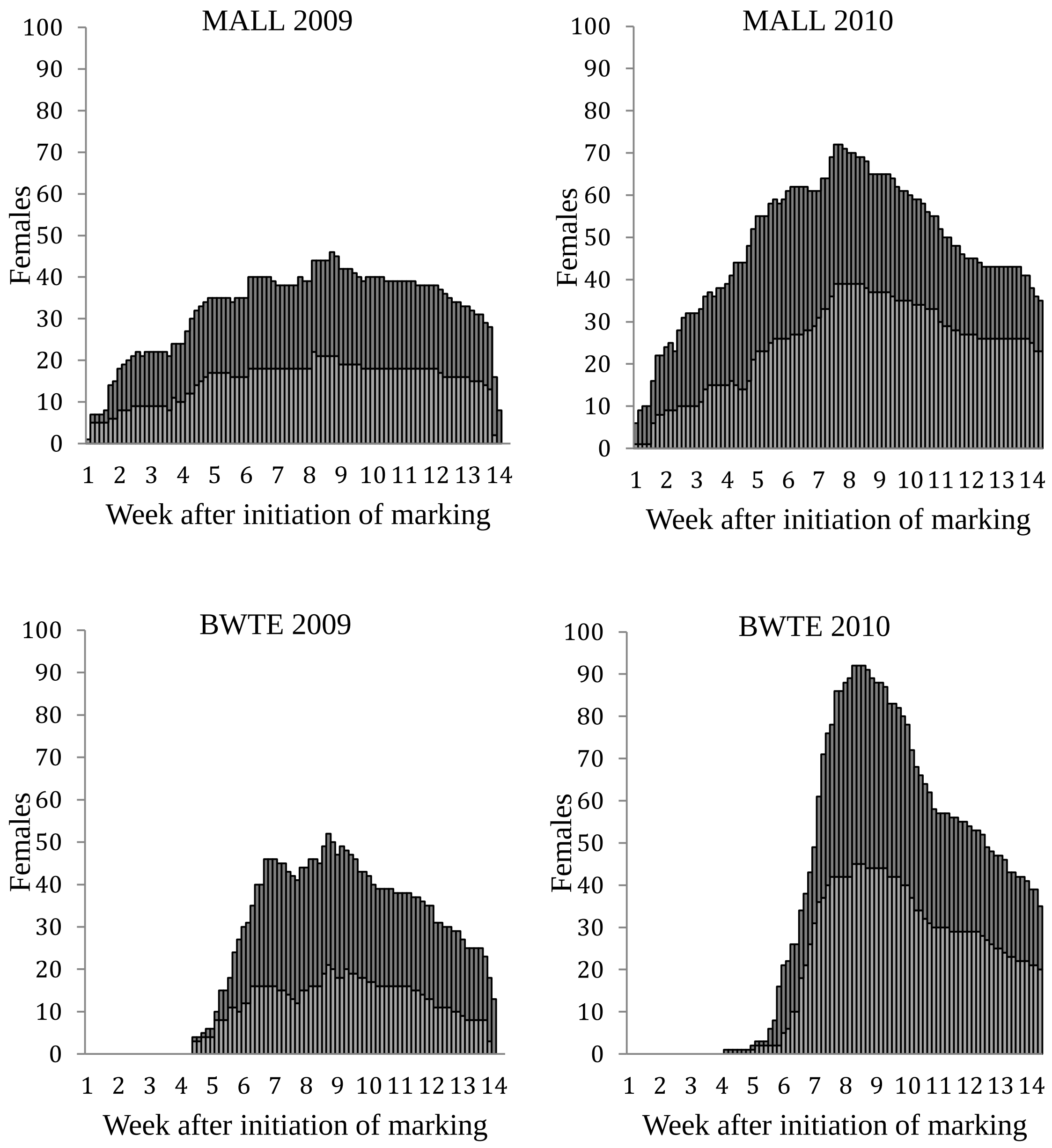


Figure 2.4: Total number of radio-marked females included in analyses for each day of the 14-week study period (mid-April – mid-July) following the initiation of marking. The light portion of each bar represents females marked at REF. The dark portion of each bar represents females marked at TWF. MALL is the acronym for mallards and BWTE is the acronym for blue-winged teal.

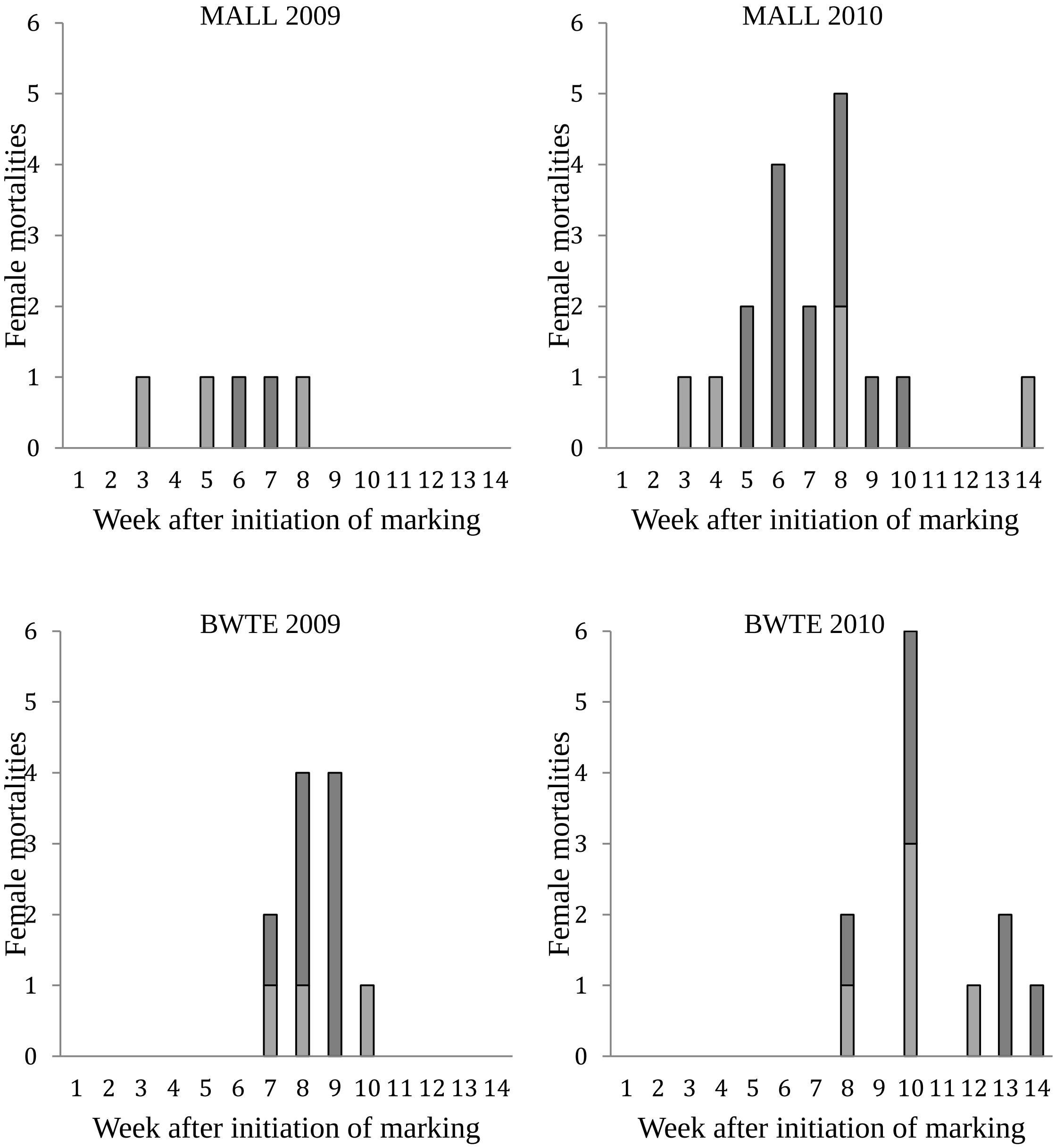


Figure 2.5: Total number of radio-marked female mortalities for each week of the 14-week study period (mid-April – mid-July) following the initiation of marking. The light portion of each bar represents females that died at REF. The dark portion of each bar represents females that died at TWF. MALL is the acronym for mallards and BWTE is the acronym for blue-winged teal.

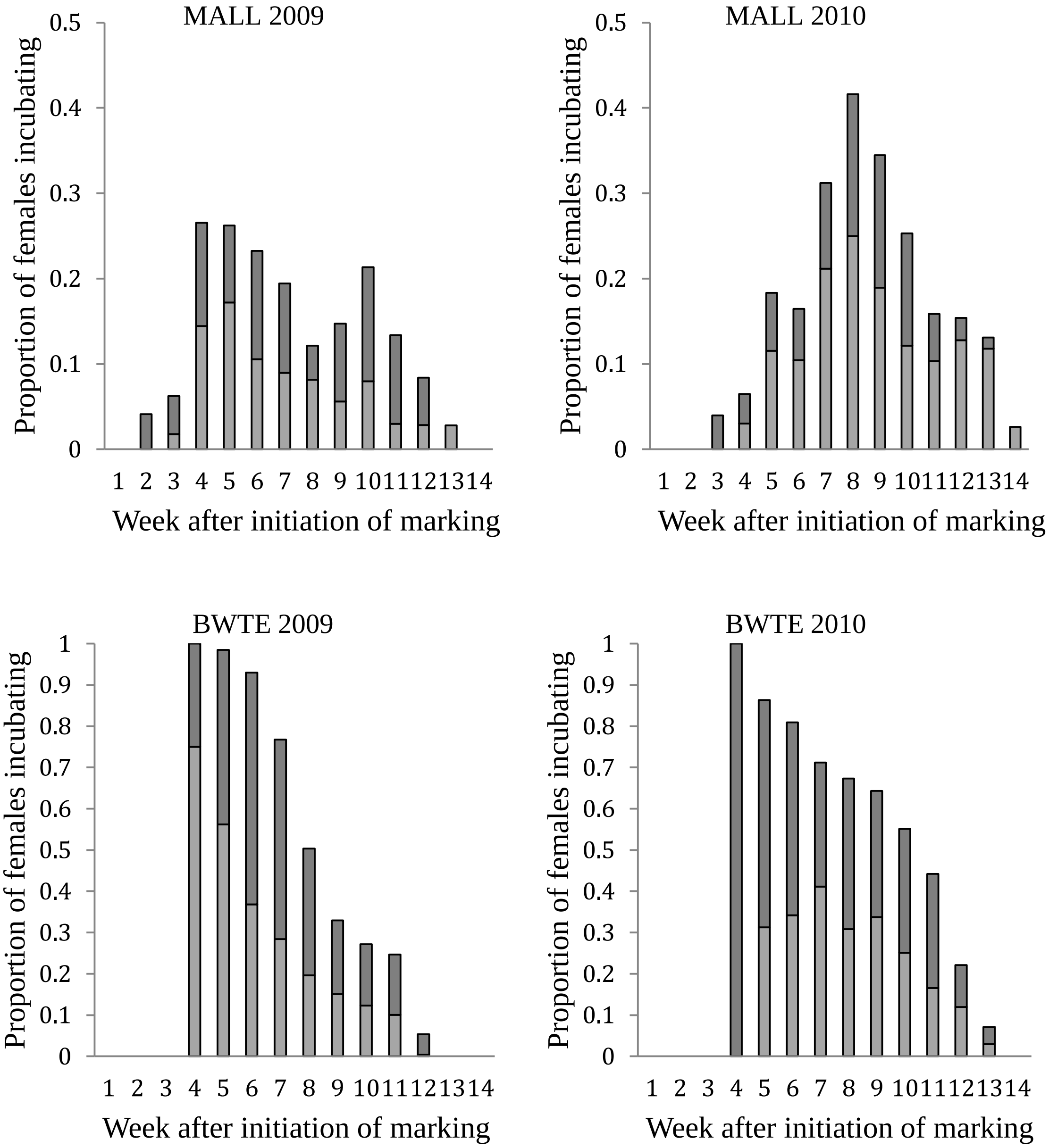


Figure 2.6: Proportion of radio-marked females known to be incubating for each week of the 14-week study period (mid-April – mid-July) following the initiation of marking. The light portion of each bar represents females known to be incubating at REF. The dark portion of each bar represents females known to be incubating at TWF. MALL is the acronym for mallards and BWTE is the acronym for blue-winged teal.

Statistical Analyses

Mallards

Nest survival models assume independent survival probabilities for individuals. Our results for mallards were robust to moderate levels of overdispersion. For example, we found that top model ranks did not change until adjustments of c exceeded 1.5. When the variance inflation factor was adjusted to 2.0, the constant model was the most parsimonious in the model set. Nonetheless, the relative importance of the effects of interest (SITE, YEAR and DATE^2) remained the same regardless of c adjustments. Thus, we discuss the mallard results and model generated survival estimates as ranked using AIC_c with $c = 1.0$ below, although the best approximating model may be slightly overfit.

We observed strong support that female mallard DSR varied within the season, as the 3 most competitive models included a quadratic time trend (Table 2.4). We accrued evidence that mallard DSR varied by year, and importantly, we observed some evidence that DSR varied by site. Our best-approximating model indicated that mallard DSR varied by each of these factors with an interaction between site and year (Table 2.4). Nonetheless, there was some model selection uncertainty and the weight of evidence in support (w_i) of the best-approximating model was 0.33. According to this model, survival varied by time such that the lowest DSR occurred during the middle of the sampling interval, which generally corresponded to the proportion of females incubating at both sites in 2009 and 2010 (Fig. 2.6, Fig. 2.7). Estimated 14-week (i.e., DSR^{93}) survival probability of radio-marked female mallards for this model at REF was 0.83 (95% CI =

0.48 – 0.95) and 0.84 (95% CI = 0.57 – 0.94) in 2009 and 2010, respectively. According to this model, 14-week survival probability at TWF was high in 2009 (S = 0.90, 95% CI = 0.61 – 0.98), but low in 2010 (S = 0.62, 95% CI = 0.31 – 0.80).

The second model did not include the effect of site; it indicated that mallard DSR varied by year and a quadratic within-season time trend. This model was nearly equally competitive as the best-approximating model (w_i = 0.29; Table 2.4). According to the second model, 14-week survival of female mallards was 0.87 (95% CI = 0.64 – 0.95) in 2009 and 0.72 (95% CI = 0.46 – 0.85) in 2010. The third model held 15% of the model weight, but included the effect of site and a quadratic time trend. According to this model, 14-week survival probability across years was 0.83 (95% CI = 0.61 – 0.93) at REF and 0.72 (95% CI = 0.46 – 0.86) at TWF.

Table 2.4: Model selection results from analysis investigating female mallard daily survival rate (DSR) at the Tatanka Wind Farm (TWF) and adjacent reference site (REF) in the Prairie Pothole Region of North and South Dakota. We modeled DSR as a function of YEAR (2009 and 2010), SITE (TWF and REF), and time (DATE) within the breeding season. Quadratic time trends (DATE^2) were used to investigate predictions about survival during 3 behavioral periods (pre-incubation, incubation, post-incubation) of female mallards. * denotes an interaction between variables. The best model was selected using Akaike's Information Criterion corrected for sample size (AIC_c). We report model weights (w_i), the number of parameters (K), and deviance for each DSR model.

DSR MODEL	**ΔAIC_c**	**w_i**	**K**	**Deviance**
SITE*YEAR+DATE^2	0.00	0.33	6	252.44
YEAR+DATE^2	0.28	0.29	4	256.73
SITE+DATE^2	1.65	0.15	4	258.10
SITE*YEAR	3.38	0.06	4	259.82
SITE+YEAR	3.80	0.05	3	262.24
YEAR	4.01	0.05	2	264.46
SITE*YEAR+DATE	4.80	0.03	5	259.24
CONSTANT	5.30	0.02	1	267.75
SITE	5.40	0.02	2	265.84

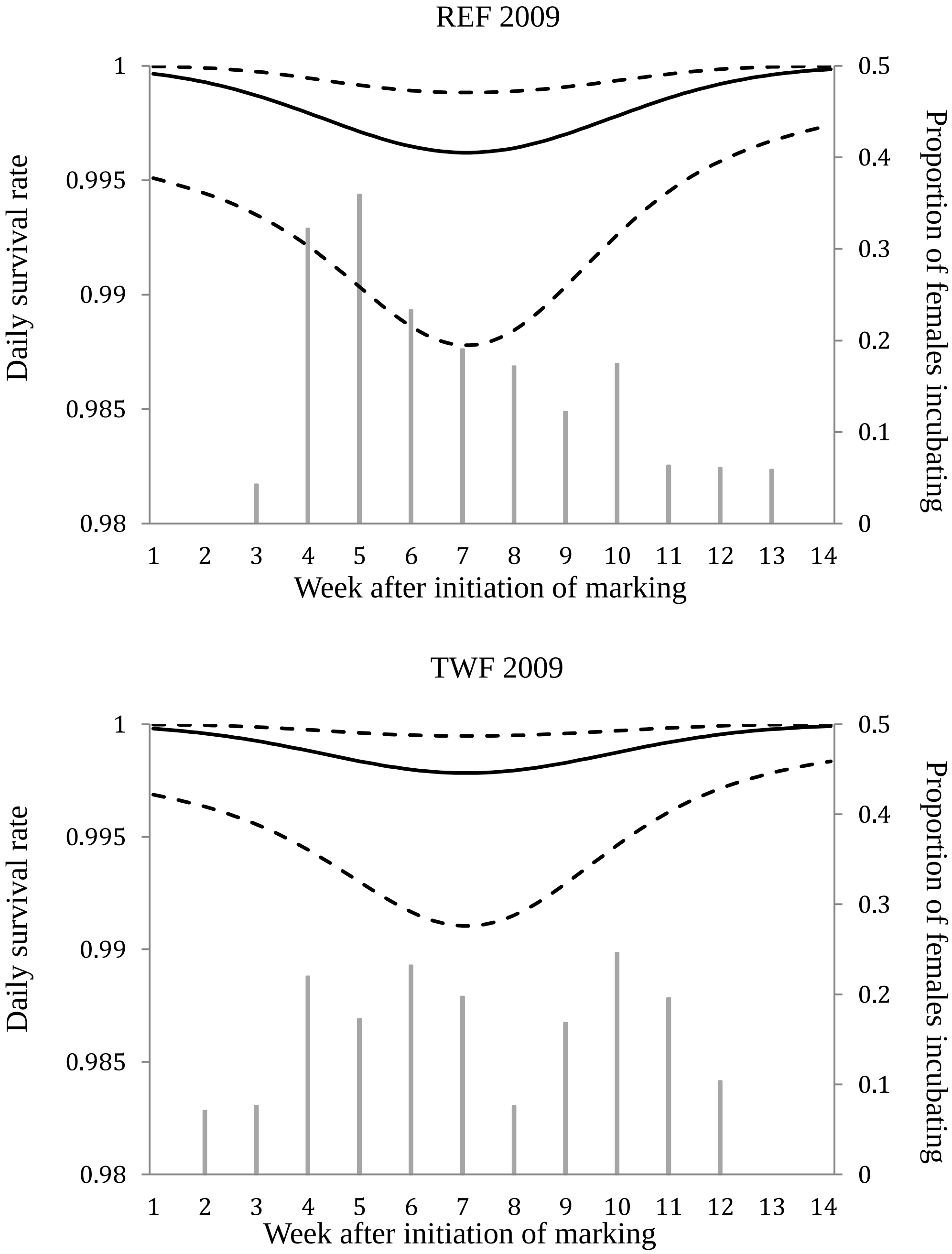
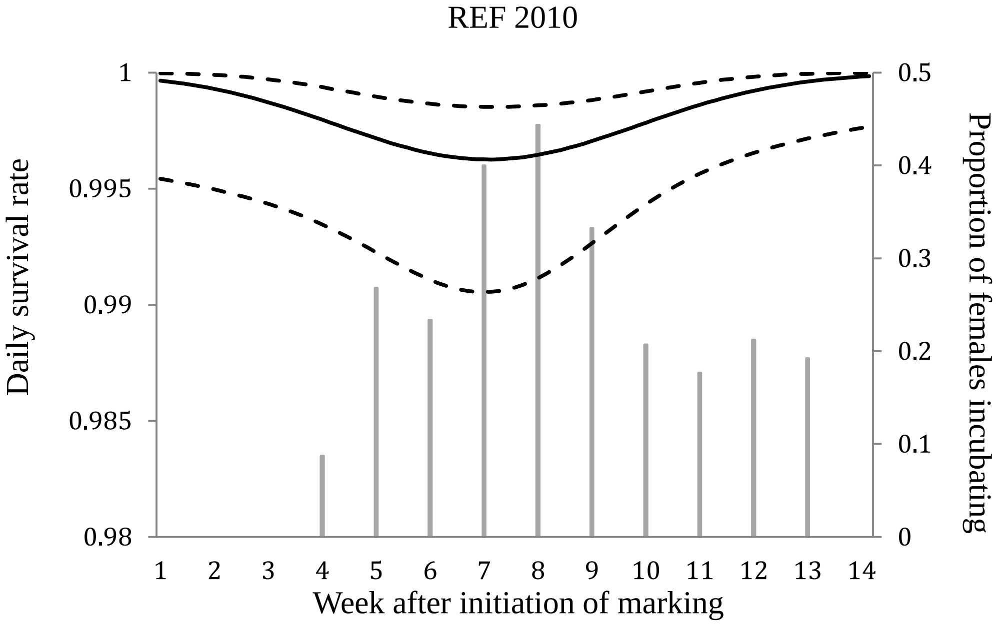


Figure 2.7: The relationship between within-season time trends as a quadratic (DATE^2) and Daily Survival Rate (DSR; primary y-axis) of female mallards at Tatanka Wind Farm (TWF) and the adjacent reference site (REF) in the Prairie Pothole Region of North and South Dakota in 2009 and 2010. The estimates are predicted by the model: DSR = SITE*YEAR+DATE^2. Dashed lines are 95% confidence limits. We include proportion of radio-marked females known to be incubating (secondary y-axis) for each week of the 14-week study period (mid-April – mid-July) following the initiation of marking.



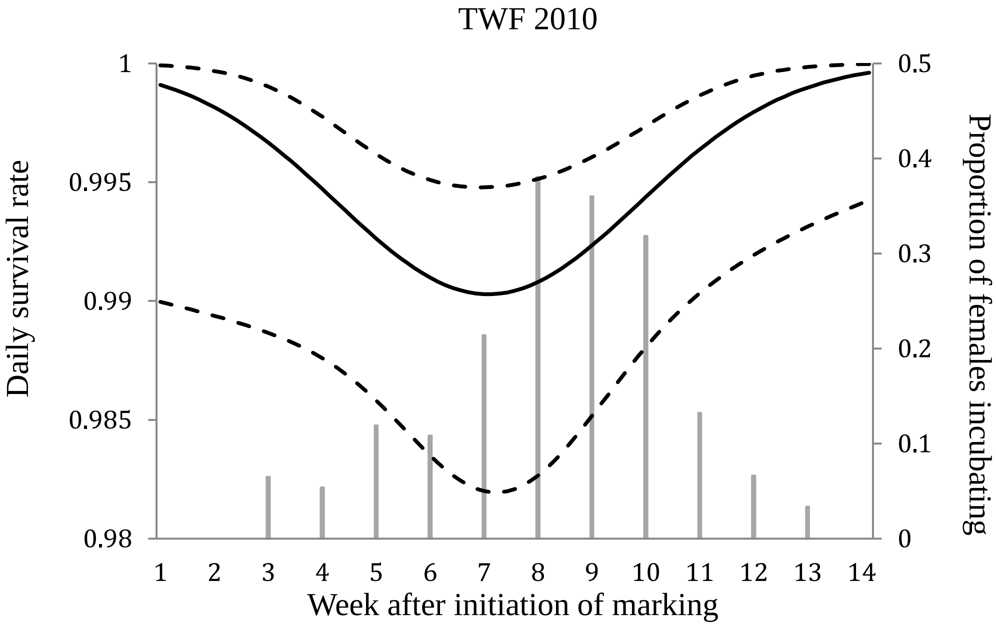


Figure 2.7 Continued: The relationship between within-season time trends as a quadratic ($DATE^2$) and Daily Survival Rate (DSR; primary y-axis) of female mallards at Tatanka Wind Farm (TWF) and the adjacent reference site (REF) in the Prairie Pothole Region of North and South Dakota in 2009 and 2010. The estimates are predicted by the model: $DSR = SITE*YEAR+DATE^2$. Dashed lines are 95% confidence limits. We include proportion of radio-marked females known to be incubating (secondary y-axis) for each week of the 14-week study period (mid-April – mid-July) following the initiation of marking.

Blue-winged teal

Our results for blue-winged teal were robust to overdispersion. Model ranks of competitive models ($\Delta\text{AIC}_c \leq 2.0$) did not change even after c reached a value of 3.0. We discuss the blue-winged teal results and model generated survival estimates as ranked using AIC_c with $c = 1.0$ below.

We observed similar levels of uncertainty in our model set for blue-winged teal and we did not observe as much support for within-season variation in survival for this species. Daily survival rate of female blue-winged teal was best described by a constant model, but there was some support for a relationship between DSR and site and year (Table 2.5). According to the constant model, estimated 11-week (i.e., DSR^{71}) survival probability of blue-winged teal was 0.75 (95% CI = 0.65 – 0.83). Extrapolated to 14 weeks for comparison with female mallard breeding season survival estimates, female blue-winged teal survival according to the constant model was 0.69 (95% CI = 0.57 – 0.78). According to the second model, which included only the effect of site and held 0.19% of the model weight, 11-week female survival was 0.81 (95% CI = 0.65 – 0.90) at REF and 0.71 (95% CI = 0.57 – 0.81) at TWF. Estimated 14-week survival according to this model was 0.76 (95% CI = 0.57 – 0.87) and 0.64 (95% CI = 0.48 – 0.76) at REF and TWF, respectfully.

Discussion

To our knowledge, this is the first investigation of the effects of wind turbines on the survival of breeding female ducks. Most of the motivation for our research was the concern that wind turbines may directly reduce survival probability of breeding females through collision with wind turbines. Collisions at TWF were uncommon. With the exception of relatively high rates of avian collision at the Altamont Pass Wind Resource Area in California (Smallwood and Thelander 2008), a large literature suggests that avian collision mortality with wind turbines may be minor compared to other potential impacts of wind farms (NRC 2007, Erickson et al. 2001, Arnett et al. 2007, Manville 2009). Similarly, wind turbines at TWF may not have directly reduced breeding female mallard and blue-winged teal survival to a level that should concern waterfowl managers.

Table 2.5: Model selection results from analysis investigating female blue-winged teal daily survival rate (DSR) at the Tatanka Wind Farm (TWF) and adjacent reference site (REF) in the Prairie Pothole Region of North and South Dakota. We modeled DSR as a function of YEAR (2009 and 2010), SITE (TWF and REF), and time (DATE) within the breeding season. Quadratic time trends (DATE^2) were used to investigate predictions about survival during 3 behavioral periods (pre-incubation, incubation, post-incubation) of female blue-winged teal. * denotes an interaction between variables. The best model was selected using Akaike's Information Criterion corrected for sample size (AIC$_c$). We report model weights (w_i), the number of parameters (K), and deviance for each DSR model.

DSR MODEL	**ΔAIC$_c$**	**w_i**	**K**	**Deviance**
CONSTANT	0.00	0.29	1	267.23
SITE	0.84	0.19	2	266.07
YEAR	1.18	0.16	2	266.41
SITE+DATE^2	2.23	0.10	4	263.46
SITE+YEAR	2.23	0.10	3	265.46
YEAR+DATE^2	2.35	0.09	4	263.57
SITE*YEAR	4.21	0.04	4	265.44
SITE*YEAR+DATE^2	5.37	0.02	6	262.59
SITE*YEAR+DATE	5.89	0.02	5	265.11

Nonetheless, one female mallard that collided with a wind turbine in 2010 and 1 other female mallard that collided with an unknown anthropogenic feature in 2009 were suspected to be in the pre-nesting phase at their time of death. Thus, we accrued some evidence supporting our prediction that pre-nesting, territorial females may be more susceptible to collision than incubating females. However, the frequency of territorial flights is highest shortly after ducks arrive on the breeding grounds (Titman 1983) and both collisions at TWF occurred when a high proportion of radio-marked females were incubating. Future research may benefit from considering alternative factors. For example, the number of available males may be a more accurate predictor of collision risk for females because males engage in pursuit flights of females regardless of female nesting status and there may be more available males later in the nesting season (Titman 1983).

Previous research suggests that collision risk may vary by species (Drewitt and Langston 2006). Species-specific collision risk is likely the result of an interaction between flight behavior and body size (Barrios and Rodríguez 2004, De Lucas et al. 2008). Blue-winged teal may be less susceptible to collisions than mallards because blue-winged teal have small home ranges (Dzubin 1955, Evans and Black 1956) and spend relatively less time in the rotor swept zone while flying among wetland and grassland nesting areas (Stewart 1977). Albeit slight, this theory is supported by the fact that we observed no blue-winged teal collisions at TWF. Although our results ultimately suggest that the risk of collision for breeding females is low, potential species-specific collision risk taken together with the importance of grassland and wetland dominated landscapes of the PPR not only to ducks, but other shorebirds (Dinsmore et al. 1999) and waterbirds (Niemuth et al. 2005), may justify additional investigation of representative species from these species groups.

Modest support for a negative effect of wind turbines on survival for both species was due to predation. The most compelling evidence supporting this is the number of predator related mortalities we observed relative to those caused by collision with wind turbines. In addition and consistent with previous studies, survival of female mallards at TWF and REF was lowest when a high proportion of females were incubating and most vulnerable to predation (Devries et al. 2003, Richkus et al. 2005). Although we did not accrue support for interannual variation in survival for blue-winged teal, which may have been an artifact of our trapping methods, we suspect that most female blue-winged teal at both sites were killed while incubating or while attending a brood.

Support for differences in survival between TWF and REF for both species may reflect site specific differences in predator foraging efficiency. It is not a novel idea that fragmentation of waterfowl nesting habitat concentrates duck nests and incubating females into smaller habitat patches, creating a potentially favorable scenario for mammalian duck predators (Johnson and Sargeant 1977, Clark and Nudds 1991). High predation of nesting females in comparatively fragmented landscapes may specifically result from changes in prey density (Larivière and Messier 1998), increased vulnerability of prey because of decreased nesting cover (Duebbert 1969, Hines and Mitchell 1983, Guyn and Clark 1997), or preference of edge habitat as travel corridors by mammalian predators (Bider 1968, Larivière and Messier 2000, Phillips et al. 2003). Schmitz and

Clark (1999) attributed a negative relationship between survival probabilities of female ring-necked pheasants (*Phasianus colchicus*) and edge habitat density within breeding season home ranges to any one or a combination of these factors. Wind turbine access roads and pads may have indirectly reduced female survival probability at TWF as well.

Potential change in mammalian predator behavior, however, does not entirely explain the variation in mallard mortalities that we observed between years at TWF. Migratory raptor mobility relative to terrestrial predator mobility and changes in local predator composition or overall predator abundance at TWF might be a more plausible explanation. Raptors are responsible for considerable female mortality in some areas of the PPR (Sargeant et al. 1993, Richkus et al. 2005). Disturbance at wind-developed landscapes may increase the abundance of raptor prey species (Morrison 1996, Thelander et al. 2003) and this may have been a potential mechanism of temporal differences in raptor abundances at TWF as well. Although we observed raptors foraging at TWF and REF in both years, we did not incorporate predator monitoring protocols during our research and have no evidence of a systematic difference in predator communities between sites or years. Long-term studies may be required to elucidate indirect effects of wind turbines on breeding season survival of ducks.

Breeding season survival of female blue-winged teal in our study was similar to that reported by other researchers. For example, Garrettson and Rohwer (1998) reported survival of backpack harness and surgically implant radio-marked female blue-winged teal during the 90-day breeding season in the Canadian prairie-parklands of 60.6 (95% CI = ± 28.4%) and 72.7 (95% CI = ± 27.7%), respectively. Their estimates bound extrapolated survival probability (i.e., DSR^{93}) estimated from the best-approximating model for blue-winged teal in our study ($S_{(.)}$ = 0.69, 95% CI = 0.57 – 0.78). However, our estimates of breeding season survival for mallards were generally high compared to estimates reported previously. Brasher et al. (2006) estimated 90-day breeding season female mallard survival in the Canadian prairie-parklands of 0.78 (SE = 0.025). Devries et al. (2003) observed a range of 90-day mallard breeding season survival estimates at 19 different sites in Canada's PPR between 0.62 (SE = 0.028) and 0.84 (SE = 0.018).

The highest estimates of female mallard survival during the breeding season that we know of is 0.87 (measures of uncertainty not reported; Cowardin et al. 1985). Cowardin et al. (1985) noted that red fox and mink may take carcasses into underground dens. Thus, signal loss and a violation of the assumption that all female fates are known with certainty was one of the suspected causes of their inflated survival estimate. We detected no radio-marked female carcasses in predator dens at either site in 2009. However, we detected 1 and 3 radio-marked blue-winged teal carcasses in predator dens in 2010 at REF and TWF, respectfully. Although it is possible that inflated mallard survival estimates were a product of failing to detect mortalities, we have few reasonable explanations for why we may have detected fewer mortalities between years and no explanations for why mortality detection may have differed between species or sites.

We initially suspected that survival estimates of mallards and blue-winged teal at both sites in 2009 may have been inflated for 2 reasons. First, the use of a PET in 2009 may have caused increased investigator disturbance of incubating females. Potential nest abandonment may have effectively reduced the number of exposure days of comparatively vulnerable incubating females. Second, the probability of incorrectly assuming emigration from TWF and REF may have been higher in 2009. For example, we detected no mortalities during 1 telemetry flight in 2009 and 3 mortalities during 5 telemetry flights in 2010. Thus, we may have incorrectly right-censored more females in 2009 if we assume that mortalities detected from fixed-wing aircraft would not have been detected from 4x4 telemetry vehicles. Although we did gain some support for annual variation for both species, we accrued little evidence that this was an artifact of differences in mortality sensors or telemetry flight frequency between years.

One of the major strengths of our study for specifically investigating collision mortality of local breeding female mallards and blue-winged teal at TWF was the use of telemetry, instead of carcass searches, to exclude bias introduced by collision mortalities of migrating individuals. However, the potential for bias resulting from capturing and monitoring techniques must also be considered. Approximately half of all female mallards (*n* = 75 of 147) and all female blue-winged teal (*n* = 163) were attending nests upon capture. Nevertheless, many nest-trapped females failed at nesting and presumably re-entered the pre-nesting phase, thus providing a sample of females attending nests and females involved in territorial behavior throughout the breeding season.

With respect to monitoring techniques, we may have misclassified causes of death at TWF and REF. Many of the predators that inhabit the contemporary PPR are known to scavenge prey. We did not investigate carcass removal rates at TWF, but removal rates at Buffalo Ridge in southwest Minnesota and eastern South Dakota averaged 7 days and ranged between approximately 4 and 8 days (Johnson et al. 2002). We located approximately 85% (*n*=39/46) of all dead radio-marked females within 4 days and approximately 96% (*n*=44/46) of all dead radio-marked females within 7 days of their last known live encounter. Only 1 female mallard carcass at TWF was discovered > 7 days after her last known live encounter. Therefore, we believe that the general lack of breeding female mortalities as a result of collision with turbines was not an artifact of our methods.

Alternatively, habitat conditions during our two year study may have influenced the observed number of collisions. Wetlands at TWF and REF were > 100% full for most of the spring during both years of our study. This was a result of above average precipitation immediately preceding and during the 2009 and 2010 breeding seasons (USFWS 2009;2010). Although female mallards may use upland habitat characteristics when selecting a home range (Mack et al. 2003), it is believed that wetland density and area are the primary habitat factors explaining female mallard distribution (Dwyer et al. 1979, Krapu et al. 1997). If waterfowl pair densities are positively related to wetland densities (Johnson and Grier 1988, Viljugrein et al. 2005) and home range sizes decrease as intraspecific competition increases (Mack and Clark 2006), then individual females breeding at TWF might have encountered fewer turbines during our study than expected in years of average or below average precipitation.

Breeding season survival of female mallards, and presumably other upland-nesting ducks, varies spatially and temporally throughout their breeding ranges (Johnson et al. 1992, Hoekman et al. 2002). We recognize that the duration and lack of site replication in our study needs to be considered when evaluating the compatibility of waterfowl conservation strategies and wind energy in the PPR. Nonetheless, breeding females occupying wetland and grassland habitat at TWF during our study rarely collided with wind turbines. Our study also raised some practical and important questions about the breeding ecology of upland nesting ducks at wind-developed landscapes in the PPR. For example, what are the effects of wind turbines on the local composition and abundance of duck predator communities? Is the potential for collision mortality consistent among landscapes with different habitat composition, such as in areas or years with lower wetland densities? Answers to these questions would be useful to waterfowl managers given projected wind energy development in the PPR.

Management Implications

Our results suggest that mortality of locally breeding female mallards and blue-winged teal due to collision with wind turbines at TWF is probably of little concern. Consistent with previous research, predators were the most influential mortality factor for female ducks during the breeding season at REF and TWF (Sargeant et al. 1984, Cowardin et al. 1985). Thus, waterfowl management strategies that include acquiring wetland and grassland easement in wind-developed landscapes may not directly reduce breeding season survival of females.

CHAPTER III

HOME RANGE AND NEST LOCATION OF UPLAND NESTING DUCKS AT A LARGE-SCALE WIND FARM IN THE PRAIRIE POTHOLE REGION

Abstract

The Prairie Pothole Region (PPR) is important for waterfowl, but it is also suitable for large-scale wind energy development. Wind energy may indirectly impact breeding waterfowl populations if pre-nesting and nesting females avoid wind turbines in otherwise suitable breeding habitat. During the 2009 and 2010 breeding seasons, we radio-marked and monitored 48 female mallards (*Anas platyrhynchos*) and 36 blue-winged teal (*Anas discors*) at the Tatanka Wind Farm (TWF) near Kulm, North Dakota. We concurrently radio-marked and monitored 42 female mallards and 25 blue-winged teal at one adjacent reference site (REF) with similar landscape characteristics and no wind turbines. We also assessed impacts of wind energy on nest location of common prairie-nesting ducks at TWF. Our objectives were to: 1) determine if the presence of wind turbines affected breeding female mallard and blue-winged teal home range sizes; and 2) determine if the spatial pattern of duck nests were indicative of avoidance of wind turbines. There was a positive association between the presence of wind turbines and home range size for female mallards (β = 0.0154, SE = 0.0711) and a negative association between the presence of wind turbines and home range size for blue-winged teal (β = -0.0892, SE = 0.1650), but we obtained no support for this effect in mallards

and moderate support for this effect in blue-winged teal. Female mallards and blue-winged teal also did not appear to avoid habitat near wind turbines during diurnal activities or when selecting nest sites. Our research was limited in spatial scale compared to projected wind energy development in the PPR, but our results suggest that breeding females in this study did not avoid individual wind turbines. Grassland and wetland habitat of the PPR in the presence of wind turbines may still hold conservation value for breeding ducks.

Introduction

Increasing energy demands and concerns about impacts of anthropogenic climate change have caused extensive development of alternative energy sources (Arnett et al. 2007, Meseguer 2007). Wind energy is the fastest growing source of alternative energy in the United States (AWEA 2010) and wind resources are particularly abundant in the Prairie Pothole Region (PPR) of the Northern Great Plains (NREL 2010). The PPR's high wetland densities and abundant grasslands also make it vital to the production of North American waterfowl (Bellrose 1980, Kaminski and Weller 1992, Reynolds et al. 2001). Yet, relatively little is known about the effects of wind energy on waterfowl populations, particularly in North America (Stewart et al. 2007). Waterfowl conservation strategies in the PPR that focused heavily on purchased easements on private lands to protect grassland and wetland habitat (Ringleman 2005) were conceived in the absence of wind energy. Uncertainties about the compatibility of current waterfowl conservation strategies and wind energy development necessitate information regarding the implications of increased wind energy development for waterfowl populations in grassland dominated habitats of the PPR.

Wind turbines may discourage wintering waterfowl from settling in an area, as documented for Pink-footed Geese (*Anser brachyrhynchus*) at a terrestrial wind farm (Larsen and Madsen 2000) and common eiders at an offshore wind farm (*Somateria mollissima*; Larsen and Guillemette 2007). Wind turbines may also cause migrating birds to adjust their migration routes, as found in common eiders (Desholm and Kahlert 2005, Masden et al. 2009). Displacement effects of wind turbines may also occur during the breeding season, as reported for some species of grassland passerines (Leddy et al. 1999, Erickson et al. 2004, Shaffer and Johnson 2008). Similarly, a critical concern related to wind energy in the PPR is indirect habitat loss resulting from behavioral avoidance of breeding ducks to wind turbines (Gleason 2010).

Avoidance of wind turbines could result in negative reproductive consequences (i.e., lower nest success, duckling or brood survival). Schoener (1968) hypothesized that individuals with smaller home ranges may allocate more energy to reproduction rather than defending large territories or visiting distant foraging locations. Consistent with this, Mack and Clark (2006) indicated that successful female mallards typically have smaller breeding season home range sizes. Individuals should attempt to use the smallest adequate home range (McNab 2002), but if breeding females avoid habitat near individual wind turbines, they may require larger areas to acquire adequate resources. Additionally, breeding female ducks may avoid anthropogenic features such as wind turbines when selecting a nest location, as documented for raptors at the Buffalo Ridge wind energy facility in Minnesota (Usgaard et al. 1997) and greater sage grouse at a natural gas development in Wyoming (Lyon and Anderson 2003). Behavioral avoidance of wind turbines by locally breeding female ducks when selecting nest sites or during other diurnal breeding season activities may ultimately result in an overall decrease in the conservation value of historically suitable habitat.

To determine if wind energy development in grassland dominated landscapes of the PPR will indirectly affect breeding waterfowl, we radio-marked and monitored breeding female mallards and blue-winged teal at a large-scale wind energy development in the PPR of North and South Dakota and one adjacent reference site with no wind turbines. Using this impact-reference study design (Morrison et al. 2008), we monitored females during the breeding season of 2009 and 2010 to test for a difference in home range size between these two sites. We predicted that if breeding female ducks avoided wind turbines, the home range size of females choosing to nest in landscapes near wind turbines would be larger than for females nesting in similar landscapes without wind turbines. We further assessed this prediction using an exploratory analysis by testing whether breeding females at the wind farm avoided individual wind turbines within estimated home ranges. We also evaluated nest locations of the most common breeding ducks in the PPR (*Anas* spp.) in relation to 3 prominent anthropogenic features (wind turbines, turbine access roads, and pre-existing anthropogenic edge habitat) and naturally occurring wetland edge habitat at the wind energy development to determine if females avoided nesting near wind turbines or associated infrastructure.

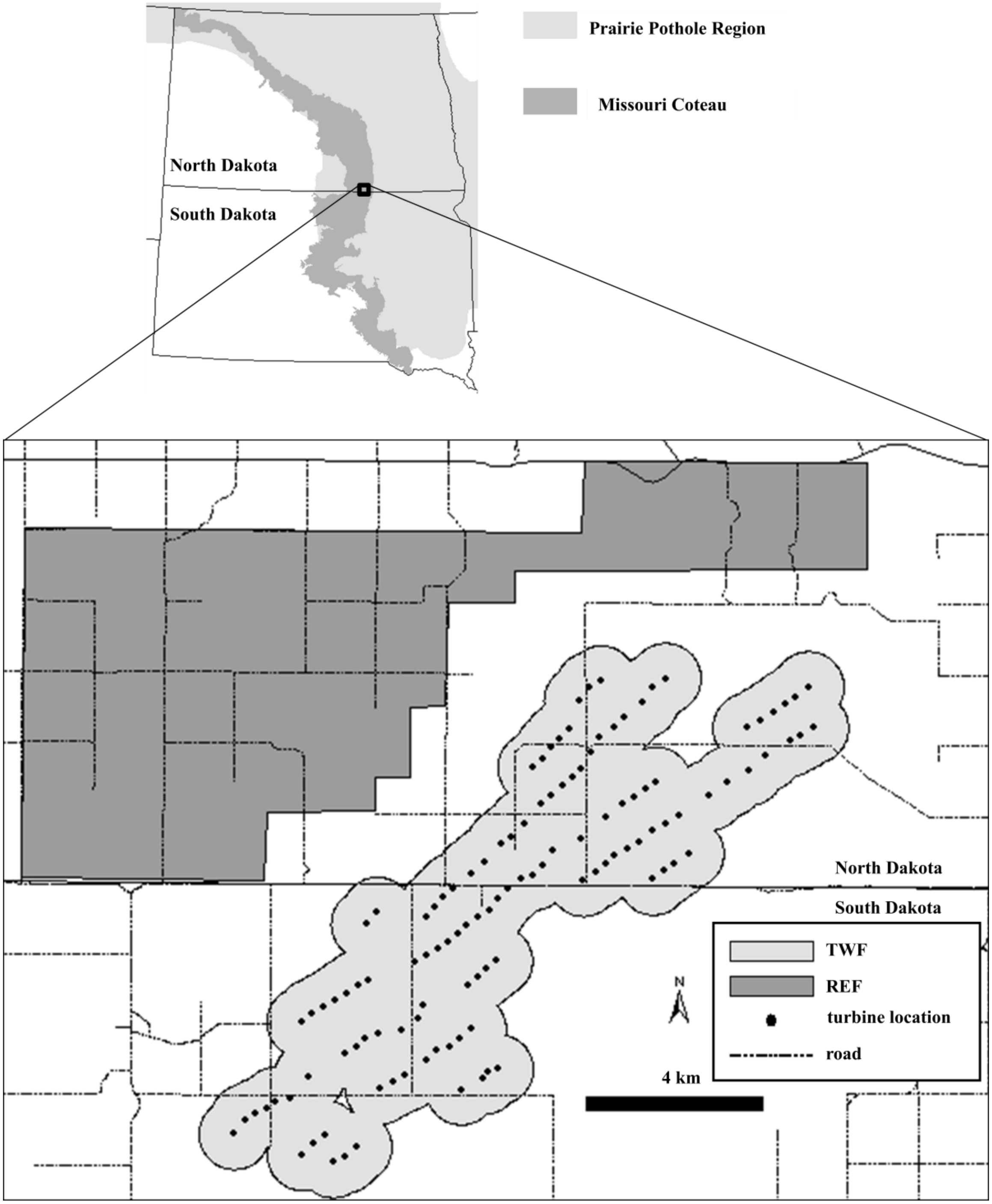


Figure 3.1: Location of the Tatanka Wind Farm and adjacent reference site in the Prairie Pothole Region of North and South Dakota. A 0.8-km buffer around each wind turbine (black circles) describes the extent of Tatanka (6,915 hectares). The reference site (8,768 hectares) was selected based on area and similarities in landscape characteristics with Tatanka.

Study Area

During the breeding season of 2009 and 2010, we conducted our study at the Tatanka Wind Farm (Acciona Energy Company, North America; hereafter TWF) and an adjacent reference site (REF) with no wind turbines. TWF is located 40 km south of Kulm, North Dakota (46°56'23"N, 99°00'20"W) and extends approximately 16.5 km on the Missouri Coteau physiographic region of the PPR in Dickey County, North Dakota and McPherson County, South Dakota (Fig. 3.1). REF is located in Dickey and McIntosh counties, North Dakota. TWF has 120 operational wind turbines located on private lands in cropland or grassland habitat. Turbine operation commenced in May 2008. Each turbine (model AW-77/1500) has three 37 m blades (76 m rotor diameter) atop an 80 m tower. The turbines operate at wind speeds between 3.5 and 25 m/s.

Both sites are characteristic of the contemporary PPR landscape; moderately sloped topography (Bluemle 1979) and many temporary, seasonal and semipermanent wetlands (Stewart and Kantrud 1971). Agricultural practices at both sites consisted primarily of livestock grazing and annually cultivated small grains and row crops. Habitat composition at TWF was 73.0 % native grassland, 14.6% wetland, 6.6% cropland, 5.4% undisturbed grassland, 0.3% forest, and 0.1% hayland. Habitat composition at REF was 51.7% native grassland, 18.9% wetland, 17.0% undisturbed grassland, 12.1% cropland, 0.2% hayland, and 0.1% forest (see Appendix for habitat definitions). Wetlands were abundant at both sites (TWF: 23.4 basins/km^2, REF: 17.3 basins/km^2). Temporary, seasonal, and semipermanent wetlands occupied 33.6, 33.7, and 32.7% of the wetland area at REF, respectfully, and 33.3, 33.4, and 33.3% of the wetland area at TWF, respectfully.

The climate at TWF and REF is continental. Average monthly temperature during our study ranged between 4.83°C – 21.4°C (U.S. Dep. Commer. 2009*a*, 2010*a*). Annual precipitation at the study site averages 49.6 cm (U.S. Dep. Commer. 2002). Between June and December 2008, the study sites received 54.9 cm of precipitation (U.S. Dep. Commer. 2008). Taken together with above average precipitation in 2009 (64.5 cm) and 2010 (53.0 cm), conditions were exceptionally wet during both years our study (U.S. Dep. Commer. 2009*b*, 2010*b*).

Methods

Study Area Definition

To our knowledge, little is known about the potential zone of influence of wind turbines for breeding waterfowl. Thus, we considered known space-use patterns of breeding ducks in the PPR to describe the extent of TWF. Breeding female mallards are known to have home ranges as large as 4.7 km^2 (Krapu et al. 1983). Blue-winged teal have comparatively small home ranges (Bellrose 1980, Anderson and Titman 1992). However, female mallards and blue-winged teal use a considerably small fraction of their entire home range during the laying and nesting periods (Gilmer et al. 1975, Dwyer et al. 1979, Stewart and Titman 1980). Therefore, we conservatively assumed that if a female spent ≥50% of the breeding season within 0.8 km of a wind turbine, it adequately represented a duck that could be indirectly influenced by wind turbines. Consequently, we described the extent of TWF as all habitat within 0.8 km from each wind turbine. REF and its boundaries were selected based on the land area, landscape characteristics, and wetland communities of TWF.

Capture, Radio Attachment, and Monitoring

We placed decoy traps in wetlands where we observed territorial pairs (Sharp and Lokemoen 1987, Krapu et al. 1997) after mallards arrived at TWF and REF in mid April. We checked decoy traps at least twice daily. To capture a representative sample of the local breeding mallard population, we relocated traps frequently and dispersed them throughout both sites.

Beginning in early May of 2009 and 2010, we used an all-terrain vehicle chain-drag technique (Higgins et al. 1969, Klett et al. 1986) to systematically search for duck nests on public and private grasslands at TWF and REF. Nest-searched areas were not randomly selected, as much of both sites were privately owned. We conducted searches between 0800 hours and 1400 hours (Gloutney et al. 1993), but we postponed searches during periods of rainfall. To increase our sample of radio-marked females, we captured incubating mallards and blue-winged teal with walk-in nest traps (Dietz et al. 1994) or mist nets (Bacon and Evrard 1990).

We marked decoy and nest-trapped females with a standard USFWS leg band and a 9-g prong-and-suture VHF transmitter equipped with mortality sensor (Model A4430, Advanced Telemetry Systems, Isanti, MN, USA). Following local anesthetic application (1cc bupivacaine), we attached transmitters near the dorsal insertion of the wings using a subcutaneous anchor and three sterile monofilament polypropylene sutures as described by Pietz et al. (1995). We weighed captured females using a Pesola spring scale (± 10g) prior to transmitter attachment to ensure that the transmitters did not exceed 3% of the females total body weight (Cochran 1980, Barron et al. 2010). We did not attach transmitters to females weighing <320 grams. We immediately released trapped females at capture sites. To reduce nest abandonment, we manually anesthetized incubating females post-procedure and placed them on their nests. Average transmitter attachment procedure duration was 22.15 minutes (±0.33 min SE). Trapping, banding, and collection was conducted under USFWS special permit (06824, and 64570) and NDGF license (GNF02601675). All female capture and marking procedures were approved by the Institutional Animal Care and Use Committee of the University of North Dakota (protocol no. 0907-4c).

We began monitoring females 24 hours after radio attachment. We generally located females between 0700 and 2100. Upon nest failure, we increased our efforts to locate individuals at times when they may have been establishing a new nest (0800 - 1400; Gloutney et al. 1993). When a radio-marked female was found in the same upland location on consecutive visits, we attempted to locate the nest (Thorn et al. 2005) and recorded the location with a Global Positioning Systems (GPS; ±15 m accuracy; Garmin GPSmap 76S; Garmin International, Olathe, KS, USA). We located each female at least once every other day until the female left the study area or died. We searched extensively for females missing during daily tracking via weekly road searches and tri-weekly aerial telemetry flights over our study area and vicinity (within approximately 3 km of study area boundaries).

To estimate female locations, we used vehicle-mounted null-peak receiving systems equipped with an electronic compass (model C100; KVH Industries, Middletown, RI, USA) and triangulation software (LOAS, version 4.0, Ecological Software Solutions LLC, Hegymagas, Hungary) or standard triangulation techniques with handheld antennas (White and Garrott 1990). We also recorded exact locations of females with a GPS upon visual confirmation.

We conducted blind tests (White and Garrott 1990, Withey et al. 2001) to assess the precision of locations estimated from telemetry vehicles. Absolute mean bearing error was 4.7° (± 0.2 SE). To improve female location estimates, we triangulated all locations for each individual within 10 min. All bearings, estimated locations, and 95% confidence ellipses were immediately plotted in LOAS following triangulation of each individual female, which allowed immediate error checking. Confidence ellipses were calculated for each triangulation by assuming a constant variance (3 standard deviations).

We only considered females for home range analysis if there was never a lapse of locating them for >5 consecutive days. We also attempted to locate each female at different times on successive days to reduce potential temporal location biases. We only included telemetry locations for a marked female that were > 1 hr apart in our home range estimates. These locations may not have been statistically independent (Swihart and Slade 1985), but we believe they were biologically independent and represented true daily movements because a female mallard or blue-winged teal could have travelled long distances within one hour (Reynolds and Laundre 1990, Mack 2003).

To further reduce error associated with locations included in the home range analysis, we only included exact locations (visually confirmed) and locations estimated from telemetry vehicles with a 95% ellipse <10 ha. Locations estimated from aerial and handheld triangulation techniques were not considered in the analysis of home ranges. Telemetry and visual observations of marked females obtained during brood-rearing were not included in estimates of home range sizes. We also censored any obvious exploratory dispersal movements because these location data can lead to overestimation of home range boundaries (Kenward 2001). Dispersal movements were identified by visually analyzing each female's movement paths in a geographic information system (GIS; ArcMap 9.3, Environmental Systems Research Institute, Redlands, CA, USA). Similar to methods described by Whitaker et al. (2007), we defined a dispersal movement as single location that was not revisited >3.62 km and >1.61 km (Reynolds et al. 2006), respectfully, from a female mallard's and blue-winged teal's previous and following location. Additionally, we included repeated nest locations in the home range analysis because incubating female mallards and blue-winged teal spend ≥80% of a 24-hr period at their nest (Afton and Paulus 1992) and we felt that estimates including these potentially autocorrelated locations would most accurately represent breeding female space-use (Reynolds and Laundre 1990, Otis and White 1999, Fieberg 2007).

Home Range Size Estimation

We used the fixed-kernel method (Seaman and Powell 1996) to calculate home ranges for individually marked female mallards and blue-winged teal because this method more accurately depicts irregular distributions (Seaman et al. 1998), which was important in assessing avoidance of individual wind turbines. Additionally, kernel estimates are less biased by potentially autocorrelated data than minimum convex polygon techniques (Swihart and Slade 1997). We defined home range as the areas encompassing 95% of the utilization distribution (Worton 1987, Worton 1989, Blundell et al. 2001). We used likelihood cross-validation (CVh) as the smoothing parameter because it produces home range estimates with less variability and better fit with small sample sizes than other smoothing parameters, such as least-squares cross-validation (Horne and Garton 2006). We used Animal Space Use 1.3 (Horne et al. 2007) to calculate CVh for marked females. We used these CVh values as the smoothing parameters in Home Range Tools for ArcGIS (Rodgers et al. 2005) to calculate home range size for each female with ≥20 locations.

Correlates of Home Range Size

We modeled home range size as either constant, a function of variables relevant to our hypothesis and factors determined in previous research to influence home range size, or an additive combination of these variables. Each female was described by site, a binary variable to investigate the presence of wind turbines (SITE). We predicted that breeding females may have larger home range sizes at TWF than those at REF if females avoid areas near individual wind turbines. We initially described each female mallard by trap method (TRAP; decoy-trapped or nest-trapped) to investigate methodological bias. All female blue-winged teal were nest trapped. We included breeding success for each female as well. Blue-winged teal were described as having either a successful or unsuccessful nest (SUCCESS). We did not detect nests for all marked female mallards, as some were decoy trapped. Consequently, we described each mallard as having no nest, failed nest(s), or a successful nest (BREEDING). We predicted that females who hatched ≥1 egg may have smaller home ranges than females that failed at nesting or did not nest. Each female was also described by the wetland area within her home range. Because temporary, seasonal and semipermanent wetlands (Stewart and Kantrud 1971) are important resources for breeding waterfowl (Krapu et al. 1997, Austin 2002), we defined wetland area as the cumulative percent of these wetland classes within each individual's home range (WET%). We predicted that home range size would decrease as the percent of wetland basins increased, as documented for breeding female mallards in the Prairie Parklands of Canada (Mack et al., 2003). We also included year (YEAR), to account for annual variation in home range size, and capture date (CAPD) in the global model. We predicted that females captured earlier may have smaller home ranges than those captured later.

Before modeling, we completed regressions between each independent variable and home range size to test assumptions of linear regression. We log transformed home range size data, but transformations were not required for independent variables. We computed tolerance values ($1\text{-}R^2$) by regressing each independent variable against the others. For mallards, trap method was strongly correlated with capture date ($1\text{-}R^2 > 0.5$). Because all blue-winged teal were captured on nests, we removed trap method from our mallard home range size models to maintain similarities in potential correlates between both species. All other variables were not strongly correlated ($1\text{-}R^2 < 0.5$). The constant model, individual covariate models, and models including all possible additive combinations of these variables resulted in a total of 32 candidate models for each species. The general linear model was the basis for investigating variables that were most strongly related to home range size of breeding female mallards and blue-winged teal. To select combinations of the best-fitting, most parsimonious models, we ranked candidate models by Akaike's information criterion adjusted for small sample size (AIC_c). We computed importance values, as cumulative AIC_c weights ($0 \leq \Sigma\, w_i \leq 1$), to assess the strength of evidence for each covariate and we used averaged coefficients and standard errors (model-averaged β ± 1SE) from competitive models ($\Delta_i < 2$; Burnham and Anderson 2002) to interpret relationships between home range size and variables of interest.

Exploratory Analysis: Home Range and Avoidance of Wind Turbines

To further explore the idea that breeding female mallards and blue-winged teal may avoid individual wind turbines during diurnal breeding season activities, we calculated the average area of habitat use per wind turbine (ha/turbine) within observed home ranges at TWF for both species. For comparison, we calculated the expected area of habitat use per wind turbine at TWF for both species. We conservatively assumed that the area we defined as TWF (0.8-km buffer around each turbine) and all observed home ranges combined, as some observed home ranges extended outside TWF, per wind turbine provided a reasonable expected value. We hypothesized that if females at TWF consistently avoided individual wind turbines, we may detect larger areas used per wind turbine in observed home ranges than the expected value.

Nest Site Location

To assess impacts of wind energy on nest location of common prairie-nesting ducks, we used nests located on private grasslands containing wind turbines (Fig. 3.2) from our opportunistic sample of nest-searched fields at TWF. Each area was searched at least once, but no more than 3 times between 1 May and 28 June in 2009, 2010, or both years. We defined a nest-searched area as a contiguously searched area with equal effort. We included all nests found while nest searching for the most common species of breeding ducks in the US PPR (blue-winged teal, gadwall [*Anas strepera*], northern pintail [*A. acuta*], northern shoveler, [*A. clypeata*], and mallard; USFWS 2010), as well as nests belonging to decoy-trapped female mallards that had active nests in nest-searched fields at the time of nest searching. All nest-searched areas contained ≥1 wind turbine and all nests included in the analysis were within 0.8 km of a wind turbine. We defined a nest as ≥ 1 egg (Klett et al. 1986) attended by a female.

GPS coordinates of nests discovered in 2009 and 2010 enabled us to construct nest point layers in a GIS for each nest-searched area. We also constructed a wind turbine point layer and screen-digitized a set of predefined habitat classes and anthropogenic features that may have influenced the location of duck nests in each of the nest-searched areas using high-resolution National Agriculture Imagery Program aerial imagery (NAIP; 2010, 1 m resolution). Anthropogenic features included turbine access roads and pre-existing edge. We defined pre-existing edge as any habitat feature, such as fencelines, farmsteads, cropland, woodland shelter-belts, and odd areas (i.e., rock piles, agricultural equipment) that was established prior to TWF’s development and was not associated with wind turbines. Habitat classes included grassland and wetland. We completed all digitizing at a scale of 1:3000 m for consistency in delineating features.

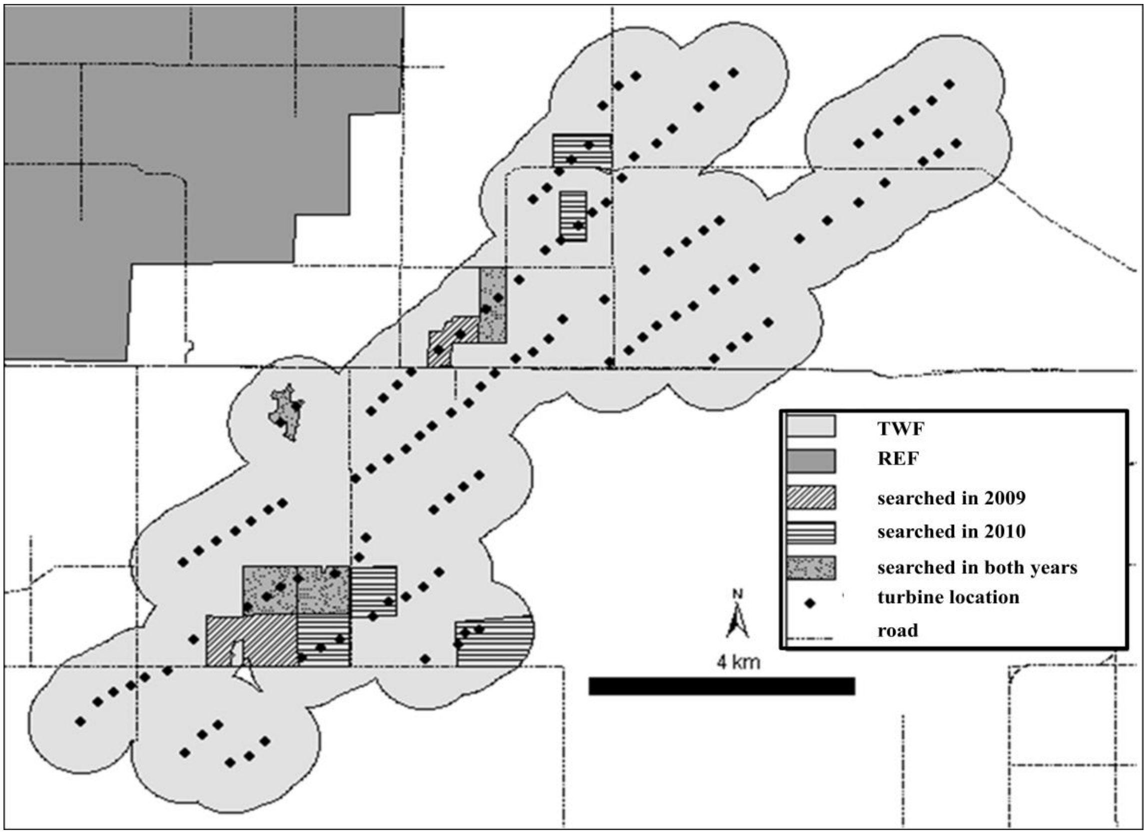


Figure 3.2: Nest-searched areas containing wind turbines in 2009, 2010, and both years at the Tatanka Wind Farm (TWF) in the Prairie Pothole Region of North and South Dakota.

Location of Nests in Relation to Features

For comparison of nest-feature distances, we generated 100 sets of random points for each nest-searched area containing wind turbines in 2009 and 2010. Each simulated data set was composed of *n* points, where *n* was the number of nests observed in the searched area. We constrained placement of random points to the area nest-searched and we eliminated the possibility of random points occurring in unsuitable nesting habitat (e.g., water and turbine access roads). We computed the distance from each random point to the closest version of each feature (turbine, turbine access road, pre-existing edge, and wetland) and the distance from each observed nest to the closest version of each feature. Some observed nests and random points were closer to wind turbines and other features outside of the nest-searched area. Thus, we considered those features outside of the nest-searched area when calculating observed nest-feature distances and random point-feature distances.

We then compared random point-feature minimum distances to observed nest-feature minimum distances. Because observed nest-feature distances at each area were not normally distributed, we calculated the median random point-feature distance for each data set. We created distributions of median random point-feature distances from each data set. The distribution of median random distances provided a basis for comparison with the observed nest-feature distances; avoidance (observed > random) or no effect (observed ≤ random). We conducted this procedure for each nest-searched area separately to gain perspective on each. We repeated this procedure for all nest-searched areas in 2009 and 2010 for an annual perspective. Although we searched for nests in different areas in 2009 and 2010, we combined these data and repeated the process described above for a cumulative perspective. We initially planned to follow similar procedures used by Pitman et al. (2005), where individual observed nest-feature distances are compared to the distribution of random point-feature distances. Instead, we used the method described above, as single nest location anomalies may cause bias (L. B. McNew, Kansas State University, personal communication). Additionally, we did not use a larger set of random points (we used 100) to create median random point-feature distance frequency distributions because of the strong dependence of statistical significance on *n*

(Johnson 1999). Arbitrarily large sets of random points may have made differences significant between any observed nest-feature median distance and random point-feature median distance.

Results

Home Range Size

After data screening according to our inclusion criteria, we included 48 and 42 female mallards monitored at TWF and adjacent REF, respectively. We included 36 and 25 female blue-winged teal monitored at TWF and REF. The median number of locations used to estimate home range size for marked female mallards was 31 (*IQR*=13, *n*=90) with a minimum value of 20 and a maximum value of 70. The median number of locations used to estimate home range size for marked female blue-winged teal was 28 (*IQR*=8, *n*=61) with a minimum and maximum of 20 and 41, respectively. Home range size was not correlated with number of locations used to estimate home range size for mallards (*r*=-0.03, *P*=0.776) and blue-winged teal (*r*=-0.02, *P*=0.877).

In our investigation of breeding female mallard home range size, models including BREEDING consistently ranked high ($\Delta\text{AIC}_c \leq 3.91$). This covariate had the highest cumulative AIC_c weight (Table 3.1). According to model-averaged coefficients, mallard home range size was best predicted by a negative relationship with breeding status such that females that nested but failed ($\hat{\beta} =$-0.0729, SE=0.2020) and females that nested successfully ($\hat{\beta} =$ -0.7090, SE=0.2680) had smaller home ranges than those females that did not nest. However, confidence intervals for females that unsuccessfully nested included zero.

Table 3.1: Cumulative Akaike's Information Criterion weights ($\Sigma\ w_i$) of home range size model covariates for female mallards and blue-winged teal at the Tatanka Wind Farm and adjacent reference site in the Prairie Pothole Region of North and South Dakota. Model covariates included YEAR (2009 and 2010), SITE (TWF and REF), CAPD (capture date), WET% (percent wetland at the home range level), BREEDING (mallards nested successfully, nested unsuccessfully, or did not nest), and SUCCESS (blue-winged teal nested successfully or nested unsuccessfully).

	$\Sigma\ w_i$	
Covariate	**Mallard**	**Blue-winged teal**
SITE	0.25	0.39
BREEDING/SUCCESS	1.00	0.24
WET%	0.21	0.38
CAPD	0.23	0.30
YEAR	0.22	0.29

Mallard home range sizes (mean ± 95%CI) at REF and TWF were 268 ha ± 60 and 296 ha ± 66, respectfully (Fig. 3.3a). Model-averaged coefficients suggested some evidence for a positive association between the presence of wind turbines and home range size for female mallards (β = 0.0154, SE = 0.0711). However, the cumulative AIC$_c$ weight for the effect of wind turbines (SITE) was 0.25 (Table 3.1). This covariate was not consistently present in competitive models. Additionally, the model including only the effect of wind turbines (ΔAIC$_c$ = 6.69) carried no weight (w_i = 0).

In our investigation of female blue-winged teal home range size, we observed no consistent pattern of covariate support. Although considerable model uncertainty resulted in similar cumulative AIC$_c$ weights for each covariate, SITE held the most relative importance (Table 3.1). Blue-winged teal home range sizes (mean ± 95%CI) at REF and TWF were 82 ha ± 17 and 68 ha ± 17, respectively (Fig. 3.3b). According to model-averaged coefficients, blue-winged teal home range size was negatively associated with the presence of wind turbines (β = -0.0892, SE = 0.1650). However, confidence intervals for this effect included zero. In addition, WET% held nearly as much cumulative AIC_c weight as SITE (Table 3.1). Model-averaged coefficients indicated some evidence that home range size was negatively associated with WET% (β = -0.0066, SE = 0.0125).

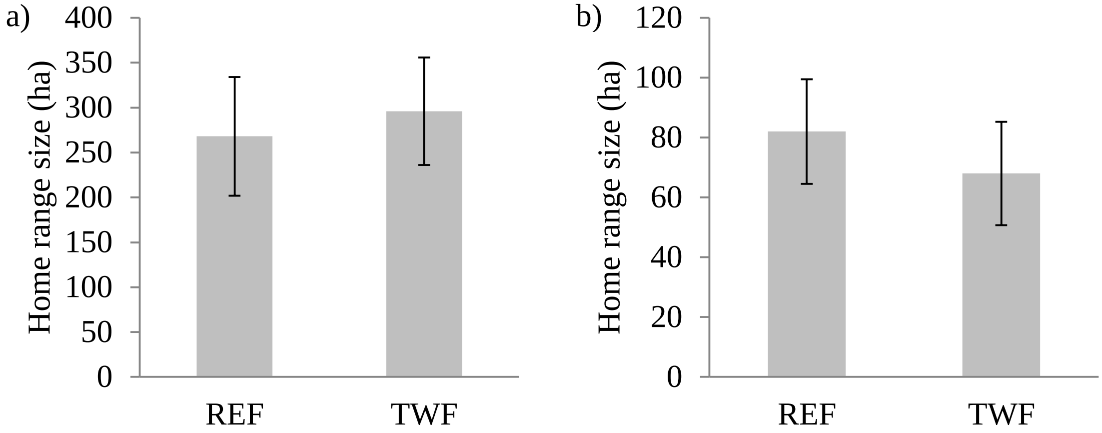


Figure 3.3: Home range size of a) female mallards and b) female blue-winged teal at the Tatanka Wind Farm (TWF) and adjacent reference site (REF) in the Prairie Pothole Region of North and South Dakota during the breeding season of 2009 and 2010. Error bars represent 95% confidence limits.

Exploratory Analysis: Home Range and Avoidance of Wind Turbines

Female mallards and blue-winged teal averaged 4.73 (±0.49 SE) and 1.06 (±0.27 SE) wind turbines, respectively, within their home ranges at TWF during 2009 and 2010. The expected number of hectares used per wind turbine by female mallards and blue-wing teal at TWF was within the 95% CI of the observed number of hectares used per wind turbine at the home range level for both species (Table 3.2).

Table 3.2: Expected number of hectares (ha) used per wind turbine compared to the observed number of hectares used per wind turbine for radio-marked female mallards and blue winged teal at the Tatanka Wind Farm in 2009 and 2010.

species	**expected ha use per turbine**	**observed ha use per turbine (±95%CI)**
mallard	72.4	74.6 (±15.9)
blue-winged teal	59.2	48.4 (±13.3)

Location of Nests in Relation to Features

We found a total of 228 nests of the most common species of ducks in the PPR during 2009 and 2010 (Table 3.3). The relative amount of our predefined set of habitat classes and anthropogenic features within each of the nest-searched areas was similar (Table 3.3), which was important for our cumulative assessment of nest locations in relation to features.

Wind turbines, turbine access roads, pre-existing anthropogenic edge features and wetlands at TWF did not influence nest location of the most common prairie-nesting dabbling duck species because observed nests were not further from these features than expected at random at each nest-searched area in 2009, 2010 (Table 3.4) and cumulatively (Table 3.5).

Discussion

Loss of grassland habitat from increased fragmentation in the PPR, which directly limits available nesting habitat (Herkert 2003) and has altered the composition and abundance of predators (Cowardin et al. 1983), is perhaps one of the greatest threats to prairie nesting ducks. Given projected wind energy development in the PPR, we reasoned that a novel impact to ducks may be an indirect loss of habitat through behavioral avoidance of breeding individuals to wind turbines or other associated infrastructure. To our knowledge, this was the first study to investigate local avoidance of wind turbines by breeding ducks in the PPR. Female mallards and blue-winged teal that settled at TWF did not appear to avoid individual wind turbines during daily breeding season activities or when selecting nest sites.

Table 3.3: Number of nests found in opportunistically nest-searched sites at the Tatanka Wind Farm by year, search frequency, and species. All nest-searched areas differed in size but had similar proportions of habitat.

					% habitat					nests					
	Searched Area	Search Frequency	Turbines	Total ha	grass	water	access road	wood	odd	MALL	BWTE	GADW	NSHO	NOPI	Total nests
2009	albertha 31	1	4	87.59	79.27	17.47	1.49	1.78	0.00	2	8	2	2	0	14
	wacker 03	1	2	22.10	60.97	37.42	1.52	0.00	0.08	0	3	0	2	0	5
	wacker 15	1	5	227.13	82.72	16.33	0.92	0.04	0.00	3	25	3	9	2	42
2010	albertha 20	2	2	47.01	87.23	11.15	1.62	0.00	0.00	1	5	2	0	1	9
	albertha 29	1	1	30.90	90.70	6.96	2.14	0.20	0.00	5	2	7	2	0	16
	albertha 31	2	2	48.22	85.84	13.13	1.02	0.01	0.00	0	3	4	2	0	9
	wacker 03	1	2	22.10	60.97	37.42	1.52	0.00	0.08	3	5	0	1	2	11
	wacker 13	1	3	83.92	79.71	18.71	1.27	0.00	0.32	5	16	6	3	4	34
	wacker 14	1	1	53.85	83.39	14.99	1.45	0.10	0.07	2	5	0	2	1	10
	wacker 15NE	3	2	59.30	80.51	17.47	2.02	0.00	0.00	5	19	5	5	8	42
	wacker 15NW	2	3	62.86	84.73	13.86	1.41	0.00	0.00	0	12	1	2	2	17
	wacker 15SE	1	3	66.29	87.98	10.84	1.17	0.00	0.00	1	11	4	1	2	19
Total			30	811.27	82.07	16.35	1.32	0.22	0.04	27	114	34	31	22	228

Table 3.4: Random point-feature distances (expected) and observed nest-feature distances in each nest-searched site at the Tatanka Wind Farm. * Indicates a significant difference between observed nest-feature median distance and random point-feature median distance. In both cases below, the * indicates no effect (observed ≤ random).

			expected distance (±95%CI) / observed median distance			
	site	*n*	Wind Turbine	Turbine Access Road	Pre-existing Edge	Wetland
2009	albertha 31	14	216.1 (±85.9) / 230.6	150.7 (±85.3) / 179.3	81.6 (±43.3) / 85.3	42.2 (±23.2) / 48.8
	wacker 03	5	161.2 (±94.1) / 97.1	102.7 (±98.2) / 49.6	49.4 (±46.4) / 6.5	28.8 (±25.7) / 22.6
	wacker 15	42	333.4 (±75.5) / 355.5	264.5 (±75.7) / 280.4	94.2 (±30.1) / 109.1	50.7 (±15.2) / 52.4
2010	albertha 20	9	206.4 (±91.2) / 268.9	120.9 (±76.1) / 161.9	131.9 (±81.2) / 154.6	55.2 (±42.6) / 41.0
	albertha 29	16	222.5 (±76.4) / 176.1	150.5 (±83.9) / 126.7	64.9 (±33.6) / 63.4	60.0 (±22.9) / 67.4
	albertha 31	9	274.3 (±112.7) / 332.4	208.1 (±129.6) / 283.7	84.2 (±62.2) / 49.7	39.1 (±24.6) / 47.3
	wacker 03	11	164.9 (±62.5) / 158.0	105.5 (±71.2) / 120.5	45.3 (±32.3) / 48.5	24.9 (±17.1) / 42.0
	wacker 13	34	371.5 (±120.6) / 419.9	326.5 (±153.8) / 314.1	* 167.2 (±65.3) / 85.3	41.8 (±14.9) / 40.2
	wacker 14	10	297.5 (±106.1) / 283.0	163.3 (±107.8) / 166.4	113.4 (±71.2) / 163.6	53.9 (±26.7) / 37.7
	wacker 15NE	42	* 284.4 (±74.8) / 187.1	154.0 (±53.6) / 105.4	93.05 (±35.6) / 90.1	54.3 (±18.2) / 56.6
	wacker 15NW	17	191.5 (±76.8) / 173.3	144.5 (±79.9) / 157.2	113.6 (±61.7) / 135.7	46.3 (±21.2) / 29.3
	wacker 15SE	19	222.3 (±86.8) / 236.6	176.2 (±81.2) / 187.0	123.1 (±64.8) / 120.7	57.6 (±28.8) / 56.8

Table 3.5: Random point-feature distances (expected) and observed nest-feature distances at the Tatanka Wind Farm in 2009, 2010 and both years cumulatively.

Year	Feature	expected distance (±95%CI)	observed median distance
2009	Wind Turbine	277.8 (±54.4)	275.7
2009	Turbine Access Road	213.1 (±58.6)	214.7
2009	Pre-existing Edge	84.5 (±25.5)	79.2
2009	Wetland	46.8 (±13.2)	44.0
2010	Wind Turbine	250.1 (±36.7)	233.0
2010	Turbine Access Road	165.4 (±30.3)	156.7
2010	Pre-existing Edge	100.9 (±18.5)	82.0
2010	Wetland	47.6 (±7.8)	44.5
Cumulative	Wind Turbine	257.4 (±30.7)	247.8
Cumulative	Turbine Access Road	176.5 (±26.9)	167.0
Cumulative	Pre-existing Edge	95.9 (±15.3)	81.4
Cumulative	Wetland	47.4 (±6.8)	44.4

Large home ranges may be energetically taxing (Schoener 1968). Thus, individuals should use resources within the smallest home range size (McNab 2002). If breeding female mallards and blue-winged teal avoided wind turbines during our study, we expected that females at TWF would have traveled further to acquire adequate resources than females at REF and this would have been reflected in their home range sizes. However, we accrued little evidence suggesting that mallards had larger home ranges at TWF and this was clearly not the case for blue-winged teal. Thus, we suspect that habitat cues remained the most important factor in determining individual female mallard and blue-winged teal home range at TWF. This is supported by our exploratory analysis of area use per wind turbine. Female mallards and blue-winged teal did not use more habitat per wind turbine than we conservatively expected.

Wetland habitat availability is thought to be a strong determinant of breeding female mallard home range size (Dwyer et al. 1979, Krapu et al. 1997, Mack et al. 2003). Titman (1983) reported that breeding mallard pairs occupied smaller areas when population density was high. Because breeding pair density may be positively associated with wetland density (Johnson and Grier 1988, Viljugrein et al. 2005) and wetlands were abundant at TWF and REF, we were surprised that wetland percent was not well supported for mallard home range size in our study. However, we measured wetland percent at the home range level and the abundance of wetlands at both sites may have weakened this effect. Mack et al. (2003) reported that females probably also select home ranges based on the availability of upland nesting habitat and perhaps unmeasured upland habitat characteristics at TWF and REF were better correlates of home range size for mallards and blue-winged teal.

Consistent with previous research, female mallards that successfully nested in our study tended to have smaller home range sizes than females that nested unsuccessfully or did not nest (Mack and Clark 2006). This corroborates Schoener (1968) supposition that individuals with smaller home ranges may be more productive and our premise that avoidance of wind turbines may influence an individual's fitness. Conversely, female success was not a strong correlate of blue-winged teal home range size. We initially suspected that this may have been an artifact of our methods; all blue-winged teal were nest-trapped. Increased dispersal has been documented for failed nesters (Lokemoen et al. 1990, Clark and Shutler 1999) and nest-trapped females that experienced a nest depredation event during our study may have subsequently emigrated from the study sites. Thus, we might have underrepresented unsuccessful female blue-winged teal according to our inclusion criteria of observing ≥ 20 locations for individuals. Nonetheless, 34 of 61 radio-marked female blue-winged teal included in our home range analysis failed to hatch ≥ 1 egg.

Upland-nesting greater sage grouse and lesser prairie chickens avoid nesting near anthropogenic features (Lyon and Anderson 2003, Pitman et al. 2005). In our study, common species of upland-nesting ducks nested randomly with respect to wind turbines and turbine access roads. Prairie grouse may avoid anthropogenic structures such as power lines or wind turbines simply because these species evolved in an environment with few vertical structures (USFWS 2004) or because of an increased risk of predation by perching raptors (Lammers and Collopy 2007). Although raptors do prey on nesting female waterfowl (Devries et al. 2003, Richkus et al. 2005) and we observed several raptor species at TWF and REF including the red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), ferruginous hawk (*Buteo regalis*), northern harrier (*Circus cyaneus*), and great-horned owl (*Bubo virginianus*), we did not observe raptors perching on wind turbines at TWF (T. Gue, personal observation). Regardless, this does not explain why females nested randomly with respect to turbine access roads, or other forms of edge for that matter.

As Howerter et al. (2008) hypothesized, we expected females to nest further from water because several species that prey on duck nests prefer to forage near wetland edges (Greenwood et al. 1999, Larivière and Messier 2000). We also expected females to nest further from terrestrial edges (pre-existing anthropogenic edge and turbine access roads) because edge habitat can influence predator foraging patterns (Phillips et al. 2003), and in some cases, be used as travel corridors (Bider 1968). However, duck nests at TWF were randomly distributed with respect to water and other edge features.

Only equivocal evidence suggests that nest-site selection for mallards, and presumably other ducks, increases fitness (Clark and Shutler 1999) and is adaptive (Howerter et al. 2008). Howerter et al. (2008) speculated that one potential reason for their failure to detect a strong relationship between nest success and nest site selection in the Prairie Parkland Region was that rapid anthropogenic changes to the landscape may have dissociated evolved nest site selection mechanisms. This may also explain why we failed to detect avoidance of anthropogenic features at TWF. During our two-year study, we did not assess evolutionary responses to wind turbines. We investigated short-term, behavioral responses. We speculate that local habitat characteristics remained of primary importance to females that settled at TWF when selecting nest sites. Albeit slight, this conjecture is supported by the fact that ducks nested closer to wind turbines at Wacker 15NE in 2010 than expected by chance (Table 3.4).

Alternatively, the risk of avian displacement by wind turbines may depend on species-specific factors (Drewitt and Langston 2006). We recognize that our cumulative analysis of nest locations in relation to anthropogenic features included 5 dabbling duck species that evolved different life history strategies and likely use different habitat cues when selecting nest sites (Greenwood et al. 1995). For example, Pasitschniak-Arts et al. (1998) found that mallards nested randomly with respect to water, but blue-winged teal nested closer to water than expected. Exactly 50% (114/228) of our cumulative sample of nests belonged to blue-winged teal. Thus, potential avoidance of wind turbines and other anthropogenic features by other species may have been masked by blue-winged teal. However, the relative species-specific proportions of nests that we observed were similar to that observed by other researchers with a large sample of nests (e.g., Klett et al. 1988) and we are confident that our cumulative interpretation of the spatial distribution of duck nests in relation to features adequately represents the most common upland-nesting ducks in the PPR.

An individual’s motivation to use a given area may change with resource availability. Wetland conditions in the eastern Dakotas during 2009 and 2010 were unprecedentedly wet (USFWS 2009;2010) and apparently adequate wetland and grassland habitat was available for females throughout TWF and REF. Thus, we suspect that local displacement effects would be evident in our home range and nest location data if females avoided individual wind turbines. However, habitat use is a hierarchical process. Johnson (1980) explained a natural order of habitat selection at several spatial scales. The scale that we investigated is similar to his description of second order: the breeding home range of an individual. Thus, we stress caution in extrapolating our results beyond those females that chose to settle at TWF and REF.

Nonetheless, our study has provided critical information in assessing local displacement effects of wind turbines in the PPR on breeding ducks. Female ducks that chose to settle at TWF continued to use historically suitable breeding habitat near wind turbines. This finding is noteworthy for waterfowl managers in the PPR given the current rate of grassland conversion and wind energy projections in this region.

Management Implications

The PPR is the most important habitat for North American duck production (Bellrose 1980, Batt et al. 1989, Kaminski and Weller 1992). Conversion of grassland and wetland habitat in this region has increased in recent years (Stubbs 2007). Wetlands in grassland habitat support higher densities of breeding duck pairs than wetlands in cropland habitat (Reynolds 2005) and large tracts of grasslands produce more ducks than comparatively fragmented landscapes (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005). Although questions about the productivity of females that nest in wind-developed landscapes still remain, ducks that chose to nest at TWF during our study did not appear to avoid wind turbines or other associated anthropogenic features.

Management practices that maintain existing wetland and grassland habitat in the PPR, even in the presence of wind turbines, might be the most effective way to maintain exploitable breeding habitat for ducks.

CHAPTER IV

SUMMARY

Cumulative Findings and Implications for Conservation and Management of Waterfowl and their Habitat Facing Wind Energy in the Prairie Pothole Region

In 2008, U.S. Fish and Wildlife Service Region 6 Habitat and Population Evaluation Team (HAPET) and Ducks Unlimited, Inc. (DU) biologists collaboratively initiated a three-year study to determine if breeding duck pair abundance in the Prairie Pothole Region (PPR) was influenced by the presence of wind turbines. Breeding duck pair distribution in the PPR is related to wetland habitat quality (Johnson and Grier 1988, Viljugrein et al. 2005). Thus, the HAPET-DU project operated on the idea that if migrating ducks failed to settle in historically suitable breeding habitat in the presence of wind turbines, the number of breeding pairs may be lower on wetlands at wind-developed areas. This scenario can be interpreted as a decrease in carrying capacity, and thus a reduction in the conservation value of the habitat. Although several years of study are required to describe parameters of temporally-dynamic populations like breeding waterfowl in the PPR, preliminary results of this project’s first data collection period during the spring of 2008 suggested that breeding pairs of five common species of breeding ducks in the US PPR (blue-winged teal [*Anas discors*], gadwall [*A. strepera*], mallard [*A. platyrhynchos*], northern pintail [*A. acuta*], and northern shoveler

[*A. clypeata*]) continued to use wetlands in grassland dominated landscapes in the presence of wind turbines (Walker et al. 2008, unpublished report). Given these preliminary findings and anticipated wind energy development in the PPR, we accordingly began to ask questions about how wind turbines may influence waterfowl at a comparatively local scale. Survival of females during the breeding season is one of the most important parameters in the population dynamics of mallards and presumably other upland nesting ducks (Hoekman et al. 2002). Thus, we reasoned that any additional mortality caused by wind turbines may reduce the landscape's productivity. We also questioned the scale at which ducks may avoid wind turbines. Consequently, we initiated this two-year telemetry project to quantify collision mortalities of breeding females at a wind energy development and determine any differences in breeding season survival of females between this wind energy development and an area without wind turbines. We also determined if breeding females avoided wind turbines when selecting nest sites or during other diurnal activities. This research effort was in accordance with the goal of the HAPET-DU project; determine the compatibility of current waterfowl conservation efforts and wind energy development in the PPR.

Female mallards occupying wetland and grassland habitat at the Tatanka Wind Farm (TWF) during the breeding season of 2009 and 2010 rarely collided with wind turbines. Predation was the major mortality factor for mallards and the only mortality factor for blue-winged teal during both years of my study. Our findings are consistent with results of many previous investigations of avian collisions with wind turbines (Erickson et al. 2001, Arnett et al. 2007, Manville 2009, but see Smallwood and

Thelander 2005) and a large literature suggesting that predation is the primary mortality factor of breeding females in the contemporary PPR (Cowardin et al. 1983, Sargeant and Raveling 1992, Sovada et al. 2001). We detected only modest support for a difference in breeding season survival of female mallards and blue-winged teal between TWF and the reference site (REF). Given that we observed few collision mortalities, any notable differences in breeding female survival between TWF and REF were not directly caused by wind turbines. The rate of collision for female mallards and blue-winged teal that settled at TWF to breed was probably not at a level of concern for waterfowl managers.

Breeding female ducks at TWF did not appear to avoid individual wind turbines when selecting nest sites or during other diurnal breeding season activities. Wetland density is an expected determinant of female mallard home range size (Dwyer et al. 1979, Krapu et al. 1983, Kirby et al. 1985). However, Mack et al. (2003) indicated that perhaps an equally important determinant of home range size is the availability of suitable upland habitat. We accrued little evidence that wetland habitat availability was related to home range size for mallards, but we believe that local habitat cues at TWF remained the most important factor in determining female mallard and blue-winged teal home range sizes and nest locations. Thus, grassland and wetland dominated landscapes in the presence of wind turbines, for females that choose to settle in areas with wind turbines at least, may still provide exploitable breeding habitat.

Larsen and Guillemette (2007) reasoned that collision risk for wintering common eiders (*Somateria mollissima*) at an offshore wind farm was negligible due to avoidance behavior during flight. We also expected that if we detected few collisions, females may have been regularly avoiding individual wind turbines and immediately adjacent habitat. Additional research corroborates this hypothesis. For example, Desholm and Kahlert (2005) found that < 1% of common eiders and geese migrating in close proximity to an offshore wind farm near Denmark were at risk of collision due to local displacement. The apparent lack of a negative relationship between female survival and a local displacement effect during our study may reflect the ability of breeding females to effectively avoid wind turbines during flight. However, our telemetry study design only allowed us to collect locations of birds at discrete time intervals when females were not in flight. Radio-marked females continued to use wetlands and grasslands in close proximity to wind turbines, but we can only speculate and rely on personal observation that females avoided wind turbines while in flight to their nests, foraging locations, and loafing sites. This may be a potentially important consideration for waterfowl managers with concerns about waterfowl productivity in wind-developed landscapes of the PPR given the presumed increased energy requirement of avoidance during flight (Fox et al. 2006) and energy requirements for egg production and incubation (Krapu 1981).

Albeit slight, some aspects of our avoidance analysis support our collision observations and existing literature suggesting that collision risk may vary by species (Drewitt and Langston 2006, Stewart et al. 2007). We detected no blue-winged teal collision mortalities during both years of our study. This is likely related to the comparatively small home range size of blue-winged teal (Dzubin 1955, Evans and Black 1956, Dwyer et al. 1979, this study). Indeed, breeding female blue-winged teal encountered fewer wind turbines than mallards during our study. Blue-winged teal pairs’ defendable territories are more discrete than mallard pairs' territories (Stewart 1977), presumably leading to comparatively less intraspecific interaction and a reduced potential for collision for blue-winged teal. Male blue-winged teal might also be less likely to actually pursue intruding pairs (Stewart and Titman 1980), resulting in shorter dispersion flights than mallards. Regardless of our speculations about collision potential for each species based on their behavioral differences, only one female mallard collision that occurred with a wind turbine and another with an unknown anthropogenic feature occurred prior to incubation. Both of these collisions occurred when a high proportion of radio-marked mallards were incubating. Future study including individual behavioral covariates may be beneficial and management strategies should continue to consider potential species specific interactions with wind turbines in the PPR, as this region provides important breeding habitat not only for ducks, but also for shorebirds (Dinsmore et al. 1999), waterbirds (Niemuth et al. 2005), and grassland songbirds (Rich et al. 2004).

Cumulative results from our research, which lacked randomization and replication of study sites, certainly do not provide enough evidence for the USFWS to discontinue the use of the precautionary approach when acquiring grassland and wetland easements in the presence of wind turbines. However, the central objective of the easement program is to protect grassland and wetland habitat from being converted to cropland at the landscape level. Wetlands in grassland habitat support higher densities of breeding duck pairs than wetlands in cropland habitat (Reynolds 2005) and large patches of grassland produce more ducks than comparatively fragmented landscapes (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005), but it has been considered that the placement of wind turbines in cropland and other disturbed lands may be the most appropriate way to avoid negative impacts of wind turbines on wildlife (Leddy et al. 1999, Kiesecker et al. 2011). Because there is considerable landowner interest in wind energy, this approach may only exacerbate the current problem regarding the loss of grassland through termination of Conservation Reserve Program contracts (reviewed by Johnson and Stephens 2011). One way to protect breeding habitat in the PPR for upland-nesting ducks may include maintenance of an easement program that will continue to be attractive for private landowners. At TWF, direct mortalities of breeding females resulting from collisions with wind turbines were uncommon and it appeared that females did not avoid wind turbines or associated infrastructure. Waterfowl managers will need to consider the consequences of acquiring wetland and grassland easements in the presence of wind development or, in the most extreme case, potentially relinquishing that habitat to annually cultivated cropland.

Recommendations for Future Research

The three most important possible impact factors of wind farms are commonly identified as: 1) increased mortality resulting from direct collision with turbine blades or other associated structures, 2) indirect habitat loss due to operating wind turbines or associated maintenance vehicle traffic, and 3) direct habitat loss due to increased fragmentation from turbine access roads and wind turbine pads. Results of our study provide much needed insight concerning the effects of wind energy on direct mortality because of collisions with turbine blades and indirect loss of habitat during the breeding season. Wind turbines and associated maintenance roads will undoubtedly introduce a novel source of direct habitat loss and fragmentation in the PPR (Bureau of Land Management 2005), which may be important for waterfowl nest survival given that nest survival is positively related to the amount of grassland habitat (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005). However, we suspect that answers to other questions, particularly about: 1) the effects of wind energy development on local predator communities, and 2) the potential for collision mortality during other life-history periods (migration), may provide a more comprehensive understanding of waterfowl productivity in wind-developed landscapes of the PPR.

Predators are the most influential factor on adult survival (Sargeant and Raveling 1992), duckling survival (Sovada et al. 2001) and nest survival (Higgins 1977, Cowardin et al. 1985, Johnson et al. 1989). This holds for adult survival even in the presence of wind turbines (this study). The fact that we detected modest support for a difference in survival between TWF and REF, but collisions were uncommon, makes us curious about the effects of wind energy development on local mammalian predator communities. Anthropogenic edge habitat such as roads are used by some predators as corridors (May and Norton 1996, Larivière and Messier 2000, Chalfoun et al. 2002) and landscape characteristics in general influence the foraging pattern and efficiency of duck predators (Phillips et al. 2003). Predators are believed to encounter more nests and presumably more nesting females in fragmented landscapes (Johnson and Sargeant 1977, Cowardin et al. 1985, Clark and Nudds 1991), but little is known about the effect of wind energy on important duck predator communities and mammals in general (Walter et al. 2006). The results of our study suggest that predator monitoring might complement our understanding of relationships between ducks and wind energy in the PPR.

Although adult survival during the breeding season is one of the most important factors on population growth, understanding the potential for collision mortality during different life-history periods might be worthwhile given the projected scale of wind energy in the PPR. Besides providing critical breeding habitat, the PPR offers essential stopover habitat for waterfowl in the spring and fall. If a female collides with a wind turbine during spring migration, she is denied the opportunity to breed, whether she was going to settle in a wind-developed landscape or not. Moreover, migrating waterfowl rely heavily on waste grains in cropland habitat (Alisauskas and Ankney 1992, Krapu et al. 1995, Pearse et al. 2011). This could be particularly important if much of the conservation community believes that placement of wind turbines in previously disturbed lands, such as cropland, is a suitable siting guideline.

APPENDIX

Habitat class descriptions provided by U.S. Fish and Wildlife Service Region 6 Habitat and Population Evaluation Team

WETLAND - Wetland basins identified by the National Wetland Inventory.

GRASSLAND - Predominant mix of native grasses, forbs or scattered low shrubs on unbroken prairie. This land cover is commonly grazed or hayed annually.

UNDISTURBED GRASS - Predominant mix of cool season grasses and forbs planted on previously cropped land. This land cover is generally undisturbed but may be hayed or grazed intermittently.

HAYLAND - Predominant mix of alfalfa and cool season grasses hayed once or twice annually.

CROPLAND - Tilled and planted with small grains or row crops that are harvested annually, includes fallow fields.

FOREST - Areas of mature trees naturally occurring or planted.

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