AN ASSESSMENT OF DIRECT MORTALITY TO AVIFAUNA FROM WIND ENERGY FACILITIES IN NORTH DAKOTA AND SOUTH DAKOTA

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife Sciences degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

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One of the most important things we can teach in life is how to live as a part of the natural world as opposed to living with the natural world. This thesis is dedicated to all the individuals that do just that.

"When one tugs at a single thing in nature he finds it attached to the rest of the world."

~John Muir

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ABSTRACT

AN ASSESSMENT OF DIRECT MORTALITY TO AVIFAUNA FROM WIND ENERGY FACILITIES IN NORTH DAKOTA AND SOUTH DAKOTA

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Renewable energy sources have the potential to provide enough energy to exceed current energy demands. In the U. S., 9% of energy consumption in 2011 was derived from renewable sources. Currently, the most technically developed and cost-effective source is land-based wind energy and the U.S. Department of Energy (DOE) has targeted 20% of electricity generated from wind by 2030. Although there are some clear advantages to using renewables, the resources are not without negative impacts to the environment. Moreover, the effects of wind energy development to wildlife are unique to each wind farm. However, these effects remain poorly understood and require additional research to elucidate and quantify.

The Northern Great Plains (NGP) contains much of the remaining temperate grasslands and, within the NGP, the Prairie Pothole Region (PPR) provides important habitat for many species of waterfowl, shorebirds, waterbirds, and grassland songbirds. This region also has high wind energy potential, but the effects of wind energy developments on wildlife populations in the NGP remains understudied. Thus, our objectives were to estimate avian and bat mortality rates, document species at high risk to direct mortality, and assess the influence of habitat variables on mortality. In 2013 and 2014, we completed turbine searches for carcasses at the Tatanka Wind Farm (TAWF) and the Edgeley-Kulm Wind Farm (EKWF) in South Dakota and North Dakota. We estimated spring (Mar-Jun) mortality of 1.86 (SE = 0.22) deaths/MW at TAWF and 2.55 (SE = 0.51) deaths/MW at EKWF. Our spring mortality rates are similar to what has been estimated for yearly mortality rates in the Great Plains, suggesting that full-year mortality rates are higher at these wind farms than others in the region. Waterfowl spring mortality rates were 0.79 (SE = 0.11) and 0.91 (SE = 0.10) deaths/MW at TAWF and EKWF, respectively. We used a Generalized Estimating Equation (GEE) to estimate the influence of landscape variables around individual turbines on waterfowl mortality and documented cropland to have a negative influence on mortality rates. We suggest future wind facility siting decisions consider avoiding grassland habitats and locate turbines in fragmented and converted habitat outside of important waterfowl areas.

A REVIEW OF DIRECT AND INDIRECT EFFECTS FROM WIND ENERGY DEVELOPMENT TO BIRDS IN NORTH AMERICA

United States energy consumption exceeded 97 quadrillion Btu (British thermal units) in 2011, the amount of energy equivalent to over 47 million barrels of oil each day (U. S. Department of Energy [DOE] 2012). Although renewable energy has the potential to supply more global energy than currently needed, only 9% of U. S. energy consumption is derived from renewable sources from 7 categories: hydroelectric (35%), wood (22%), biofuels (21%), wind (13%), waste (5%), geothermal (2%), and solar power (2%; DOE 2012). Minimal pollution and danger to humans, as well as seemingly unending resources, are viewed as clear advantages of renewable energies, even though the resources are often much more difficult to control and manipulate than conventional energies (Lior 2010). Ironically, the use of large-scale renewable energy as an "environmentally friendly" alternative to fossil fuels may increase impacts on the environment and wildlife populations at both the local and regional scales (Bezdek 1993, Abbasi and Abbasi 2000, Lovich and Ennen 2011).

Currently, the cheapest and most technically developed renewable energy source is land-based (onshore) wind farms, leading to a large number of proposed developments in many habitats (Pearce-Higgins et al. 2009). Wind energy developments are typically sited in open landscapes where average wind speeds are high (Drewitt and Langston 2006) and are sited to take advantage of some of the same air currents that birds use (Barrios and Rodriguez 2004). While the effects of wind energy to wildlife are highly variable and site-specific, the four main impacts to wildlife include habitat loss, barrier effects, avoidance, and collision mortality (Drewitt and Langston 2006, Sprague et al.

2011). These effects remain poorly understood, however, as wind turbines are often constructed in short time frames (e.g., <6 months) without preconstruction environmental impact assessments (Pruett et al. 2009) and few studies are conducted on a year-round basis (Manville 2009). Most studies have concentrated on either collision mortality or habitat loss through avoidance behavior (Masden et al. 2009). We review the documented and potential indirect and direct impacts of onshore wind energy development to U. S. bird populations.

Indirect Effects

Wind energy development generally has a small permanent footprint of <1 acre/turbine, meaning little wildlife habitat is directly lost (NRC 2007). Combined with roads, buildings, and transmission lines, the overall direct habitat loss is roughly 5–10% of the entire site being developed (Bureau of Land Management 2005). However, avoidance and displacement after wind energy development can reduce the amount of suitable habitat for many species (Drewitt and Langston 2006), especially those sensitive to human activities (Stickland et al. 2011).

Although the distance can vary across sites and species, avoidance has been documented in multiple grassland bird species (Leddy et al. 1999, Larsen and Madsen 2000, Larsen and Guillemette 2007, Devereux et al. 2008). The effects of turbines to grassland birds is especially concerning, since these species are already among the most threatened in North America as a result of land practice changes (e.g., grazing regimes, fire cycles, conversion to row-crop agriculture) and habitat fragmentation (Rich et al. 2004, Pruett et al. 2009). In North and South Dakota, Shaffer and Johnson (2008) documented small-scale displacement of songbirds. Although displacement distances vary between sites and species (Leddy et al. 1999, Shaffer and Johnson 2008), a distance between 100–200 m around the turbine is typically avoided by grassland nesting species (Pearce-Higgins et al. 2009).

Similarly, waterfowl disturbance has been documented up to 800 m from wind farms (Pedersen and Poulsen 1991), although 600 m is often considered the maximum reliable recorded distance of disturbance for onshore developments (Drewitt and Langston 2006). Turbines also may disrupt foraging and breeding behaviors of waterfowl (Winkelman 1989, Pedersen and Poulsen 1991), ultimately resulting in additional habitat loss (Osborn et al. 1998, Larsen and Madsen 2000, Guillemette and Larsen 2002, Barrios and Rodriguez 2004). Five species of dabbling duck (mallard [*Anas platyrhynchos]*, blue-winged teal [*A. discors*], gadwall [*A. strepera*], northern pintail [*A. acuta*], and northern shoveler [*A. clypeata*]) in North Dakota exhibited avoidance to wind energy development (Loesch et al. 2013), and although breeding ducks were still using habitat around turbines, abundance was reduced in those habitats, consistent with behavioral avoidance (Schneider et al. 2003, Loesch et al. 2013).

The indirect effects of wind energy to raptors are variable. While most research documents negligible disturbance to raptors from wind facilities, a few exceptions exist (Madders and Whitefield 2006). Hunt et al. (1995) documented some displacement of golden eagles from wind energy in comparison to a reference area in California. Northern harriers (*Circus cyaneus*) in Minnesota also were found to exhibit avoidance of turbines in the year following construction at both a small scale (<100 m from turbines) and larger scale (100–300 m; Johnson et al. 2000). In Minnesota, raptor densities were higher outside of areas directly surrounding turbines and raptor nests were not found on lands where turbines were present, even though suitable nesting habitat was available (Usgaard et al. 1997). At the Altamont Pass Wind Resource Area (APWRA) in California, the habitat alteration at the turbine pad itself may have created additional habitat for small mammals, which increased both prey populations as well as collision risk for raptors (Curry and Kerlinger 1998, Thelander 2004). However, even in areas where direct mortality is not documented, the apparent loss of suitable nesting habitat may indirectly affect local raptor populations (Usgaard et al. 1997).

Prairie grouse, including greater sage-grouse (*Centrocercus urophasianus*), Gunnison's sage-grouse (*C. minimus*), sharp-tailed grouse (*Tympanuchus phasianellus*), lesser prairie-chicken (*T. pallidicinctus*), and greater prairie-chicken (*T. cupido*), require extensive grassland and sagebrush habitats with open horizons (Giesen 1998, Fuhlendorf et al. 2002). Because their leks (traditional display grounds) are often found on flat grassland sites away from vertical obstructions (e.g., trees, buildings, transmission lines; Flock 2002), grouse may be especially vulnerable to wind energy as these habitats often overlap with potential development sites (Arnett et al. 2007b, Strickland et al. 2011). Although prairie grouse still may use habitats nears wind facilities after development, studies on the effects of oil and gas development to greater sage grouse suggested that there may be a 2–10 year delay before the effects of development become apparent (Harju et al. 2010, Strickland et al. 2011).

Along with their associated transmission lines, wind facilities are expected to have significatnt impacts on lesser prairie chicken, an already threatened species, due to their avoidance of tall structures and human activities (Robel et al. 2004, Pruett et al.

2009). Although lesser prairie chickens readily move across flat landscapes with slight habitat modifications (e.g., roads, barbed-wire fences), they are known to avoid otherwise suitable habitat surrounding large structures (e.g., buildings, transmission lines; Robel et al. 2004, Pitman et al. 2005), suggesting the species will likely be displaced from wind energy facilities (Pruett et al. 2009). Many of the states where lesser prairie chickens are found also harbor some of the highest wind energy development potential in the U. S. (Pruett et al. 2009) and wind energy facilities constructed in lesser prairie chicken range could pose as barriers to movement and serve to isolate populations (Risser et al. 2007).

Wind facilities acting as barriers to movement has recently been identified as a potential problem and thus, few studies have evaluated the issue (Langston and Pullan 2003, Fox et al. 2006, Madders and Whitfield 2006, Masden et al. 2009). Although barrier effects have been identified in a few studies, none of them appeared to have significant impacts on the populations studied (Drewitt and Langston 2006). However, two circumstances exist that could potentially have population level impacts. First, a wind farm may effectively block the regularly used flight paths between nesting and foraging areas, leading birds to forage or nest in less desirable habitat or increase the energy costs of traveling between habitats (Drewitt and Langston 2006). Second, multiple wind farms in an area may interact and create extensive barriers, potentially leading to large diversions in migratory pathways and requiring more energy during an already energetically-expensive time of year (Drewitt and Langston 2006).

Additionally, the construction of roads to service turbines presents another possible indirect impact to many bird populations. While not studied directly on wind energy facilities, the effects of roads have been evaluated in other locations (Kuvlesky et al. 2007). Habitat fragmentation is often a result of road systems (Saunders et al. 2002) and leads to reduced habitat quality and quantity, the primary global threat to biodiversity (Geneletti 2003, Kuvlesky et al. 2007). The construction and presence of roads facilitates both the introduction and range expansion of exotic plant species (Kuvlesky et al. 2007). In a study by Rentch et al. (2005), roadsides provided exotic plants with optimal growing sites and allowed the exotic species to ultimately suppress native species in the area. Additionally, increased traffic and associated noise levels have been documented to reduce bird densities (Reijnen et al. 1997, Brotons and Herrando 2001, St. Clair 2003, Bautistia et al. 2004, Kuvlesky et al. 2007), species diversity (Green and Baker 2002), and movement (Laurance et al. 2004) in habitat bordering roads.

Direct Effects

Collision mortality, including strikes with communication towers, power lines, buildings, fences, and other structures, may represent the largest source of unintended anthropogenic mortality to flying vertebrates (e.g., birds and bats; Kelm et al. 2004, Bispo et al. 2013). Recently, the attention has focused on collisions at wind energy facilities (Drewitt and Langston 2006, Bispo et al. 2013), which are documented for many species of raptors, passerines, upland gamebirds, shorebirds, and waterfowl (Drewitt and Langston 2006, Kuvlesky et al. 2007, Loesch et al. 2013). Direct mortality at wind energy facilities is typically considered as collision with a turbine, but associated structures such as guy cables, power lines, and meteorological masts may also cause mortality (Drewitt and Langston 2006). Evidence also has indicated that birds can be drawn into the vortex created by moving rotors and forced to the ground (Drewitt and Langston 2006, 2008). Although the effects of wind turbines on birds are more extensively studied than other structures, there remains a lack of peer-reviewed published papers (Drewitt and Langston 2008). However, many theories have been hypothesized as to why birds are susceptible to wind energy collisions, including siting (Pearce-Higgins et al. 2009), weather patterns (Winkelman 1985, Barrios and Rodriguez 2004), time of year (Smallwood et al. 2009) and species behavior (Smallwood et al. 2009).

Mortality rates vary from no mortality at some wind farms (Byrne 1983, Winkelman 1985, Higgins et al. 1995, Usgaard et al. 1997) to substantial mortality (Orloff and Flannery 1992, Usgaard et al. 1997) at a few farms, with poorly sited wind facilities having mortality rates that produce population-level effects for some species (Everaert and Stienen 2006, Sterner et al. 2007, Thelander and Smallwood 2007). Fatality rates at wind farms in North American range from <1 bird/MW/year to almost 14 birds/MW/year (Strickland et al. 2011) and averages approximately 3.04/MW/year (Erickson et al. 2005). Turbine configuration may affect collision rates (Drewitt and Langston 2008), with those in rows resulting in more collisions than randomly clustered turbines (Kuvlesky et al. 2007). Additionally, turbines located at the end of rows or edges of clusters have higher mortality rates than other turbines (Orloff and Flannery 1992, Smallwood and Thelander 2004, Thelander and Smallwood 2007, Drewitt and Langston 2008). However, the height, blade length, tip speed, and presence and type of lighting of each individual turbine also can impact collision vulnerability (Kuvlesky et al. 2007).

Collision risk also changes with changing weather conditions, with increasing mortality attributed to poor visibility due to fog or rain (Winkelman 1985, Erickson et al. 2001, Barrios and Rodriguez 2004, Drewitt and Langston 2006). Many turbines are equipped with warning lights for aircraft and birds can be especially attracted to these lights on overcast nights with drizzle or fog (Drewitt and Langston 2008). Adverse weather conditions (e.g., precipitation, high wind, and fog), air temperature, and humidity also influence flight height of birds, potentially increasing the risk of collision (Drewitt and Langston 2008).

Smallwood et al. (2009) documented that flights through turbine rows during late spring and summer resulted in higher fatality rates to raptors. For songbirds, spring and fall migration periods may result in more mortalities than other periods, due to the large number of birds moving (Gauthreaux and Belser 2006, Drewitt and Langston 2008, Strickland et al. 2011). Higher mortality rates during migration may be due to the lack of familiarity with the locations of obstacles, such as wind turbines, compared with resident species (Rose and Baillie 1989, Drewitt and Langton 2008), although resident species are often still at risk for collision (Hunt 2002, Hunt and Hunt 2006, Drewitt and Langston 2008). Some species exhibit higher collision rates in the period directly following breeding, when large numbers of young birds are added to the local population (Drewitt and Langston 2008).

Specific behaviors may predispose species to collisions with operating wind turbines (Orloff and Flannery 1992, Erickson et al. 1999, Smallwood and Thelander 2004, 2005, Smallwood et al. 2009). The amount of time a species utilizes a wind farm may contribute to collision rates (Morrison 1998, Anderson et al. 2001, Hunt 2002), although some studies have found no relationship between fatality and utilization rates (Orloff and Flannery 1992, Smallwood et al. 2009). Additionally, habituation to turbines, flying at heights near the rotor-swept area, and foraging near turbines may increase collision vulnerability (Winkelman 1985, Orloff and Flannery 1992, Barrios and Rodriguez 2004, Smallwood et al. 2009). Interactions between individuals, including territory defense or chase flights in waterfowl, may distract birds and lead to collisions with turbines (Smallwood et al. 2009). Species that tend to flock, especially for migration, appear more prone to collision, potentially because each individual in the flock pays less attention to their surroundings when following a lead bird (Alonso and Alonso 1999, Drewitt and Langston 2008). The overall abundance of birds likely interacts with these various behaviors to influence collision rates, although the relationships between factors are unknown and may vary among species (Strickland et al. 2011).

Three-quarters of bird collisions with wind turbines are songbirds (i.e., passerines; Erickson et al. 2001). Passerine fatality rates range from <1/MW/year at some facilities to 11.7/MW/year at Buffalo Mountain Wind Energy Center in Tennessee (Nicholson 2003, Kunz et al. 2007), with some wind farms reporting >30/MW/year (Kuvlesky et al. 2007). Although rates appear similar in agriculture, grassland, and forested landscapes, there is some evidence that passerine collision rates may be higher in the Midwestern and eastern U. S., particular in the mountainous areas (Strickland et al. 2011). Passerines that migrate nocturnally account for almost half of the species reported as fatalities (Kunz et al. 2007), particularly during spring and fall migration periods (Drewitt and Langston 2008, Strickland et al. 2011).

Although most collisions are songbirds, raptors may be the most vulnerable to collisions (Strickland et al. 2011). Approximately 6% of fatalities reported at wind energy facilities are raptors, though the proportion of mortalities to raptor abundance is higher than most other groups of birds (e.g., passerines; NRC 2007, Strickland et al.

2011). Raptor mortality rates range from 0/MW/year to over 0.8/MW/year (Strickland et al. 2011), with some of the most concerning levels of mortality for raptors at the APWRA in California (Howell and DiDonato 1991, Orloff and Flannery 1992). Red-tailed hawk (*Buteo jamaicensis*), American kestrel (*Falco sparvarius*), and golden eagle (*Aquila chrysaetos*) make up the majority of species found as raptor mortalities (Orloff and Flannery, Erickson et al. 2005). Raptor mortality rates at APWRA are higher than other facilities in the U. S. (Erickson et al. 2005). Because raptors have longer life spans and lower reproductive rates than many other species of birds (e.g. passerines), collision rates with wind turbines are expected to more dramatically effect raptor populations since raptor populations are not as easily able to compensate for additional mortality on an annual basis without declining (Kuvlesky et al. 2007, Drewitt and Langston 2008).

The rapid development of wind energy facilities within the whooping crane (*Grus americana*) migratory flyway has raised concerns regarding the potential effects of wind energy on the species (Belaire et al. 2014). Because direct mortality, avoidance, and alteration in flight paths have been demonstrated in other species of bird (Erickson et al. 2004, Masden et al. 2009, Pruett et al. 2009), infrastructure associated with wind energy facilities may pose a hazard to migrating cranes (USFWS 2009). Cranes also may avoid recently used stopover habitat if wind farms are sited nearby, potentially extending flight distances and negatively affecting the physical condition of migrating cranes and increasing mortality (USFWS 2009, Belaire et al. 2014). For a species with low reproductive potential and low overall populations, any additional mortality can be significant (Drewitt and Langston 2006).

Although collision rates with wind turbines are generally low, any additional level of mortality can be significant for species that have long lifespans, low productivity, slow maturation rates, or low overall populations (Drewitt and Langston 2006). For populations already plagued by other anthropogenic factors (e.g., habitat loss and fragmentation, pesticide poisoning, introduced predators), the addition of collision mortality may not allow some species to compensate for the cumulative mortality, causing population declines (Drewitt and Langston 2008). The widespread population declines in species once thought to be abundant (Robbins et al. 1989, Butcher and Niven 2007) supports this concern and creates a need for the mitigation of further impacts (Drewitt and Langston 2008).

CONCLUSION

Most wind energy impact studies focus on one season or year, even though multiple years of data may be required to obtain more precise estimates of mortality rates (Smallwood and Thelander 2004); however, few long-term studies exist (de Lucas et al. 2008). As wind energy facilities continue to increase in size and abundance, the potential for cumulative impacts that affect populations must be considered (NRC 2007). While wind energy development can be used as a step to limit greenhouse gas emissions, the potential benefits should be balanced with negative effects to wildlife, especially species sensitive to human disturbance (Pruett et al. 2009). The focus for concern will likely remain at a local population level, where effects have the potential to be the greatest (Strickland et al. 2011).

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CHAPTER TWO: AN ASSESSMENT OF DIRECT MORTALITY TO AVIFAUNA FROM WIND ENERGY FACILITIES IN NORTH DAKOTA AND SOUTH DAKOTA

This chapter is being prepared for submission in the Journal of Wildlife Management and was coauthored by Jonathan A. Jenks, Joshua D. Stafford, Kent. C. Jensen, and Troy W. Grovenburg.

ABSTRACT The Northern Great Plains (NGP) contains much of the remaining temperate grasslands, an ecosystem that is one of the most converted and least protected in the world. Within the NGP, the Prairie Pothole Region (PPR) provides important habitat for >50% of North America's breeding waterfowl and many species of shorebirds, waterbirds, and grassland songbirds. This region also has high wind energy potential, but the effects of wind energy developments on migratory and resident bird and bat populations in the NGP remains understudied. This is troubling considering >2,200 turbines are actively generating power in the region and numerous wind energy projects have been proposed for development in the future. Our objectives were to estimate avian and bat mortality rates separately for wind turbines situated in cropland- and grassland-dominated landscapes, document species at high risk to direct mortality, and assess the influence of habitat variables on waterfowl mortality at two wind farms in the NGP. From 10 March to 7 June 2013–2014, we completed 2,398 turbine searches for carcasses at the Tatanka Wind Farm (TAWF) and the Edgeley-Kulm Wind Farm (EKWF) in South Dakota and North Dakota. We found 92 turbine-related mortalities comprising 33 species and documented a greater diversity of species (n = 30) killed at TAWF than at EKWF (n = 9). After accounting for detection rates, we estimated spring mortality of 1.86 (SE = 0.22) deaths/MW at TAWF and 2.55 (SE = 0.51) deaths/MW at EKWF. Our spring mortality rates are similar to what has been estimated for yearly mortality rates in the Great Plains, suggesting that full-year mortality rates are higher at these wind farms than others in the region. We also observed a greater diversity of species killed at turbines located in grasslands when compared to turbines located in agricultural fields. Waterfowl spring (Mar-Jun) mortality rates were 0.79 (SE = 0.11) and 0.91 (SE = 0.10)

deaths/MW at TAWF and EKWF, respectively. We used a Generalized Estimating Equation (GEE) to estimate the influence of landscape variables on around individual turbines waterfowl mortality and documented cropland to have a negative influence on mortality rates. Future wind facility siting decisions should consider avoiding grassland habitats and locate turbines in pre-existing fragmented and converted habitat outside of high densities of breeding waterfowl and major migration corridors.

KEY WORDS bat, bird, carcass, collision, fatality, mortality, turbine, wildlife, wind energy

INTRODUCTION

As demands for energy increase around the world, so does the need to generate electricity without emitting harmful pollutants or greenhouse gases (National Wind Coordination Collaborative [NWCC] 2010, Korner-Nievergelt et al. 2011, Vladislavleva 2013). Wind energy offers one renewable energy solution and the U.S. Department of Energy (DOE) has targeted that 20% of electricity generated from wind by 2030 (United States Department of Energy 2008, Fargione et al. 2012, Rollins et al. 2012). Currently, wind energy is the fastest growing energy source in the world (Warudkar and Ahmed 2013).

The Northern Great Plains (NGP) has both strong and consistent winds, ideal conditions for wind energy development (Fargione et al. 2012, Gue et al. 2013, Niemuth et al. 2013). South Dakota and North Dakota rank 5th and 6th, respectively, in wind energy resource potential, and each state is capable of producing over 200 times its current energy usage (American Wind Energy Association 2014). However, this area also has much of the remaining temperate grasslands, an ecological system that is the most converted and least protected in the world (Hoekstra et al. 2005, Fargione et al.

2012). Within the NGP, the Prairie Pothole Region (PPR) consists of millions of glaciated wetlands, many of which are interspersed among remaining grassland and cropland. The PPR is the main breeding area for many of the upland nesting duck species in North America (Batt et al. 1989, Sorenson et al. 1998, Loesch et al. 2013) and it annually supports over half of the North American breeding waterfowl population (Bellrose 1980, Loesch et al. 2013). The PPR also provides important breeding habitat for shorebirds, waterbirds, and grassland songbirds (Knopf 1996, Dinsmore et al. 1999, Rich et al. 2004, Niemuth et al. 2005, 2013), including almost 40% of the species on the Partners in Flight Continental Watch List (Rich et al. 2004). Thus, in an area important to both energy development and breeding birds, siting decisions that incorporate collision risk to birds are crucial to minimizing potential mortality risk associated with wind turbines.

The ecological footprint associated with wind energy development in the PPR is likely to affect many species of wildlife (Fargione et al. 2012). Habitat loss, fragmentation, direct mortality, and avoidance are some of the concerns associated with wind energy (NWCC 2010, Strickland et al. 2011, Fargione et al. 2012). Although indirect effects of wind energy are important, they also are more difficult to study and as a result, most research examining wildlife interactions with turbines has concentrated on direct mortality (Barclay et al. 2007, Kuvlesky et al. 2007, Arnett et al. 2008, Fargione et al. 2012, Beston et al. 2015). Up to three-quarters of mortalities at U.S. wind farms were songbirds (Erickson et al. 2002, Johnson et al. 2002, Kuvlesky et al. 2007, NWCC 2010), which are the most numerous of North America's migratory species (NWCC 2010). While current mortality rates for most species are unlikely to significantly affect songbird population trends (National Academy of Sciences 2007, Manville 2009, NWCC 2010), even small changes in populations, are thought to have biological consequences (Longcore et al. 2013). This is especially true for species that are long-lived and have slow maturation rates (e.g., golden eagles [*Aquila chrysaetos*]), or those rarer species of conservation concern (e.g., Sprague's pipit [*Anthus spragueii*]; Drewitt and Langston 2006, Fargione et al. 2012, Beston et al. 2015).

Evidence of bat mortality (~450,000 bats/year; Cryan 2011) associated with wind turbines has generated increased interest in bat migration patterns (Baerwald and Barclay 2011), as most fatalities in North America are migratory tree-roosting bats, including the hoary (*Lasiurus cinereus*), eastern red (*L. borealis*), and silver-haired (*Lasionycteris noctivagans*) bats (Arnett et al. 2008, Baerwald and Barclay 2011, Jameson and Willis 2012). Some studies of wind energy facilities have documented high mortality rates in certain species of bats, which may have long-term population effects (Kunz et al. 2007, Cryan and Barclay 2009). As wind energy facilities increase in number and size, bird and bat mortalities also are expected to increase (Erickson et al. 2001, Johnson et al. 2002). More importantly, the interaction of direct and indirect impacts from wind energy for both birds and bats may cause increased mortality and risk of predation, alter the availability of food and breeding resources, and potentially affect demographics and population viability (National Research Council 2007, Kunz et al. 2007).

Loss et al. (2013) reported that per turbine mortality of all avian species was lowest in the Great Plains but that an estimated 23.1% of total United States wind energy mortality occurred in this area. Studies used for the analysis were from five states (South Dakota, Minnesota, Iowa, Oklahoma, and Texas), making it difficult to predict future impacts across the NGP. Previous research by Kiesecker et al. (2011) noted that wind energy potential in the Great Plains could be sufficient to meet the output capacity goal of 20% mandated by the DOE, even if turbines were restricted to siting only on previously disturbed lands (e.g., cultivated cropland). However, future construction would include areas where limited wind energy-related mortality data exists. Additionally, few studies have compared mortality rates in disturbed versus undisturbed lands. Our objectives were to document species colliding with turbines, calculate mortality rates for species of concern at the state and federal level, compare raptor nesting densities to raptor mortality rates, and assess differences in mortality rates for wind turbines situated in agricultural fields versus those located in pasture/grasslands at two wind farms in the PPR.

STUDY AREA

During 2013 and 2014, we surveyed two wind facilities in North Dakota (ND) and South Dakota (SD) during spring (Mar–Jun). Mean (30-yr) spring temperature ranged from –1.2° C to 18.9° C with mean annual (30-yr) precipitation of 49.6 cm (NDAWN 2014, South Dakota Office of Climatology 2014). The study area was located within the Missouri Coteau of the Prairie Pothole Region (Bluemle 1979) in North and South Dakota. The PPR consists of rolling hills interspersed with many temporary, seasonal, and semi-permanent wetlands (Stewart and Kantrud 1971, Bluemle 1979). Prior to European settlement, the predominant vegetation of the Missouri Coteau was native mixed-grass prairie (Kuchler 1964). Although over half of the grassland has been converted to agriculture, the area contains a large portion of the intact grassland left east of the Missouri River (Stephens et al. 2008). Native vegetation was predominantly western wheatgrass (*Pascopyrum smithii*), needle-and-thread (*Stipa comata*), green needlegrass (*Nassella viridula*), prairie Junegrass (*Koeleria cristata*), and blue grama (*Bouteloua gracilis*; Blank and Fosberg 1989). Cultivated crops in the study area included corn, soybeans, alfalfa, wheat, and sunflower.

The Tatanka Wind Farm (TAWF; Acciona Wind Company, Chicago, IL), located 36 km south of Kulm, North Dakota (46°56’23”N, 99°00’20”W), was commissioned in 2008 and at approximately 5,700 ha, is the largest wind farm in North and South Dakota.. The wind farm was oriented from southwest to northeast; 59 turbines were located in McPherson County, South Dakota, and 61 turbines were located in Dickey County, North Dakota, with wind farm buffers extending into McIntosh County, North Dakota (Fig. 1). Each of the 1.5-MegaWatt (MW, equal to one million watts) operational turbines (Acciona; model AW–77/1500) had an 80-m tower with three, 37-m blades. The wind farm was capable of operating between wind speeds of 3.5 and 25 m/s (Acciona Wind Company, unpublished data). Over 90% of the turbines were located in grassland or pasture habitat, although some conversion to row-crop agriculture occurred at specific turbines during the study period.

The Edgeley-Kulm Wind Farm (EKWF; Nextera Energy Resources, Juno Beach, Florida) was commissioned in 2003 and was located 3.2 km east of Kulm, North Dakota in LaMoure County. The wind farm was oriented north to south and each of the 41 operational 1.5–MW turbines (General Electric, Fairfield, CN, model CWE IEC IIa) had a 64.5-m tower with three blades between 35 and 41 m in length. The wind farm was capable of operating between wind speeds of 3.6 and 25 m/s (Nextera Energy Resources, unpublished data). All but one turbine in LaMoure County was located in row-crop (i.e., corn, soybean) agricultural fields.

METHODS

We obtained landowner access and searched 52 turbines at TAWF and 17 turbines at EKWF and searched for bird and bat carcasses from 11 March to 7 June at turbines during 2013 and from 10 March to 6 June during 2014. The sampling period was chosen to coincide with spring migration and the initial nesting period for most grassland nesting birds (e.g., waterfowl, shorebirds, upland game, raptors, and passerines). Searches were not conducted after the first week of June because vegetation height in grasslands and in croplands limited searcher efficiency.

The majority of turbine-related avian mortalities are found within 50 m of turbines (Higgins et al. 1996, Smallwood and Thelander 2008) and the U. S. Fish and Wildlife Service (USFWS) recommends search plots have widths equal to twice the turbine height (USFWS 2012). Therefore, we centered a 1.5-ha circular plot (radius of approximately 70 m from turbine base) around each turbine to ensure all areas within 50 m of the turbine were searched (Anderson et al. 1999, Johnson et al. 2002), as well as distances out to twice the turbine height (USFWS 2012). A two-person crew surveyed each 1.5-ha plot using parallel transects, maintaining 4-6 m between transects (Smallwood and Thelander 2008), depending on snow cover, grass height, and topography.

We searched a sub-sample of turbines daily because many migratory species are small and there is a potential for bias associated with high numbers of periodic mortalities (USFWS 2012). We searched 20 turbines per day based on the time needed for a two-person team to complete a search. We established a 3-day search rotation where we searched a subset of 10 turbines (all at TAWF) daily and then rotated the searching of the remaining 10 turbines among the remaining for which we had access, with 10 turbines at the Edgeley-Kulm site searched every third day.

We recorded date, start time, end time, observer(s), wind farm, turbine number, turbine status (i.e., operating, not operating, under maintenance) for each search as per the USFWS established protocol (USFWS 2012). When a carcass was located, we flagged the remains and continued the search. After the entire plot was searched, we returned to each carcass and recorded date, species, sex and age (when possible), observer, turbine number, wind farm, distance from turbine (including GPS coordinates), and condition of carcass (entire, partial, scavenged). We took digital photographs of each carcass and wore sterile vinyl gloves when handling all carcasses. In the event that a carcass could not be identified, we placed the carcass in a labeled plastic bag (USFWS 2012) for further examination in the laboratory (South Dakota State University). All carcasses were handled in accordance with research permits granted by the USFWS (Permit No. MB03605B-0), South Dakota Department of Game, Fish and Parks (Permit No. 33), North Dakota Game and Fish Department (Permit No. GNF03343177) and the Institution Animal Care and Use Committee (Approval No. 12-064E) at South Dakota State University, Brookings, SD.

We assigned cause-specific mortality for all carcasses or body parts (e.g., primary, secondary, and tail feathers, head, wing, tarsi) found (Smallwood and Thelander 2008). Additionally, we classified all carcasses as either small-bodied or large-bodied (i.e., <38 cm body length or ≥ 38 cm body length, respectively) because size can influence detection probability of the carcass (Smallwood and Thelander 2008). We determined the probable cause of death based on injuries and proximity to turbines. Potential injuries associated with wind turbine collision included severed or twisted torso, decapitation, severed wing(s), tail, or leg(s), and other forms of blunt trauma (Smallwood and Thelander 2008). We attributed predation to carcasses with feathers plucked and scattered or those located in close proximity to intraspecific nests. We estimated number of days since death by assessing carcass decomposition and date of previous site visit (Smallwood and Thelander 2008).

We evaluated observer detection bias by placing carcasses of salvaged birds randomly in turbine search plots. We used 26 species of birds (both small- and large-bodied) for detection trials, obtained via USFWS collection, individuals found and collected during a previous turbine search, trapped (i.e., European starling [*Sturnus vulgaris*]) or raised domestically (rock pigeon [*Columba livia*]). Each week, 8–12 bird carcasses were placed in plots scheduled to be searched within 7 days. We used a double-blind approach where the location and number of carcasses placed in each plot varied and was unknown to searchers (Higgins et al. 2007). We then calculated search detection rates for non-raptors classified as small-bodied or large-bodied (Smallwood 2007, Smallwood and Thelander 2008). We estimated overall mortality rates as well as species-specific mortality rates yearly at each wind farm.

We estimated adjusted mortality using the following equation: $M_a = M_u/D$, where M_u is unadjusted mortality expressed as the number of fatalities per wind turbine per period or number of fatalities per MW of rated wind power capacity per period, and D is the overall detection probability determined by searcher detection trials (K. Smallwood, Independent Environmental Services Professional, personal communication). We calculated the standard error, ($SE[M_a]$), using the delta method (Goodman 1960):

$$SE[M_a] = [(1/D \times SE[M_u])^2 + (M_u \times -1/D^2 \times SE[D])^2]^{1/2}$$

We made no adjustment for background mortality (caused by factors independent of wind turbines and associated infrastructure), which is typically small (Smallwood and Thelander 2008). Additionally, we did not adjust for crippling bias, search radius bias, or carcass removal by maintenance personnel. Consequently, our adjusted estimates of mortality are likely conservative because additional mortalities would increase mortality estimates by unknown degrees by adding undiscovered mortalities to the total (Smallwood and Thelander 2008).

During each year, we ground mapped the study area and used ArcGIS 9.3 (ESRI, Inc., Redlands, CA) to digitize the area within 1,600 m of each turbine, or approximately the size of a mallard (*Anas platyrhynchos*) home range (Cowardin et al. 1988, Loesch et al. 2013). We used the 2012 National Agriculture Imagery Program (NAIP) satellite imagery with a resolution of 1 m and digitized at the 1:2000 scale, classifying land use as development (e.g., roads, railroads, farmstead,), trees, wetland, crop (e.g., corn, soybean, wheat, sunflower), hay/alfalfa, or pasture/grassland.

We used FRAGSTATS Version 4.2 to calculate landscape-level metrics associated with each buffered turbine (McGarigal et al. 2002; Grovenburg et al. 2012). Landscape metrics included total area (TA), patch density (PD; number of patches/100 ha of the habitat category), landscape shape index (LSI; total length of edge in the landscape, divided by the minimum total length of edge possible), mean area; mean area coefficient of variation, mean shape, interspersion and juxtaposition, patch richness (PR; number of different patch types present within the landscape boundary), Shannon's Diversity Index (SHDI; equals 1 minus the sum of the proportional abundance of each patch type multiplied by that proportion), and Simpson's Diversity Index (SIDI; equals 1 minus the sum of the proportional abundance of each patch type squared). Because metrics within each FRAGSTATS category often are correlated (Hargis et al. 1998, Grovenburg et al. 2012), we selected ≤2 metrics within each selected category (Kie et al. 2002). To test for potentially confounding relationships, we evaluated collinearity between predictor variables using Pearson's correlation coefficient ($r > |0.60|$).

We used a Generalized Estimating Equation (GEE) using SAS 9.4 (SAS Institute Inc., Cary, NC) to evaluate the influence of landscape metrics on turbine-related mortality. We used the GEE method to account for possible temporal (i.e., individual turbines monitored for >1 season) and spatial (i.e., overlap of 1600-m buffers around turbines) correlation among outcome variables (Pan 2001, Molenberghs and Verbeke 2005, Cui and Qian 2007). We then used quasi-likelihood under the independence model criterion (QICu) to evaluate models that best described those landscape metrics associated with mortality rates (Cui and Qian 2007, Allison 2012). The QICu is an approximation of QIC, the GEE equivalent of the Akaike's Information Criterion (AIC) statistic, used to compare models with different predictor variables (Pan 2001, Allison 2012). The GEE method is based on quasi-likelihood theory (Wedderburn 1974) whereas AIC is developed under maximized-likelihood theory (McCullagh and Neider 1989), statistics derived from one method cannot be directly applied to the other (Cui and Qian 2007, SAS Institute Inc. 2008, Grovenburg et al. 2011). Although a smaller QICu statistic is preferred, we recognized models differing by ≤2 ΔQICu from the top model as potential alternatives (Pan 2001). We also calculated model weights (w_i) to better estimate the relative probability of each model.

We used raptor nesting density data from companion studies concurrently conducted in the TAWF and EKWF study areas to examine dependency between nesting density and spring raptor mortality.

RESULTS

We completed 2,398 turbine searches and found 141 bird and bat fatalities. We excluded 49 carcasses from mortality estimates because they were identified as non-turbine related ($n = 3$; i.e., predation of a hen on nest) or non-spring migration ($n = 46$; e.g., outside of Mar-Jun, often found as snow melted) mortalities (Table 1). We used 52 carcasses for the 2013 data analysis and 40 carcasses for the 2014 data analysis. We found carcasses ranging from 4 m to 72 m ($\bar{x} = 35.12$, SE = 1.83) from turbines (Table 2). Carcasses included in analysis were comprised of 33 species and included 56 (61.0%) waterfowl, 20 (21.7%) passerines, 5 (5.4%) waterbirds, 5 (5.4%) upland game birds, 4 (4.3%) shorebirds, and 2 (2.2%) bats (Tables 3 and 4). Forty eight (52%) carcasses were intact, 25 (27%) were considered scavenged, and 19 (21%) were dismembered.

Detection rates were similar between years, but differed by size-class of carcass and habitat type. Detection rates also were similar between observers (95% CIs overlapped) for both large and small carcasses. Overall detection rates, including both years and both size classes, were 47% (SE = 0.05) at TAWF and 37% (SE = 0.07) at EFWF. Large bird detection rates for both wind farms were 70% (SE = 0.10) and 65% (SE = 0.07) in 2013 and 2014, respectively. The rates of small bird detection were 22% (SE = 0.10) in 2013 and 25% (SE = 0.06) in 2014. For both sites over both years, the average large bird (>38cm) detection rate was 67% (SE = 0.06) while the average small bird (<38cm) detection rate was 24% (SE = 0.05).

Unadjusted mortality extrapolated to unsearched turbines for 2013 and 2014 spring mortality at TAWF was 84 and 87 individuals, respectively, and 39 and 21 individuals, respectively, at EKWF. After adjusting for detection rates, we estimated spring mortality at TAWF at 303 (95% CI = 0–645) individuals in 2013 and 171 (95% CI = 73–269) individuals in 2014. Adjusted estimates for the EKWF were 62 (95% CI = 4–120) individuals in 2013 and 52 (95% CI = 0–110) individuals in 2014. We estimated mortality rates during our sampling period as 1.86 (SE = 0.22) deaths/MW at TAWF and 2.55 (SE = 0.51) deaths/MW at EKWF. Mortality rates (deaths/MW) between the farms did not differ in either year as standard errors overlapped, even though TAWF is predominantly grassland and EKWF is row-crop agriculture (Table 5). However, the number of species killed at TAWF ($n = 30$) was greater than at EKWF ($n = 9$). Orders with the greatest magnitude of mortality included Anseriformes and Passeriformes (Tables 3 and 4). Species most commonly found included: mallard, northern pintail (*A. acuta*), and redhead (*Aythya americana*).

We combined fatality counts and detection trials from both years at each wind farm to estimate partial-year mortality. Fresh carcasses were found starting in April of each year, with the exception of one carcass in 2013, and mortalities remained relatively constant throughout the remainder of field searches (Figs. 2 and 3). We averaged the number of carcasses found in the last 10 weeks of field seasons and then extrapolated that number for the summer and fall migration period (31 weeks total; 1 Apr to 31 Oct) to estimate partial-year mortalities. We did not include winter months because fewer species are present in the area during this time and we did not identify these species as overly susceptible to turbine-related mortality based on turbine searches in March. We estimated partial-year mortality as 2.92 (SE = 0.36) deaths/MW at TAWF and 3.62 (SE = 0.78) deaths/MW at EKWF.

Since a majority (56 of 92 fatalities) of our carcasses were waterfowl (Family: Anatidae), we calculated unadjusted and adjusted mortality of waterfowl at each wind farm and generated 7 *a priori* models based on habitat selection patterns for breeding waterfowl (Stephens et al. 2005, Drever et al. 2007, Loesch et al. 2013, Walker et al. 2013, USFWS 2014). After combining large-bird detection rates for both years at each wind farm, we estimated unadjusted spring waterfowl mortality at 0.55 (SE = 0.06) deaths/MW at TAWF and 0.51 (SE = 0.10) deaths/MW at EKWF. Adjusted spring mortality rates were 0.79 (SE = 0.11) deaths/MW and 0.91 (SE = 0.27) deaths/MW at TAWF and EKWF, respectively. Similar to above, we averaged number of waterfowl found weekly (Figs. 4 and 5) and extrapolated that out to estimate partial-year mortality for waterfowl at TAWF as 1.52 (SE = 0.34) deaths/MW and EKWF as 1.13 (SE = 0.16) deaths/MW.

Land cover in the 1600-m buffer was dominated by cropland at EKWF and grass/pasture at TAWF (Table 5). Between 2013 and 2014, land use changes were minimal around turbines; at TAWF, hay/alfalfa decreased 1% and cropland increased 1%. Remaining land cover percentages were unchanged between years at both farms. We recognized two potentially competitive GEE models (Table 6) based on unadjusted spring waterfowl mortality. Our top-ranked model (CropArea, $w_i = 0.68$) indicated that waterfowl mortality was negatively ($\beta = -0.0011$, 95% CI = -0.0013– -0.0009) influenced by percentage of cropland within 1600 m of turbines. The weight of evidence supporting this model was 2.6 times the next model and >39 times remaining models. We also considered the model CropArea + WetPatchNumber (w_i = 0.26) as competitive; this model was 1.89 ΔQICu from the top-ranked model. Again, the β-estimate and 95% confidence intervals for CropArea (β = −0.0013, 95% CI = −0.0014– −0.0009) were negative, indicating increased cropland had a negative effect on waterfowl mortality rates. The β-estimate and 95% confidence intervals for WetPatchNumber (β = −0.0101, 95% CI = −0.0344–0.0141) included zero, indicating the model was only competitive because it also included CropArea. Thus, we excluded this model from consideration.

We found no spring raptor mortalities at either wind farm. Although we identified 469 raptor nests comprised of 5 species (Swainson's hawk [*Buteo swainsoni*], red-tailed hawk [*B. jamaicensis*], ferruginous hawk [*B. regalis*], northern harrier [*Circus cyaneus*], and great horned owl [*Bubo virginianus*]) in a 4-county (McPherson County, SD, and Dickey, McIntosh, and Logan counties, ND) area, only 4 active raptor nests were within 1,600 m of a turbine at TAWF or EKWF (Figs. 6 and 7).

DISCUSSION

Fargione et al. (2012) suggested that siting wind energy developments on disturbed lands, which are seemingly low in wildlife value, rather than in large, intact natural habitats, may reduce impacts to wildlife. While our study documented no difference in mortality rates between a wind farm situated in intact grassland and one in agricultural lands, the diversity of species killed at the wind farm located in grasslands was more than three times higher than that located in agricultural fields. Most (67%) of the species found at EKWF were waterfowl, which are locally abundant in almost every habitat due to the density of wetlands that provide both migration stopover points and breeding and brooding habitats (Loesch et al. 2013, USFWS 2014). However, cropland did play a role in waterfowl mortality at the individual turbine level. Due to their importance to waterfowl nest success in the PPR, we expected the amount of grassland cover (Greenwood et al. 1995, Horn et al. 2005, Stephens et al. 2005, Howerter et al. 2014, USFWS 2014) and abundance of wetlands (Walker et al. 2013, USFWS 2014) to play an important role in estimating waterfowl mortality at site-specific turbine locations; though neither of those variables was competitive in our top-ranked models. Wetland density likely did not play a significant role in our models due to the abundance of wetlands at both wind farms. Most (78.3%) of the 1600-m turbine buffers were comprised of between 10% and 20% wetlands. However, grassland was highly ($r = -0.98$) correlated with cropland. If cropland had been omitted from our models, the top-ranked models then would have included wetland and grassland variables, with grassland having a positive relationship (95% CI did not overlap zero) with waterfowl mortality. Nevertheless, the negative relationship with cropland has been documented as a factor in waterfowl nest success (Drever et al. 2007, Devries and Armstrong 2011, Bloom et al. 2013, USFWS 2014). While many dabbling ducks (e.g., mallard, northern pintail, northern shoveler [*Anas clypeata*], blue-winged teal [*A. discors*], gadwall [*A. strepera*]) use cropland for nesting cover, especially in areas with high wetland densities, both overall abundance and reproductive success is lower in cropland landscapes (Higgins 1977, Boyd 1985, Bethke and Nudds 1995, Greenwood et al. 1995, Drever et al. 2007). Thus, siting wind energy facilities outside grassland areas that are considered important for waterfowl breeding may reduce turbine-related waterfowl mortality, as long as siting incorporates areas with higher percentages of cropland (prior to energy development) on both the individual turbine and wind farm scales. Coincidentally, avoiding areas with high waterfowl breeding densities, based on USFWS Habitat and Population Evaluation

Team data, also may reduce overall mortality because these areas also represent critical habitat for many other species of wetland-dependent birds (Reynolds et al. 2006, Niemuth et al. 2008, Fargione et al. 2012).

Although we estimated the mortality rates for all species found during searches, many of those estimates are imprecise. The lower bound seasonal mortality estimate for most species was <0, typically due to few carcasses being found and low detection rates. Lack of precision is common among many wind energy mortality studies, including those from the Tehachapi and San Gorgonio Wind Resource Areas (Anderson et al. 2004, 2005) and the Altamont Pass Wind Resource Area (Smallwood and Thelander 2008).

We were unable to attribute detected avian mortality to resident or migrant populations and thus, an effect on local or regional populations could not be established for two reasons. First, our estimates excluded those individuals killed by vehicular-collision, power lines, barbed-wire fences, predation, or those killed outside of the spring migratory period; although we did record these carcasses separately. And second, we were not able to include any individuals that may have been injured and then left the study site, or those that were removed by landowners or wind turbine maintenance crews between searches.

While estimated mortality rates for most species were low, many migratory bird populations are declining (North American Bird Conservation Initiative 2014), and additional sources of mortality, such as wind energy, may be cause for concern. Our mortality rate estimates for just our sampling period (a 13-week span) are similar to full-year estimates at other wind farms in the U. S. (e.g., Johnson et al. 2002, Smallwood and Thelander 2008; also see Erickson et al. 2005). Our extrapolated, partial-year mortality estimates were higher than the Great Plains overall estimate of 1.81 birds/MW/year (Loss et al. 2013). However, mortality rates at multiple phases of construction ranged from 2.86 deaths/MW/year to 5.93 deaths/MW/year at Buffalo Ridge, Minnesota (Johnson et al. 2002). Comparatively, estimates from the Altamont Pass Wind Resource Area for three sets of turbines were 2.28, 1.51, and 1.82 deaths/MW/year (Smallwood and Thelander 2008). While we believe our estimates are representative of the turbine-related mortality in our region, we are aware that estimates from partial year sampling extrapolated to estimate annual mortality may underestimate total mortality rates (Loss et al. 2013). For instance, 90% of bat fatalities occur between July and September (Erickson et al. 2002, Kuvlesky et al. 2007), a period outside the sampling frame for our study. Therefore, we likely dramatically underestimated bat mortality at TAWF and EKWF (see Bicknell and Gillam 2013). Collision risk also can vary seasonally, thus influencing species-specific mortality estimates (Kuvelesky et al. 2007). We recognize our results may not be reflective of turbine-mortality for all species in our area throughout the year.

Although we documented no spring raptor mortality, we did find two species of raptor as potential turbine-mortalities from the fall migration period. A study at Buffalo Ridge Wind Resource Area in Southwestern Minnesota found that raptors avoided nesting on lands were turbines were located, despite the presence of seemingly suitable tree-belt and riparian habitat (Usgaard et al. 1997). While we cannot conclude that raptors are avoiding the wind farms in the Dakotas, since we have no pre-construction or behavioral data, the presence of turbines has caused avoidance of other species of birds at EKWF and TAWF (see Gue et al. 2013, Loesch et al. 2013, and Niemuth et al. 2013).

Thus, raptors may be more susceptible to the indirect effects of wind energy than direct mortality at these two wind farms.

We did not find carcasses of any federally threatened or endangered species during our study; however, it is important to note that five listed or candidate migratory birds (whooping crane [*Grus americana*], least tern [*Sterna antillarum*], piping plover [*Charadrius melodus*], red knot [*Calidris canutus rufa*], and Sprague's pipit) and one threatened bat (northern long-eared bat [*Myotis septentrionalis*]) use habitats on the Missouri Coteau during migration or breeding (USFWS 2015). Other species are considered regional conservation priorities, particularly wetland and grassland species that are experiencing habitat loss and fragmentation due to grassland conversion for production agriculture (Wright and Wimberly 2013) and tile drainage (Stodola et al. 2014). We categorized species of concern for our region as those referenced in North Dakota's 100 Species of Conservation Priority (Hagen et al. 2005), South Dakota's Heritage Species, Priority Species listed in the All Bird Conservation Plan, and Species of Greatest Conservation Need listed in the South Dakota Wildlife Action Plan (South Dakota Game, Fish and Parks 2014), and the USFWS Birds of Conservation Concern (2008a) and Birds of Management Concern (2011). Overall, we found 14 species of conservation priority as mortalities at wind turbines during our spring study, including the American white pelican (*Pelecanus erythrorhynchos*), upland sandpiper (*Bartramia longicauda*), northern pintail, redhead, sharp-tailed grouse (*Tympanuchus phasianellus*), Le Conte's sparrow (*Ammodramus leconteii*), brown creeper (*Certhia americana*),silver-haired bat (*Lasionycteris noctivagans*), eared grebe (*Podiceps nigricollis*), eastern wood-pewee (*Contopus virens*), American tree sparrow (*Spizella arborea*), savannah sparrow

(*Passerculus sandwichensi*), dark-eyed junco (*Junco hyemalis*), and western meadowlark (*Sternella neglecta*). Of these, 3 species were found at EKWF and 13 were found at TAWF, consistent with the idea that many bird species of conservation concern are less abundant and may experience less turbine-mortality in disturbed areas (Fletcher et al. 2011, Fargione et al. 2012).

Although many of the species we reported as turbine-mortalities, such as the mallard and barn swallow, are not included in the above state and federal lists, they are protected under the Migratory Bird Treaty Act (USFWS 2013). Most of the species we reported were found as turbine mortalities at other facilities nationwide (e.g., Johnson et al. 2002, Smallwood and Thelander 2008). Additional wind facilities constructed in the NGP, PPR, and elsewhere may have an increased effect on these populations. In 2014, 822 new turbines were proposed for construction in the four-county area surrounding our study sites (USFWS, unpublished data). Assuming mortality rates comparable to our results, we estimate that an additional 3,602 deaths would occur in the four-county area during the partial year (Apr–Oct), with as many as 2,290 deaths occurring during the spring migration period (Mar-Jun). These additional turbines have the potential to impact species we documented as susceptible to turbine-strikes as well as enhancing the risk of mortality to threatened and endangered species in the region. While recent research on alternative turbine designs, including redesigned rotors and pattern-painted blades, could help to reduce mortality (Tucker 1996, Hodos et al. 2001, McIsaac 2001), any wind facilities sited in bird migration corridors and the fatalities associated with them remain a justifiable concern (Erickson et al. 2005, Kuvlesky et al. 2007).

MANAGEMENT IMPLICATIONS

Despite low precision in mortality estimates, our fatality counts and associated mortality estimates indicate that wind energy operations on the NGP and in the PPR have the potential to negatively affect many avian species. Although mortality rates for cropland and grassland dominated wind farms were similar, more species of concern were found as fatalities at turbines located in grassland habitats. Future siting of wind facilities focused on pre-existing disturbed land, such as cropland, at the turbine-site scale may help to reduce avian mortality. We suggest siting future wind energy facilities in cropland landscapes with wind-energy resources (≥6.5 m/s average annual wind speed at an 80-m height; DOE 2014) and low duck nesting densities (<25 breeding pairs per square mile; USFWS 2008). Since important upland duck nesting habitat often coincides with critical habitat for other grassland species, the use of these areas also may minimize overall mortality.

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Table 1: All carcasses found during mortality searches at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm in LaMoure County, North Dakota, USA, 2013–2014.

	Scientific Name	# of Spring Turbine-Mortalities	# of Potential Turbine-Mortalities (non-spring)	Predation of Hen on Nest	Total
Canada Goose	*Branta canadensis*		9		9
Mallard	*Anas platyrhynchos*	39	9	1	49
Gadwall	*A. strepera*	2	2		4
Green-winged Teal	*A. crecca*	1			1
Northern Pintail	*A. acuta*	7	4		11
Northern Shoveler	*A. clypeata*		1		1
Blue-winged Teal	*A. discors*	2	3	2	7
Redhead	*Aythya americana*	5	2		7
Anatidae spp.			2		2
Ring- necked Pheasant	*Phasianus colchicus*	3	1		4
Sharp-tailed Grouse	*Tympanuchus phasianellus*	2	1		3
Eared Grebe	*Podiceps nigricollis*	1			1
America White Pelican	*Pelecanus erythrorhynchos*	1	3		4
Swainson's Hawk	*Buteo swainsoni*		1		1
Red-tailed Hawk	*B. jamaicensis*		1		1
Buteo spp.			1		1

Table 1 continued: List of all carcasses found during mortality searches at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm in LaMoure County, North Dakota, USA, 2013–2014.

Species	Scientific Name	# of Spring Turbine-Mortalities	# of Potential Turbine-Mortalities (non-spring)	Predation of Hen on Nest	Total
Sora	*Porzana carolina*	1			1
Virginia Rail	*Rallus limicola*	1			1
American Coot	*Fulica americana*	1	1		2
Upland Sandpiper	*Bartramia longicauda*	2			2
Wilson's Snipe	*Gallinago delicata*	2	1		3
Eastern Wood-pewee	*Contopus virens*	1			1
Red-eyed Vireo	*Vireo gilvus*	1			1
Warbling Vireo	*V. olivaceus*	1			1
Tree Swallow	*Tachycineta bicolor*	1			1
Barn Swallow	*Hirundo rustica*	2			2
Brown Creeper	*Certhia americana*	1			1
Swainson's Thrush	*Catharus ustulatus*	1			1
European Starling	*Sturnus vulgaris*	2			2
Snow Bunting	*Plectrophenax nivalis*	2			2
American Tree Sparrow	*Spizella arborea*	1	1		2
Savannah Sparrow	*Passerculus sandwichensis*	1			1

Table 1 continued: List of all carcasses found during mortality searches at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm in LaMoure County, North Dakota, USA, 2013–2014.

Species	Scientific Name	# of Spring Turbine-Mortalities	# of Potential Turbine-Mortalities (non-spring)	Predation of Hen on Nest	Total
Le Conte's Sparrow	*Ammodramus leconteii*	1			1
Song Sparrow	*Melospiza melodia*	1			1
Dark-eyed Junco	*Junco hyemalis*	1			1
Western Meadowlark	*Sternella neglecta*	1			1
Red-winged Blackbird	*Agelaius phoeniceus*	1			1
Common Grackle	*Quiscalus quicula*	1			1
Brown-headed Cowbird	*Molothrus ater*		1		1
Unknown Bird spp.			2		2
Silver-haired Bat	*Lasionycteris noctivagans*	2			2

Table 2: Distances carcasses were found from turbines at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm in LaMoure County, North Dakota, USA, 2013–2014.

Distance from turbine	Number of carcasses	Percentage of carcasses
0–10 m	8	9
10–20 m	17	18
20–30 m	11	12
30–40 m	18	20
40–50 m	18	20
50–60 m	14	15
60–70 m	5	5
70+ m	1	1

Table 3: Turbine-strike species found during mortality searches at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, 2013–2014, including number of carcasses found for each species, estimated mortalities based on searcher detection rates, and the 80% confidence interval for those estimates.

		Tatanka					
		2013			2014		
Species	Scientific Name	Found	Estimated	80% CI	Found	Estimated	80% CI
Gadwall	*Anas strepera*	1	3	*0–7	1	4	*0–9
Mallard	*A. platyrhynchos*	12	40	24–56	15	55	38–72
Blue-winged Teal	*A. discors*				2	7	0–14
Northern Pintail	*A. acuta*	4	14	5–23	3	11	3–19
Green-winged Teal	*A. crecca*				1	4	*0–9
Redhead	*Aythya americana*	2	7	1–13	2	7	0–14
Ring-necked Pheasant	*Phasianus colchicus*	1	3	*0–7			
Sharp-tailed Grouse	*Tympanuchus phasianellus*	2	7	1–13			
Eared Grebe	*Podiceps nigricollis*				1	10	*0–23
American White Pelican	*Pelecanus erythrorhynchos*	1	3	*0–7			
Virginia Rail	*Rallus limicola*	1	16	*0–41			
Sora	*Porzana carolina*	1	16	*0–41			
American Coot	*Fulica americana*				1	4	*0–9
Upland Sandpiper	*Bartramia longicauda*				2	20	1–39
Eastern Wood-Pewee	*Contopus virens*				1	10	*0–23

Table 3 continued: Turbine-strike species found during mortality searches at the Tatanka Wind Farm in McPherson County, South Dakota and Dickey County, North Dakota, 2013–2014, including number of carcasses found for each species, estimated mortalities based on searcher detection rates, and the 80% confidence interval for those estimates.

		Tatanka					
		2013			2014		
Species	Scientific Name	Found	Estimated	80% CI	Found	Estimated	80% CI
Warbling Vireo	*Vireo gilvus*				1	10	*0–23
Red-eyed Vireo	*V. olivaceus*	1	16	*0–41			
Tree Swallow	*Tachycineta bicolor*	1	16	*0–41			
Barn Swallow	*Hirundo rustica*	2	32	3–61			
Brown Creeper	*Certhia americana*	1	16	*0–41			
Swainson's Thrush	*Catharus ustulatus*	1	16	*0–41			
European Starling	*Sturnus vulgaris*	1	16	*0–41			
Snow Bunting	*Plectrophenax nivalis*	1	16	*0–41			
American Tree Sparrow	*Spizella arborea*				1	10	*0–23
Savannah Sparrow	*Passerculus sandwichensis*				1	10	*0–23
Song Sparrow	*Melospiza melodia*	1	16	*0–41			
Dark-eyed Junco	*Junco hyemalis*	1	16	*0–41			
Western Meadowlark	*Sternella neglecta*				1	10	*0–23
Common Grackle	*Quiscalus quicula*	1	16	*0–41			
Silver-haired Bat	*Lasionycteris noctivagans*	1	16	*0–41			

*Indicates negative lower confidence interval value truncated to zero.

Table 4: Turbine-strike species found during mortality searches at the Edgeley-Kulm Wind Farm in LaMoure County, North Dakota, 2013-2014, listing the number of carcasses found for that species, estimated mortalities based on searcher detection rates, and standard deviations for those estimates.

		Edgeley-Kulm					
		2013			2014		
Species	Scientific Name	Found	Estimated	80% CI	Found	Estimated	80% CI
Mallard	*Anas platyrhynchos*	6	21	10–32	6	38	18–58
Redhead	*Aythya americana*	1	3	*0–7			
Ring-necked Pheasant	*Phasianus colchicus*	2	7	1–13			
Wilson's Snipe	*Gallinago delicata*	2	10	*0–21			
European Starling	*Sturnus vulgaris*	1	5	*0–12			
Snow Bunting	*Plectrophenax nivalis*	1	5	*0–12			
Le Conte's Sparrow	*Ammodramus leconteii*	1	5	*0–12			
Red-winged Blackbird	*Agelaius phoeniceus*				1	14	*0–32
Silver-haired Bat	*Lasionycteris noctivagans*	1	5	*0–12			

*Indicates negative lower confidence interval value truncated to zero.

Table 5: Land-cover percentages at the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey and McIntosh Counties, North Dakota, and the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, 2013-2014.

Land-cover Class	TAWF	EKWF
Grass/Pasture	70%	6%
Crops	6%	69%
Wetlands	13%	16%
Hay/Alfalfa	8%	6%
Trees	2%	1%
Development	1%	2%

Table 6: Generalized estimating equation (GEE) evaluating the influence of habitat variables (within 1600 m of a turbine) on waterfowl wind turbine-related mortality rates at the Edgeley-Kulm and Tatanka wind facilities in North Dakota and South Dakota, USA, 2013–2014.

Model[a]	K^b	QICu[c]	ΔQICu[d]	w_i^e
CropArea	2	21.49	0.00	0.68
WetPatchNumber + CropArea	3	23.39	1.89	0.26
WetAvgPatchArea	2	28.84	7.34	0.02
WetPatchDensity	2	28.99	7.49	0.02
GrassArea + HayArea	3	29.82	8.33	0.01
WetAvgPatchArea + GrassArea + HayArea	4	30.46	8.97	0.01
WetArea + GrassArea + HayArea	4	31.37	9.88	0.00
WetPatchDensity + GrassArea + HayArea	4	31.71	10.21	0.00
GrassArea + HayArea + WetPatchDensity + TotalGrassEdge	4	32.51	11.02	0.00

[a]CropArea= area (in ha) of corn or soybeans, WetPatchNumber = number of wetlands, WetAvgPatchArea = average area of wetland patches, WetPatchDensity = density of wetland patches, GrassArea =area of grassland including pasture, HayArea= area of hayland and alfalfa, WetArea = total area of all wetland patches, TotalGrassEdge = total amount of edge of grassland including pasture.
[b]Number of parameters.
[c]Quasi likelihood under the independence model criterion for GEE (Cui and Qian 2007).
[d]Difference in QICu relative to minimum QICu.
[e]QICu model weight

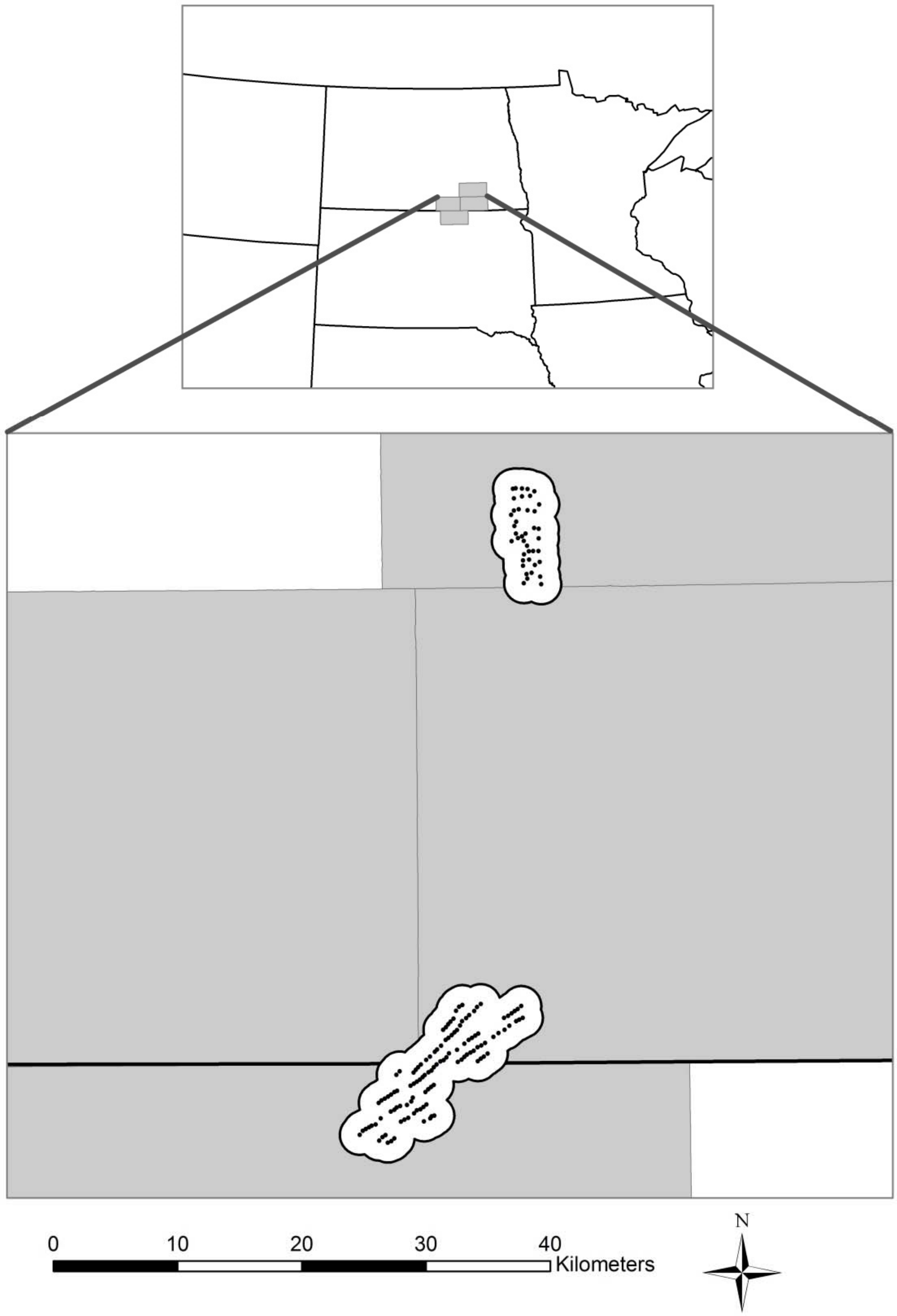

Figure 1, Study area including the Tatanka Wind Farm within Dickey and McIntosh counties, North Dakota and McPherson County, South Dakota, and the Edgeley-Kulm Wind Farm within LaMoure County, North Dakota.

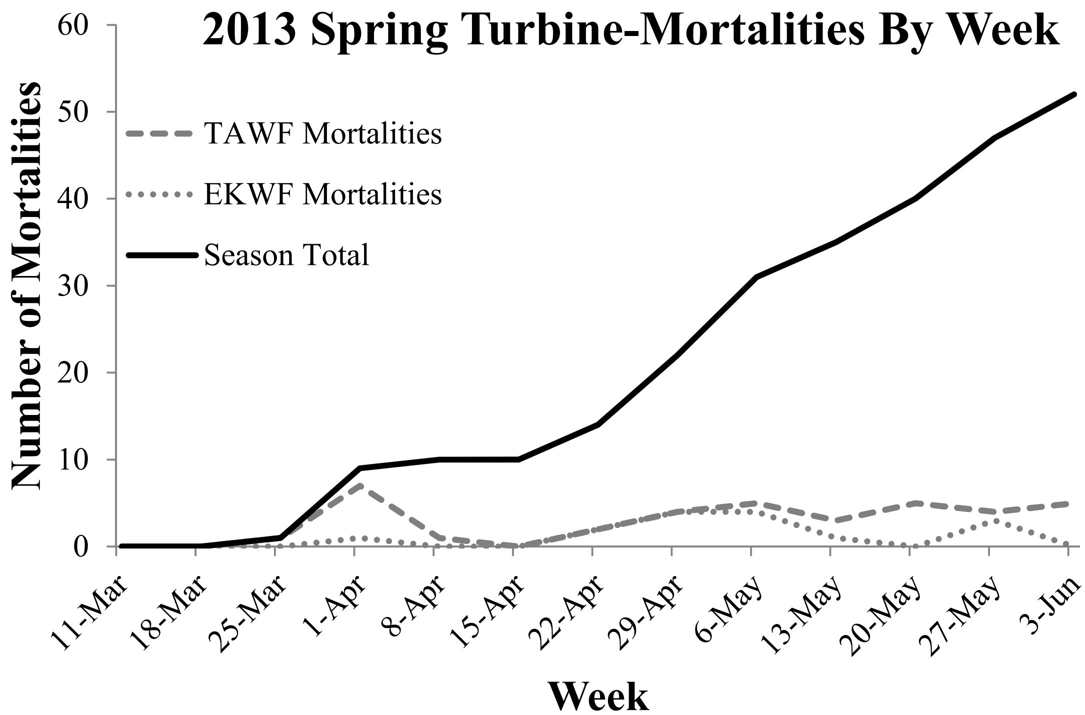

Figure 2, Weekly and seasonal total wind energy related-mortalities (n = 52) at the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, USA, 2013.

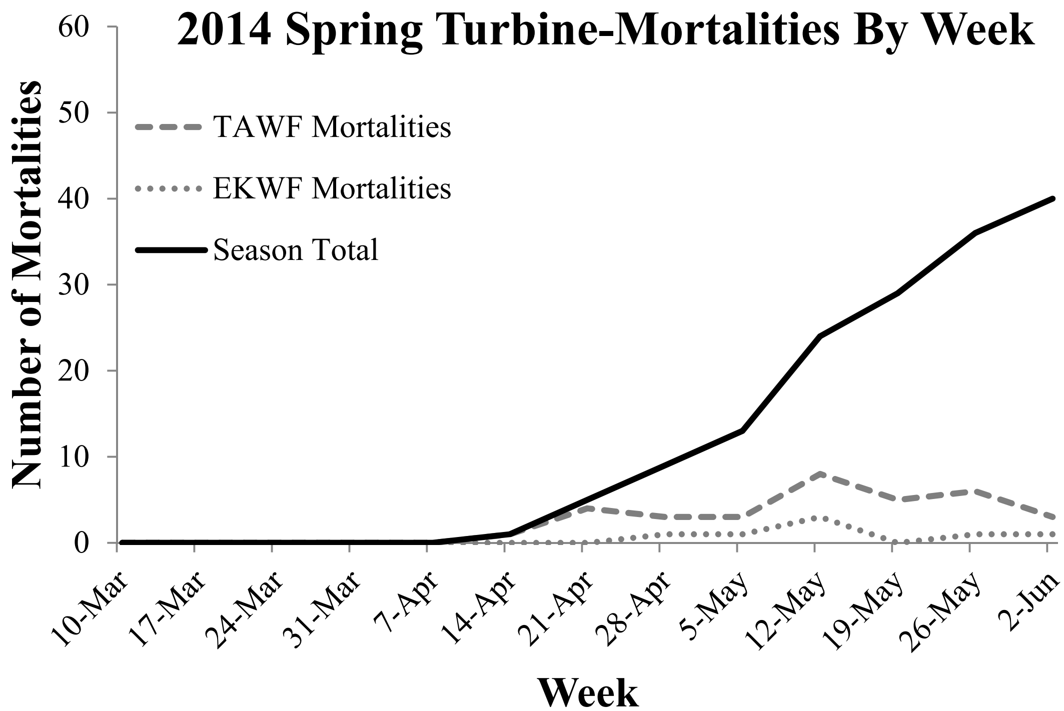

Figure 3, Weekly and seasonal total wind energy related-mortalities (*n* = 40) at the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, USA, 2014.

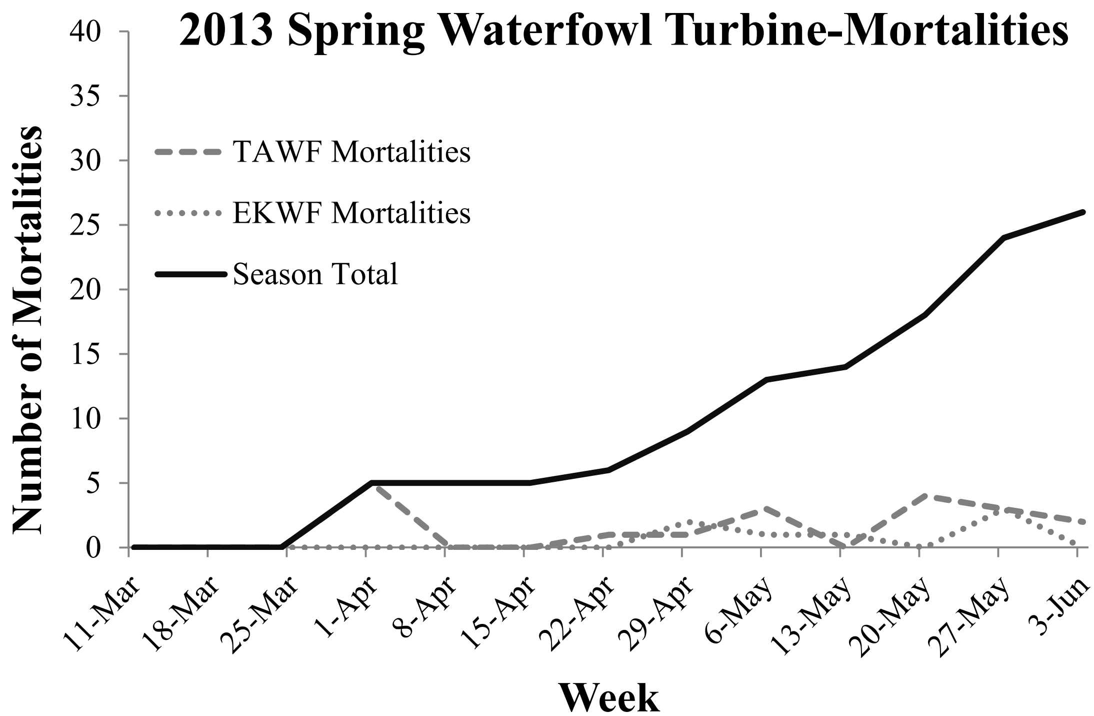

Figure 4, Weekly and seasonal total waterfowl wind energy related-mortalities (n = 26) at the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, USA, 2013.

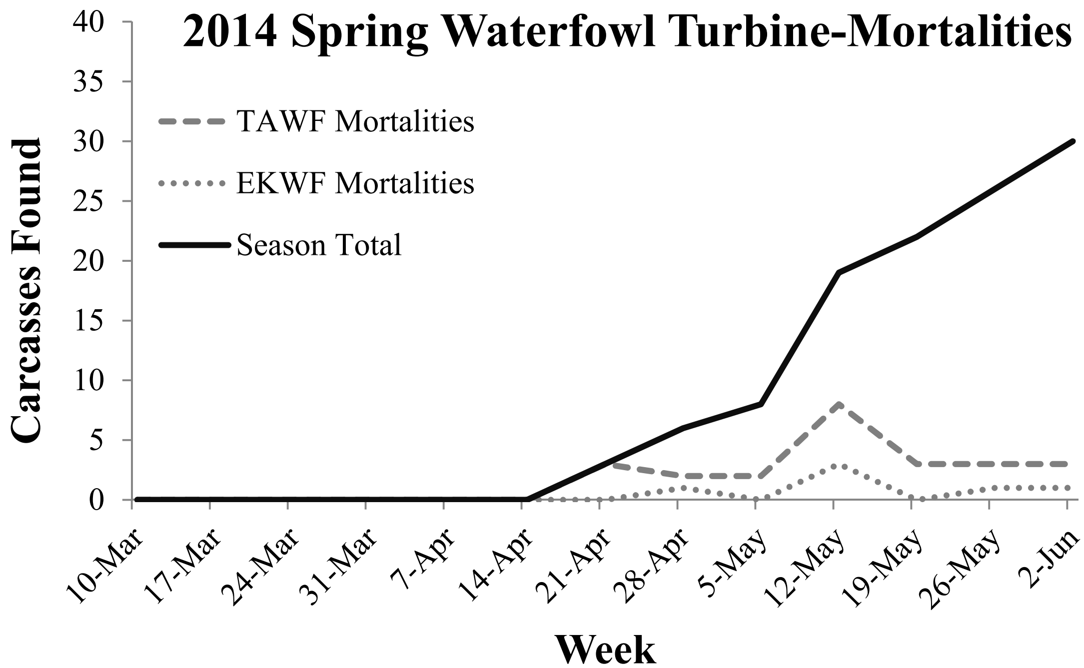

Figure 5, Weekly and seasonal total waterfowl wind energy related-mortalities ($n = 30$) at the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey County, North Dakota, and the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, USA, 2014.

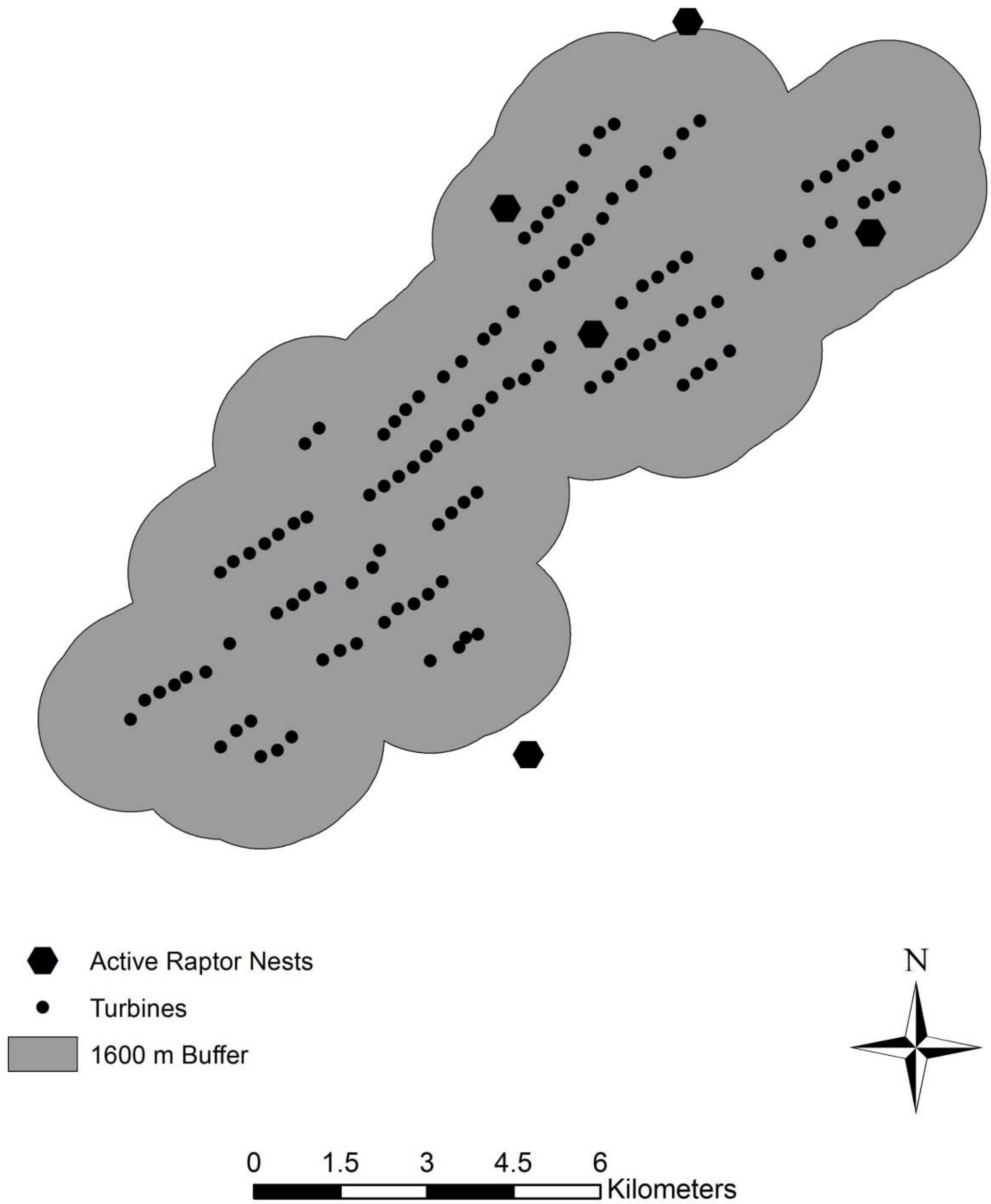

Figure 6, Active raptor nests within 1000 m of the Tatanka Wind Farm (TAWF) in McPherson County, South Dakota and Dickey County, North Dakota, USA, 2013–2014.

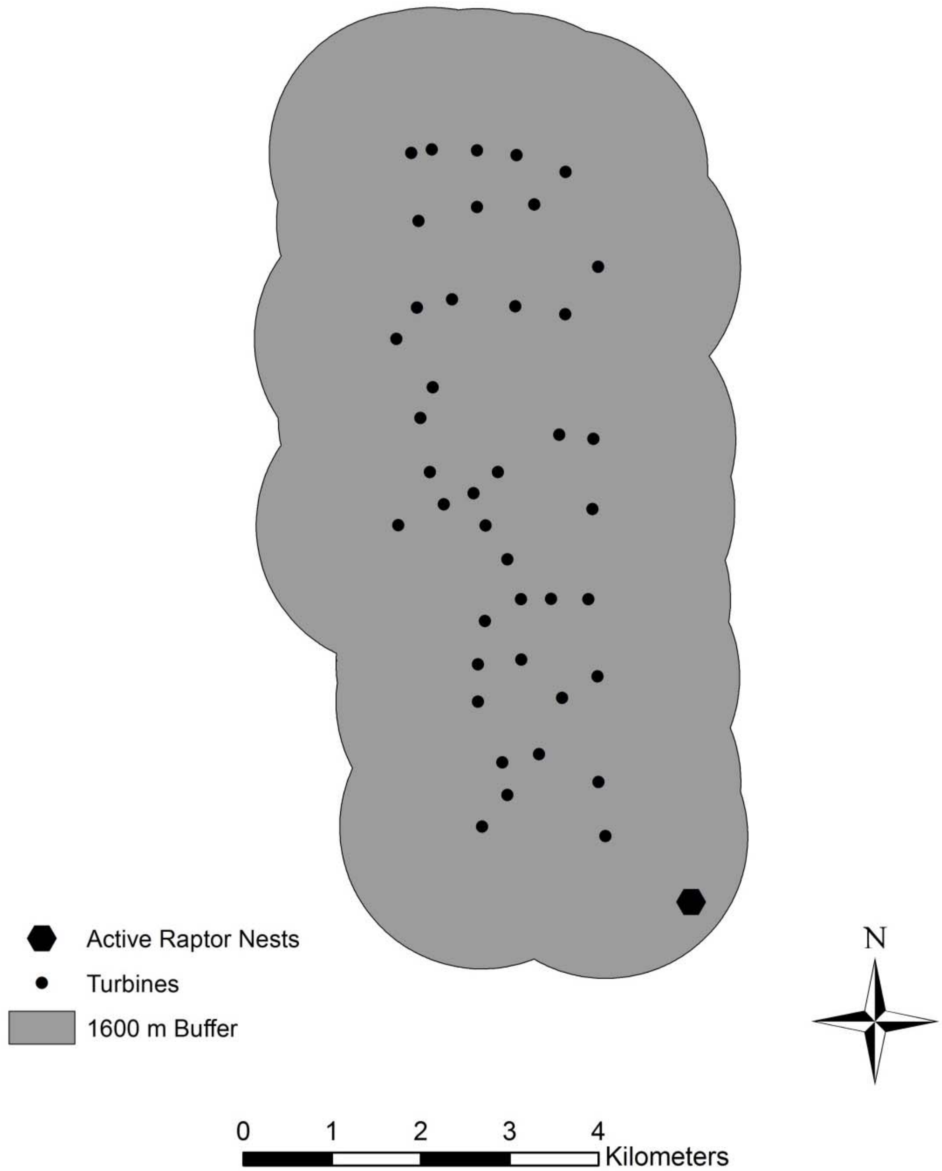

Figure 7, Active raptor nests within 1000 m of the Edgeley-Kulm Wind Farm (EKWF) in LaMoure County, North Dakota, USA, 2013–2014.