PATTERNS OF AVIAN AND BAT MORTALITY AT A UTILITY-SCALED WIND FARM ON THE SOUTHERN HIGH PLAINS

by

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COMPOSITION OF THESIS

This thesis is composed of a literature review of wind energy developments and the consequent avian and bat species interactions and three manuscripts that are formatted for submission to peer-reviewed scientific journals. Chapter I outlines the major findings and limitations of wind energy research in North America. It is composed of a brief introduction to wind energy development and wildlife interactions, a review of previous research related to impacts on avian species, a review of previous research related to impacts on bat species and presentation of the goals of this study. All following chapters are formatted for submission into The Journal of Wildlife Management, a publication of The Wildlife Society. Chapter II and III explore the patterns of avian and bat mortality, respectively, at a utility-scale wind energy center in the Texas Panhandle. Chapter IV develops a predictive model for bat species mortality based on species' presence within and geophysical characteristics of a wind energy development along the Caprock Escarpment in Texas.

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ABSTRACT

Wind energy has been utilized commercially in the United States since the 1970s. Empirical evidence suggests that direct collision mortalities of avian and bat species are consequences of wind energy development. Texas has the most installed wind energy generation capacity in the United States, yet no empirical data are available to assess the impact to local avian and bat populations. It is the goal of this study to determine the spatial and temporal distribution of avian and bat mortality at a utility-scale wind energy development along the Caprock Escarpment and to develop an accurate mortality estimate for avian and bat mortality at the site. Further, this study seeks to incorporate the year-long continuous mortality study, species use of the site and the site's geophysical characteristics into a predictive model for wind energy development along the Caprock Escarpment.

From September 2006 to September 2007, I conducted standardized carcass searches at 28 turbines and 3 anemometer towers (n = 1,551). Additionally, I assessed removal rate of carcasses by scavengers and the efficiency of searchers in finding carcasses in trials concurrent to carcass searches. I calculated observer efficiency as the proportion of trial carcasses that were detected by observers, carcass persistence as the average length of time trial carcass remained onsite before complete removal and modeled mortality estimates using the Young et Al. (2003) formula. I estimate mortality for bat species for an eight-month season of occupancy, and for avian species on a yearly basis. To identify spatial and temporal distributions, I conducted chi-squared test analysis of deviance for avian and bat taxa separately.

During standardized carcass searches, observers detected 25 avian carcasses and 47 bat carcasses. Turkey vultures (*Cathartes aura*) accounted for 36 percent of avian carcass detections, and Brazilian free-tailed bats (*Tadarida brasiliensis*) accounted for 94 percent of bat carcass detections. Using a 63 percent observer efficiency rate and a 9.5 day carcass persistence, I estimate avian mortality to be 0.5 individuals per MW per year (SE = 0.24). I estimate bat mortality to be 36.9 individuals per MW per season of occupancy (SE =111.89) using a 23 percent observer efficiency rate and 1 day carcass persistence. There was no significant spatial distribution of avian or bat carcasses within the wind energy development. Avian carcass detections were significantly higher during the fall season ($\chi^2 = 20.87$, d.f. = 2, P = 0.0001). Bat carcass detections were significantly higher during the fall and spring season ($\chi^2 = 52.47$, d.f. = 2, P < 0.0001).

The local impact of the Red Canyon Wind Energy Center on avian species appears to be low and similar to results seen in Oklahoma. In contrast, the relatively high mortality estimate for bat species indicates further study is required. These results are the first publicly available mortality estimates for the Caprock Escarpment region and identify the potential for population-level impacts of collision mortality to local bat species.

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CHAPTER 1: INTRODUCTION

Wind energy has been commercially used in the United States since the mid-1970s, with increased development beginning in 1992 in response to the Energy Policy Act that offered federal production tax credits in support of renewable energy resource development (United States Government Accountability Office (GAO) 2005). Individual states provide further incentives for wind energy development through renewable portfolio standards, partnered grants through the U.S. Department of Energy, and tax incentives. Driven by technological advances that decreased the cost of energy generation from wind resources (Hansen et al. 1992, Redlinger et al. 2002), wind energy has become a major sector of the renewable energy industry (Pasqualetti et al. 2004, United States GAO 2005). Wind energy generation currently occurs in 25 states, and the American Wind Energy Association (AWEA) predicts that 6% of the nation's energy will be from wind resources by 2020 (AWEA 2005). Wind energy is seen as a "green" energy source, mitigating environmental impacts associated with fossil fuel energy generation (Keith et al. 2003). However, recent studies have indicated that wind energy development is associated with negative impacts on avian and bat species. Negative impacts of wind energy generation can be apportioned into two types: 1) direct mortality due to collision with wind turbine generators, and 2) indirect impacts due to avoidance, habitat disturbance and displacement (National Wind Coordinating Committee 2004).

Of the 300-plus wind energy developments currently in operation in North America, only 33 developments have been studied to assess wildlife impacts. Wind energy developments may have significant environmental impacts, but the empirical evidence is poor, methodologically weak, and short-term in nature (Kunz et al. 2007, Stewart et al. 2007). The U.S. Fish and Wildlife Service (2003) has developed guidelines for impact assessment in regards to migratory bird species, threatened and endangered species, and species of conservation concern. but the use of the guidelines is voluntary. Requirements for pre-construction and post-construction study of wind energy development wildlife impacts vary from state to state. For example, the Pennsylvania Game commission has quantified risk assessment for raptor species during migration at potential wind energy development sites (Pennsylvania Game Commission 2007). In contrast, California's Department of Fish and Game has outlined voluntary, science-based guidelines to assess and mitigate potential impacts (California Energy Commission 2006).

The wind energy industry, in cooperation with private consulting groups and non-governmental organizations, has independently developed pre-construction and post-construction study guidelines. In 1999, the Avian Subcommittee of the National Wind Coordinating Committee developed a metrics and methods document for use in monitoring impacts on birds at existing and proposed wind energy sites (Anderson et al. 1999). The document covers evaluation of site biology, and basic experimental design for impact studies, manipulative studies, and risk reduction strategies. However, the focus of the guidance document and later guidelines (Morrison 1998, Morrison et al. 2007) are on avian species. Bat mortalities at wind energy developments gained focus in 2003 when a large mortality event occurred at a wind energy development in West Virginia (Kerns and Kerlinger 2004). In response, guidelines have been developed with focus placed on bat species impact monitoring (Arnett 2006, Lausen et al. 2006, Reynolds 2006).

DIRECT IMPACTS OF WIND ENERGY ON AVIAN SPECIES

Of greatest focus in wind energy development influences on wildlife is the study of direct mortality of avian species due to collision with wind turbine generators. In reviewing literature related to avian collision mortality at wind energy developments, it should be noted that no studies have been completed for the leading wind energy generating state, Texas (Kuvlesky et al. 2007). Of the 33 sites studied for collision mortality in North America, 22 sites have been studied under the guidelines suggested by Anderson et al. (1999), which include standardized carcass searches and bias corrections (Barclay et al. 2007).

Early Studies at California Wind Energy Developments

The first large-scale development of wind energy occurred in California. Subsequent reports of avian mortalities lead the California Energy Commission (CEC) to commission studies to gather data and identify avian mortality estimates at the Altamont Pass, San Gorgonio, and Tehachapi Wind Resource Areas (WRA). Over a three-year study period (1985-1988), 178 avian carcasses, including 101 raptors of seven species, were found near wind turbine generators and infrastructure (Haussler 1988). With few exceptions, most of the mortalities detected during this period were incidental to other duties occurring on site (Haussler 1988).

Following the initial CEC report, the 150 km^2 area of Altamont Pass and its 8,200 turbines were studied intensively with the express purpose of quantifying mortality (Estep 1989, Thelander and Smallwood 2007). In the first comprehensive avian mortality study at a wind energy development, Orloff and Flannery (1992) documented 182 carcasses, 68% of which were raptor species and 26% were passerine species; they estimated that as many as

567 raptors may have been directly killed over the two-year study period. During a later 18-month study in 1997, 72 mortalities, 44 of which were raptor species, were found at a 53-turbine sample (Howell 1997). In Montezuma Hills WRA, just north of Altamont Pass WRA, 25 mortalities, 17 of which were raptors, were identified in a one-year period at a sampling of the development's 81 turbines(Howell and DiDonato 1991). In a later study, Howell (1997) detected 13 mortalities, 9 of which were raptors, over a ten-month study of 76 turbines at Montezuma Hills. An early study of 156 turbines at Techachapi Pass WRA detected 9 raptor mortalities (Estep 1989), while a subsequent 1-year study failed to detect mortalities (Orloff and Flannery 1992). By pooling data for all mortalities detected at Altamont Pass, Montezuma Hills, and Techachapi Pass, Howell and DiDonato (1991) determined golden eagles (*Aquila chrysaetos*) to be the most impacted species, and concluded that the number of mortalities alone could have significant impacts on local populations.

Early studies completed at California wind energy developments are informative to collision mortality risks, but fail to provide conclusive, comparable results. The studies were conducted over lengths of time ranging from 10 months to 6 years, with inconsistent research protocols. An early emphasis on raptors left passerine and upland species out of mortality searches or they were reported incidentally. Based on early studies in California, later collision mortality studies report all avian species and make attempts at consistent study protocols.

Recent Studies at North American Wind Energy Developments

Collision mortality studies conducted in California were conducted in similar habitat types, specifically the Central Valley grasslands and Sierra Nevada foothills. Comparison between developments is relatively robust, as the developments have similar avian species communities with similar collision mortality risk-probabilities. However, comparison to other wind energy developments across the United States and Canada is restricted. Habitat types, and species communities, differ between regions. It is, therefore, more informative to compare direct impacts of wind energy development on a regional basis.

Collision mortality at wind energy developments in Canada

Development of wind energy in Canada offers empirical evidence of avian mortality in cropland and seeded pasture agricultural ecosystems (Table 1). From January 2005 to January 2006, a mortality study at Summerview Wind Power Project, Alberta, Canada detected 50 avian carcasses at 39 wind turbines for a mortality estimate of 1.9 birds per turbine per year (Brown and Hamilton 2006). Another study conducted at McBride Lake Wind Farm, Alberta, Canada detected 41 avian carcasses at 114 wind turbines and estimated 0.36 avian mortalities per turbine per year (Brown and Hamilton 2004). However, the McBride Lake Wind Farm study did not incorporate bias corrections into mortality estimates.

Collision mortality at wind energy developments in the Pacific Northwest region

Development of wind energy in the U.S. Pacific northwest generally occurs in agricultural and Conservation Reserve Program areas (Table 1). During a one-year study at Vansycle Wind Project, Oregon, 12 avian carcasses were detected and mortality was estimated at 0.63 mortalities per turbine per year (Erickson et al. 2000). At the Stateline Wind Project along the border of Oregon and Washington, researchers conducted a study of 454 turbines, found 232 carcasses, and estimated mortality at 1.89 per turbine per year (Erickson et al. 2004). During a one-year study of 16 turbines at the Klondike Phase I Wind Project in Oregon, 8 avian carcasses were used to estimate 1.42 mortalities per turbine per year (Johnson et al. 2003). Erickson et al. (2003) detected 36 avian carcasses at the Nine Canyon Wind Power Project during a yearlong study in Washington for a mortality estimate of 3.59 per turbine per year at the 37-turbine site. At the 41-turbine Combine Hills Wind Resource Area in Oregon, mortality was estimated at 2.56 per turbine per year based on 105 avian carcass detections (Strickland and Johnson 2006).

Collision mortality at wind energy developments in the Rocky Mountain region

The Rocky Mountain region includes wind energy developments in Colorado and Wyoming (Table 1). The initial phase of Foote Creek Rim Wind Power Project occurred in a short-grass steppe ecosystem on a mesa top in Wyoming. The 69 turbines were studied from November 1998 to June 2002, during which 122 avian carcasses were located and mortality was estimated at 1.50 per turbine per year (Young et al. 2003). In a study conducted at the National Wind Technology Center, Colorado from 1999 to 2001, Schmidt et al. (2003) located six avian carcasses and estimated mortality at 24 individuals per year for all aerial features on the site, including meteorological towers and experimental turbines.

Collision mortality at wind energy developments in the Midwestern United States

The Midwestern United States, including the Great Plains, is experiencing increasing wind energy development and provides data related to grassland ecosystem wildlife impacts (Table 1). Jain (2005) conducted a mortality survey at a random sample of 26 turbines at the 89-turbine Top of Iowa Wind Farm, Iowa, and located two avian carcasses for an estimated mortality of 1.29 per turbine per year. At the Northeast Community Wind Farm in Wisconsin, a study of 31 turbines detected 25 avian mortalities and estimated mortality at 1.29 per turbine per year (Howe et al. 2002). The Buffalo Ridge Wind Resource Area in Minnesota has had ongoing mortality monitoring since initial development in 1994. Osborn et al. (2003)

estimated mortality at 0.98 per turbine per year for the initial 73-turbine Phase I development based on 12 carcasses. Johnson et al. (2002) estimated mortality at 2.27 per turbine per year at the 143-turbine Phase II development based on 22 carcasses and estimated mortality at 4.45 per turbine per year at the 138-turbine Phase III development based on 20 mortalities. In a three-month study conducted in successive years, Piorkowski (2006) detected 11 avian carcasses at the 68-turbine Oklahoma Wind Energy Center and estimated a mortality range of 0.04 – 0.12 per turbine per year.

Collision mortality at wind energy developments in the Eastern United States

Wind energy development in the Eastern United States occurs primarily along ridge tops in heavily forested ecosystems (Table 1). At the 3-turbine initial phase of Buffalo Mountain Wind Farm in Tennessee, 47 avian carcasses were used to estimate mortality at 7.27 per turbine per year (Nicholson et al. 2005). An additional 15 turbines were constructed at Buffalo Mountain, and a subsequent study estimated mortality at the additional site at 1.8 per turbine per year based on 9 avian carcass detections (Fielder et al. 2007). Jain et al. (2007) studied the Maple Ridge Wind Power Project's 195 turbines over one year in New York, detecting 125 avian carcasses for a mortality estimate range of 3.13 – 9.59 per turbine per year. Incidental to a larger study on bat mortality, the 44-turbine Mountaineer Wind Energy Center in West Virginia estimated avian mortality is 4.04 per turbine per year (Strickland and Johnson 2006).

Patterns of Direct Impacts to Avian Species

Although study protocols follow the general guidelines offered by the National Wind Coordinating Committee with standardized carcass searches and bias corrections, the studies mentioned above do so under various iterations. Standardized carcass search intervals range from daily to monthly, bias corrections utilize inconsistent carcass sizes, and sampling schemes are not consistent. Estimated mortalities per turbine are highly variable across North America, ranging from 0.04 to 9.59 mortalities per turbine per year. Mortality estimates are also variable within regions, (i.e. Pacific Northwest mortalities range from 0.36 to 3.59 per turbine per year).

Development characteristics, such as local avian population, ecological region and climatic conditions, affect bias corrections and species present at risk of collision mortality. To account for differences within study protocol and regions, Strickland and Johnson (2006) conducted meta-analysis of known mortality estimates for individual wind energy developments across the United States and estimated the national avian species mortality is 4.27 individuals per turbine per year. The authors created weighted averages for individual sites by averaging bias corrections, mortality detections, and number of turbines searched. Future research on avian collision mortality should quantify local conditions that influence mortality estimations (National Research Council 2007).

INDIRECT IMPACTS OF WIND ENERGY ON AVIAN SPECIES

In addition to direct impacts, indirect impacts of wind energy development include behavioral changes, habitat alteration, and avoidance. Avian behavior within the wind energy development may differ from behavior observed outside the development. Some avian species appear to habituate to wind turbine generators, and behaviors such as perching on turbines may increase risk of collision mortality (Nelson and Curry 1995). For example, Hoover and Morrison (2005) reported red-tailed hawks (*Buteo jamaicensis*) engaging in more stationary soaring within wind energy developments in California.

Wind energy development construction alters the physical landscape, increasing access to substrate for burrowing prey species and artificially increasing such species abundance. The increases in prey abundance increase the likelihood of raptor mortalities due to collision with wind turbine generators during hunting activities (Hoover et al. 2001). Human presence, wind turbine generator noise, and physical movement of turbine blades have been postulated as the cause of decreased density of nesting grassland birds within 80 meters of wind turbine generators (Leddy et al. 1999). Breeding density of great crested flycatchers (*Myiarchus crinitus*) and greater roadrunners (*Geococcyx californiansus*) at wind turbine generator sites were lower than adjacent control sites in Oklahoma (O'Connell and Piorkowski 2006).

Avoidance of wind turbine generators and related development infrastructure has become a recent area of study, especially in European wind energy developments. Wind energy development can disrupt habitat utilization patterns, and reduce the use of favorable habitat. The avoidance of favorable wetland habitat decreases the overall habitat available. Avoidance distances of 200 meters for swans (Winkelman 1989) to 400 – 600 meters for white-fronted geese (*Anser alibfrons*) (Kruckenberg and Jaene 1999) have been found in coastal wind energy developments along the North Sea. Pink-footed geese (*Anser brachyrynchus*) have avoidance distances of 100 meters from linear wind turbine generator strings and 200 meters from clustered wind turbine generators, decreasing available habitat by 13% (Larsen and Madsen 2000).

DIRECT IMPACTS OF WIND ENERGY ON BAT SPECIES

Interest in impacts of wind energy development on bat species has increased in recent years, specifically due to large mortalities reported at wind energy developments in the

Eastern United States (Arnett 2005, Fiedler et al. 2007). However, bat species mortality due to wind energy development is not a new phenomenon. The first reported mortality of bat species occurred at early generation wind turbines in Australia. Hall and Richards (1972) reported 22 white-striped mastiff bat (*Tadarida australis*) mortalities over a four-year study period. Early studies of wildlife impacts due to California wind energy development reported occasional bat mortality (Cryan 2006). For example, one red bat (*Lasiurus borealis*) mortality was reported by Howell and DiDonato (1991). A review of mortality studies conducted at wind energy developments in North America indicates 21 studies at 19 developments have reported bat mortality.

Recent Studies at North American Wind Energy Developments

Collision mortality at wind energy developments in Canada

Canadian bat mortality studies report relatively high mortalities of bat species (Table 2). At the 39-turbine Summerview Wind Power Project in Alberta, Brown and Hamilton (2006) located 532 bat carcasses of five species and estimated mortality at 18.48 per turbine per year. Fifty-four bat carcasses of four species were detected during one-year monitoring at the 114-turbine McBride Lake Wind Farm in Alberta, resulting in a mortality estimate of 0.47 per turbine per year (Brown and Hamilton 2004) without bias corrections.

Collision mortality at wind energy developments in the Western United States

In the western United States, bat mortality estimates are among the lowest in North America (Table 2). The Vansycle Wind Project in Oregon estimated 0.74 mortalities per turbine per year based on 28 bat carcasses detected at the 38-turbine site (Erickson et al. 2000). Along the Oregon-Washington border, the Stateline Wind Project estimated 1.1 mortalities per turbine per year based on 150 bat carcasses detected at the 454-turbine site

(Erickson et al. 2004). Based on 6 bat carcass detections at Klondike Phase I Wind Project in Oregon, Johnson et al. (2003) estimated mortality at 1.16 per turbine per year for the 16-turbine project. A study of the Nine Canyon Wind Power Project's 37-turbines detected 27 bat carcasses during one year and estimated mortality at 3.21 per turbine per year (Erickson at al. 2003). The three-year study of 69-turbine Foote Creek Rim Wind Power Project in Wyoming estimated mortality at 1.3 per turbine per year based on 79 bat carcasses (Young et al. 2003).

Collision mortality at wind energy developments in the Midwestern United States

The Midwestern United States has a wide range of bat mortality estimates from 0.1 to 7.8 mortalities per turbine per year (Table 2). Jain's (2005) study of the 89-turbine Top of Iowa Wind Farm reported 75 bat carcasses and estimated mortality at 7.8 per turbine per year over the two-year study period. Similarly, the Northeastern Community Wind Farm in Wisconsin reported relatively high mortality estimates of 4.26 bats per turbine per year for the 14-turbine development based on 75 carcasses (Howe et al. 2002). The intensively-studied Buffalo Ridge Wind Resource Area in Minnesota reports a range of mortality estimates for the three-phase development. Study of the Phase I development of 73 turbines reported 9 bat carcasses over four years of study for an estimate of 0.07 per turbine per year (Osburn et al. 1996, Johnson et al. 2003), 200 bat carcasses over two years at the 143 Phase II development for an estimate of 1.78 mortalities per turbine per year (Johnson et al. 2003), and 44 bat carcasses at the 138-turbine Phase III development for an estimate of 2.04 mortalities per turbine per year during one year of study (Johnson et al. 2003). Piorkowski (2006) reported

111 bat carcasses at the Oklahoma Wind Energy Center for a mortality estimate of 1.2 per turbine per year at the 68-turbine development during a brief three-month study.

Collision mortality at wind energy developments in the Eastern United States

Wind energy developments in the Eastern United States have seen the highest numbers of bat carcasses detections, resulting in the highest mortality estimates for North America (Table 2). The original development at Buffalo Mountain Windfarm in Tennessee had 3-turbines but 120 carcasses were located over the three year study for a mortality estimate of 20.82 per turbine per year (Nicholson et al. 2005). Expansion of the development added an additional 15 turbines. A one-year study of the expanded facility located 243 bat carcasses for a mortality estimate of 63.9 per turbine per year (Fielder et al. 2007). Jain et al. (2007) initiated a one-year study of the 195-turbine Maple Ridge Wind Power Project in New York in 2006 and found 326 bat carcasses for a mortality estimate of 24.5 per turbine per year.

Bat mortalities at wind energy developments gained national attention in 2003 when an estimated 1,400 – 4,000 bats died in collisions with wind turbine generators at developments in West Virginia (Kern and Kerlinger 2004). The highest mortality estimates to date are reported for developments along the Appalachian Ridges in West Virginia and Pennsylvania. The baseline study reported by Kern and Kerlinger (2004) of 44-turbine Mountaineer Wind Energy Center estimated mortality at 48.0 per turbine per year. A later 6-week study of the development located 398 bat carcasses for a mortality estimate of 38.0 per turbine per year (Arnett 2005). The adjacent 20-turbine Meyersdale Wind Energy Center study detected 262 bat carcasses during the six-week study for a mortality estimate of 23.0 per turbine per year (Arnett 2005).

Patterns of Direct Impacts to Bat Species

Of the 45 species of bats in North America, eleven have been located as mortalities underneath wind turbine generators. Of the eleven species, 75% were eastern red bats (*Lasiurus borealis*), hoary bats (*Lasiurus cinereus*) and silver-haired bats (*Lasionycteris noctivagans*). The other species include big brown bats (*Eptesicus fuscus*), western red bats (*Lasiurus blossevilli*), Seminole bat (*L. seminolus*), long-eared myotis (*Myotis evotis*), little brown bat (*M. lucifugus*), northern long-eared bats (*M. septentrionalis*), eastern pipistrelles (*Pipistrellus subflavus*), and Brazilian free-tailed bats (*Tadarida brasiliensis*) (Kunz et al. 2007). Although highly variable in periodicity, mortalities generally peak during late summer and fall which coincides with migration of the Lasiurine species. Mortalities appear inconsistent across wind energy developments, although most mortalities occur at the end of linear turbine strings (Arnett et al. 2008).

Arnett et al.'s (2008) synthesis of bat mortality at North American wind energy developments estimates mortality ranges from 0.1 per turbine per year to 48.0 per turbine per year. Most studies follow the suggested guidelines of Anderson et al. (1999), incorporating bias corrections into standardized carcass searches to determine mortality estimates. However, as with avian mortality studies, bat mortality studies occur under different search intervals, sampling schemes, and with a range of bias correction techniques. Protocols specific to bat mortality monitoring studies have been developed to address this inconsistency (Arnett 2006, Lausen et al. 2006). These protocols incorporate acoustic monitoring into standardized carcass searches and bias corrections trials.

Hypothesis Regarding Bat Species Collision Mortality

Based on the above mentioned studies, bat mortality at wind turbine generators is of greater magnitude than avian mortality (Durr and Bach 2004, Kunz et al. 2007, Arnett et al. 2008). Mitigation of bat direct impacts is limited due to limited knowledge of how and why bats are being killed by wind turbine generators (Larkin 2006). For this reason, intensive study of bat species migration patterns and behaviors at wind energy developments has been initiated. Acoustic monitoring of the Maple Ridge Wind Project in New York detected bats flying close to the tree canopy, well below the turbine blade height (Reynolds 2006), contrary to mortalities being detected on the ground (Jain et al. 2007). Intensive thermal imagery studies at Mountaineer Wind Energy Center in West Virginia, where mortality estimates are the highest in North America, demonstrated bats actively interacting with turbine blades (Horn et al. 2008).

Several hypothesis of why bat mortality is higher than avian mortality at wind energy developments in North America have been developed. Given the skewing of mortalities to migratory tree-roosting bat species, it is possible wind turbine generators are perceived as possible roosting sites (Arnett 2005, Kunz et al. 2007, Horn et al. 2008). The presence of insect prey along ridge top wind energy developments in the Eastern United States has lead some to hypothesize that bats are using wind turbine generators as perches for feeding (Horn et al. 2008), similar to that of behavior observed in raptor species at California wind energy developments (Nelson and Curry 1995). Cryan and Brown (2007) hypothesize that flocking and mating behaviors of migratory bat species during high mortality periods, summer and fall migration, center on the tallest prominent landscape features, and thus mortality probability increases. Horn et al. (2008) documented bats chasing turbine blades, a phenomenon in support of Kunz et al. (2007) theory of audible sounds of wind energy generation attracting bats.

Although general patterns of bat mortality can be identified (Arnett et al. 2008), there is a dearth of knowledge as to long-term impacts of wind energy generation on bat species. Direct impact for bat species studies have been conducted within the guidelines offered by National Wind Coordinating Committee, but varying levels of search effort, small sample sizes in bias corrections of different methodology, the use of avian species as surrogates for bat species in bias correction trials, and low accounting of variation among habitats make definitive conclusions difficult. No studies have been conducted, to date, to document direct impacts to bat species in Texas, the leading state in wind energy generation, and, an area that has large populations of Brazilian free-tailed bats (Cryan 2006, Arnett et al. 2008).

STATEMENT OF PROBLEM

Empirical evidence suggests that direct collision mortality of avian and bat species are consequences of wind energy development. To date, no studies have been completed in Texas, the leading wind energy generating state in the nation. The range of collision mortalities per turbine per year from around North America make predictions of the impact of wind energy development on local avian and bat species difficult. The Panhandle region, encompassing the Caprock Escarpment, contains Texas's greatest expanse of high quality winds. As development of wind energy centers along the Caprock Escarpment and similar areas in Texas increases, there is a pressing need for studies to be completed to assess the direct impacts of wind energy development on local avian and bat species.

There have been few studies that correlate wind energy development, direct impacts to local species and geophysical characteristics of development sites. While studies have been conducted to determine relative collision risk to general taxa, i.e. raptor species and tree-roosting bat species, few have assessed the geophysical and ecological site characteristics that correlate to mortality. What is most needed in wind energy development is a predictive mortality model that incorporates use of site by species, the geophysical site characteristics, and documented mortality in such a manner as to refine mortality estimates and to decrease, if not mitigate, direct impacts.

It is the goal of this study to determine the spatial and temporal distribution of avian and bat mortality at a utility-scale wind energy development along the Caprock Escarpment and to develop an accurate mortality estimate for avian and bat mortality at the site. Further, this study seeks to incorporate the year-long continuous mortality study, species use of the site and the site's geophysical characteristics into a predictive model for wind energy development along the Caprock Escarpment.

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Table 1. Summary of direct impact studies on avian species

Region	Development	No. of Turbines	Mortality per turbine per year
Canada	Summerview	39	1.9
	McBride Lake	114	0.36
Pacific Northwest	Vansycle	-	0.63
	Stateline	454	1.89
	Klondike, Phase I	16	1.42
	Nine Canyon	37	3.59
	Combine Hills	41	2.56
Rocky Mountain	Foote Creek Rim, Phase I	69	1.50
	National Wind Technology Center	-	24
Midwest	Top of Iowa	89	1/29
	Northeast Community	31	1/29
	Buffalo Ridge, Phase I	73	0.98
	Buffalo Ridge, Phase II	143	2.27
	Buffalo Ridge, Phase III	138	4.45
	Oklahoma	68	0.04 – 0.12
Eastern	Buffalo Mountain, Phase I	3	7.27
	Buffalo Mountain, Phase II	15	1.8
	Maple Ridge	195	3.13 – 9.59
	Mountaineer	44	4.04

Table 2. Summary of direct impacts studies on bat species

Region	Development	No. of Turbines	Mortality per turbine per year
Canada	Summerview	39	18.48
	McBride Lake	114	0.47
Pacific Northwest	Vansycle	38	0.74
	Stateline	454	1.1
	Klondike, Phase I	16	1.16
	Nine Canyon	37	3.21
Rocky Mountain	Foote Creek Rim	69	1.3
Midwest	Top of Iowa	89	7.8
	Northeastern Community	14	4.26
	Buffalo Ridge, Phase I	73	0.07
	Buffalo Ridge, Phase II	143	1.78
	Buffalo Ridge, Phase III	138	2.04
	Oklahoma	68	1.2
Eastern	Buffalo Mountain, Phase I	3	20.82
	Buffalo Mountain, Phase II	15	63.9
	Maple Ridge	195	24.5
	Mountaineer,	44	38.0 - 48.0
	Meyersdale	20	23.0

CHAPTER 2: AVIAN MORTALITY AT A UTILITY-SCALE WIND ENERGY DEVELOPMENT ALONG THE CAPROCK ESCARPMENT

ABSTRACT

Wind energy has been utilized commercially in the United States since the 1970s. Texas has the most installed wind energy generation capacity in the United States, yet no empirical data are available to assess the impact to local avian populations. I assessed the incidence and frequency of mortality, modeled estimates of mortality, and identified the spatial and temporal distribution of avian mortality at a utility-scale wind energy development consisting of 56 turbines southeast of Lubbock, Texas. From September 2006 to September 2007, I conducted standardized carcass searches (n = 1,551) at 28 sample turbines. To enhance accuracy of mortality estimations, I assessed removal rates of carcasses by scavengers and the efficiency of searchers in finding carcasses in bias correction trials concurrent to mortality searches. During standardized carcass searches, observers detected 25 avian carcasses of which 36 percent were turkey vultures *(Carthartes aura*). Carcass detections were highest during the fall season with no indication of spatial distribution across the three-linearly distinct mesas. Mortality estimates suggest the impact of wind turbines on local avian species at my study site is minimal (0.50 individuals per MW per year, SE = 0.024).

Key Words: collision mortality, wind energy, Texas Panhandle, *Cathartes aura*, avian impacts

Driven by technological advances that decreased the cost of energy generation from wind resources (Hansen et al. 1992, Redlinger et al. 2002), wind energy has become a major sector of the renewable energy industry (Pasquealetti et al. 2004). Wind energy generation currently occurs in 25 states, and the American Wind Energy Association (AWEA) predicts that 6% of the nation's energy will come from wind resources by 2020 (AWEA 2005). Wind energy is seen as a "green" energy source, mitigating environmental impacts associated with fossil fuel energy generation. However, recent studies have indicated that wind energy development is associated with negative impacts on avian species. Negative impacts of wind energy generation can be apportioned into two types: 1) direct mortality due to collision with wind turbine generators, and 2) indirect impacts due to avoidance, habitat disturbance, and displacement (National Wind Coordinating Committee 2004).

Over 30 studies have been conducted at nineteen wind energy developments in North America to assess the impacts of wind energy generation on avian species (Barclay et al. 2007). The emphasis of these studies has been on direct collision mortality of avian species with wind turbine generators. Texas is the leading wind energy generating state in the nation with an approximate 300 MW of generation (AWEA 2005). To date, no studies have been conducted in Texas to determine the impact to local avian species (Kuvlesky et al. 2007). Wind energy development in Texas is focused along the Caprock Escarpment, a unique geological formation in the Southern Panhandle region, with other regions slated for future development. Although empirical evidence quantifies direct impacts to avian species in various regions, experimental designs are inconsistent (Stewart et al. 2007) and prediction of impacts to Texas avian populations is difficult. Given the Caprock Escarpment's unique geophysical characteristics and avian community, a study to assess direct impacts from wind energy generation is essential. I conducted a post-construction mortality study in the Southern Texas Panhandle to assess the incidence and frequency of avian mortality, model estimates of mortality rates and identify the spatial and temporal distribution of avian mortality within a wind energy development.

STUDY AREA

The study area was the Red Canyon Wind Energy Center (RCWEC) located in Borden, Garza, and Scurry Counties in the southern portion of the Texas Panhandle (32º 53' N, 101º 8'W). The site is located along the edge of the Caprock Escarpment, a distinct palisade-like escarpment identified by the Ogallala group of sediments (Matthews 1969). The escarpment forms a border between the High Plains and the Rolling Central Plains. Average annual precipitation is 47.4 centimeters with the highest amounts occurring in the spring and fall. Average annual temperature ranges from 8˚C to 24˚C with June being the warmest month averaging 32˚C and December being the coolest month averaging -3˚C (Lubbock International Airport Site, National Climatic Data Center2004). The historical plant climax species on the top of the caprock consist of mixed grass, forbs, and shrubs. Dominant shrub species present are redberry juniper (*Juniperus pinchotti*), mesquite (*Prosopis glandulosa*), catclaw mimosa (*Mimosa nuttalli*), prickly pear (*Opuntia polycantha*), and hackberry (*Celtis retiulata*). The most common grasses are little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indiangrass (*Sorgastrum nutans*), and grama species (*Bouteloua* spp.) (Bell 2004). The study area is under rotational grazing management for cattle. The current plant community consists primarily of shrub stands with infrequent patches of grasses.

Development of the site was completed in May of 2006 with the construction of 56 General Electric 1.5 MW wind turbine generators (WTG) and related facilities, including distribution lines, meteorological towers, transformers, roads, and operation and management facilities. Turbines have a hub height of 70 meters and a rotor diameter of 70 meters, resulting in rotor-swept area of 35 to 105 meters above ground. Turbines have a wind direction sensor within the hub that maneuvers the turbine into the wind with a 360-degree directional yaw. Thus, turbines have a spherical rotor-swept area of approximately 179,594 m^3 in which collision mortality may occur. The turbines are linearly arranged on three distinct mesas (Figure 1). The west mesa turbine string consists of 21 wind turbine generators, of which I sampled 11 during the study period. The central mesa turbine string consists of 17 wind turbine generators, of which I sampled 8 during the study period. The east mesa turbine string consists of 18 wind turbine generators, of which I sampled 9 during the study period.

METHODS

Standardized Carcass Searches

I conducted carcass searches each week for 52 weeks, beginning in September 2006, on a systematic sample of 28 of the 56 turbines (Appendix A-1). In addition to myself, there were two other trained observers. Beginning with the first numbered turbine, I chose every other turbine. When the turbine string was not truly linear (i.e. turbines followed caprock peninsulas) I chose the end turbine for sampling. I divided the study period into four 13-week seasons: 1 September – 30 November 2006 (Fall), 1 December 2006 – 28 February 2007 (Winter), 1 March – 31 May 2007 (Spring), and 1 June – 31 August 2007 (Summer). There were two searchers, including myself, throughout the study period. Searchers searched all areas within a 200 meter x 200 meter square plot centered on sample turbines using a strip transect approach with transects located 7 meters apart. Searchers did not search areas within 5 to 10 meters of the caprock edge due to safety concerns. Searchers searched sample turbines every 14 days for the fall and winter seasons. Searchers also searched 3 anemometer towers 5 times per season during this time. Anemometers were searched under the same protocol as turbines. All turbines were operational during study period; however, one sample turbine was removed from sampling, due to safety hazards, beginning June 2007.

At the end of the winter field season, I determined a 14-day search interval was too long to account for short carcass persistence rates onsite (see discussion of carcass removal trials below). Further, searchers did not detect carcasses further than 59 meters from the sample turbines ($\bar{x}$= 16.0). Thus, beginning with the spring field season, I decreased the search plot area to a 160 meters x 160 meters to make more frequent searches possible and increased searches to every 7 days. During the summer season, I further increased searches to every 3 days. During the spring and summer season, searchers searched meteorological towers weekly.

For each carcass detected, I took digital photographs and completed a casualty report. Casualty reports included: time and date of collection, turbine number, UTM coordinates of the location, common and scientific names of species found, temperature, pertinent weather conditions, and photograph number (Appendix A-2). When possible, I recorded the age and sex of the carcass and evidence of trauma or of scavenging. I recorded the condition of each carcass found using the following categories: “intact” included carcasses that were completely intact with little or no evidence of decomposition or scavenging, “partial” carcasses showed signs of scavenging or a dismembered carcass of greater than 50% intactness, and “feather spot” indicated 10 or more feathers and/or two of more primary feathers were located in a single location. I retained intact carcasses as voucher specimens and labeled each with a unique number associated with the casualty report that indicated date of find, turbine number where located, searcher, and species.

Bias Corrections

The ability of searchers to detect carcasses is influenced by searcher skills, the vegetation composition of the search area, the characteristics of individual species (e.g. body size, color), and carcass removal due to scavenging prior to searches. I conducted searcher efficiency and carcass removal trails to account for such biases and to improve the accuracy of mortality estimation. Bias correction trials were conducted seasonally to account for differences in vegetation and scavenger-predator characteristics. For bias correction trials, I utilized carcasses collected from the South Plains Wildlife Rehabilitation Center and carcasses located during surveys at the RCWEC. I limited carcasses used to species native to the Caprock Escarpment Region. I classified carcasses into three categories based on size: “large” carcasses weigh more than 200 grams (e.g., raptors), “medium” carcasses weigh between 50 and 200 grams (e.g., doves, jays and robins), and “small” carcasses weigh less than 50 grams (e.g., sparrows, wrens). Carcasses were stored in a sub-zero refrigerator, and I removed carcasses from frozen storage at least four hours prior to bias correction trials.

I conducted searcher efficiency trials to estimate the number of animals that go undetected by searchers and determine each searcher’s ability to find carcasses. Searcher efficiency trials were conducted at sample turbines. Trials consisted of a single carcass placed at a turbine, and were conducted per searcher. I conducted trials in a double-blind manner with proctors placing efficiency trial carcasses at random locations in search plots no more than ten hours prior to search plots being searched. I considered trials successful when searchers located trial carcasses. When searchers did not detect trial carcasses, I considered the trial unsuccessful only if trial carcasses could be recollected by proctors, (i.e., trial carcasses had not been removed by a scavenging animal). If the trial carcass was not recollected by proctors, the trial was not included in analysis. During the fall, I conducted 9 efficiency trials per searcher with carcasses selected randomly from four size classes. However, preliminary results were highly variable due to the small number of carcasses representing some size classes (8 large carcasses, 4 medium carcasses and 2 small carcasses). Accordingly, during the winter, spring, and summer seasons, I conducted 3 trials per searcher per season per size class (9 trials per searcher, 3 of each size class).

I conducted carcass removal trials to estimate the onsite persistence of carcasses before removal by scavengers. Carcass removal trials were conducted underneath turbines not sampled in standardized carcass searches. I conducted 3 carcass removal trials per mesa per season (27 carcasses per season, 9 per mesa, 3 per size class) to account for differences among mesas and seasons related to geophysical characteristics and scavenger-predator composition or abundances. Based on anecdotal evidence (Gritski, pers. comm. 2006), I decided to place carcasses during a time when visual cues to scavengers, such as ravens or crows, would be less likely. Specifically, all carcasses were placed during either early morning hours no later than 2 hour post-sunrise or before 2 hours pre-sunset to avoid immediate removal. During each trial on each mesa, I placed a total of 9 carcasses at randomly generated distances and directions from turbines. No more than 2 carcasses were placed at a single turbine. I recorded the UTM location of each carcass and the tracking number of the carcass. I observed carcasses at days 1, 2, 3, 7, 14, 21, and 28 with observations made as to the presence or absence of carcasses, the decomposition rate, and evidence of scavenging (Young et al. 2003). At the end of each carcass removal trial period, I removed all remaining carcasses or evidence of the carcasses.

Statistical Analysis

The behavioral characteristics of some avian species make it highly unlikely that individuals would fly at heights that coincide with the wind turbine rotor-swept area. For example, the northern bobwhite (*Colinus virginianus*) flight height has been recorded at maximum of 2.4 m (Kassinis and Guthery 1996). Therefore, to improve the accuracy of analysis, the carcasses of such species were excluded. Including mortalities not due to the wind turbines would include bias by increasing mortality estimates and lead to erroneous results. Similarly, I excluded carcass detections of unknown avian species whose flight height could not be identified. Therefore, to assess avian mortality, I removed the northern bobwhite, greater roadrunner (*Geococcyx californianus*) and unknown avian species from analysis. The unknown avian species detection was a single keel bone that was located in Fall 2006, and identification of species was not possible. In addition, I excluded a great horned owl (*Bubo virginianus*) carcass because the cause of death was determined to be gunshot. The analyses include 13 avian carcasses (9 turkey vultures (*Carthartes aura*), 1 red-tailed hawk (*Buteo jamaicensis*), 1 blue jay (*Cyanocitta cristata*), 1 mourning dove (*Zenaida macroura*) and 1 northern mockingbird (*Mimus polyglottus*).

I calculated searcher efficiency as the proportion of carcasses that are detected by searchers. Efficiency rates are estimated by size class, by season and as a yearly average. Carcass persistence is the average length of time a carcass remains onsite before it is removed by a scavenging animal(s). For this study, all carcass removal trials were terminated at 28 days, yielding censored observations at 28 days. I estimated removal rates by size class, by season, and as a yearly average. I estimated the annual mortality rate (M) by (Young et al. 2003) :

$$M = {}^{(N \times I \times C)}/_{(k \times t \times p)}$$

where *N* is the total number of turbines within the wind energy center, I is the average interval between search efforts, *C* is the number of carcass found during a defined search period (e.g. season, year), *k* is the number of turbines searched, *t* is the mean persistence time of carcasses onsite as estimated by carcass removal trials, and *p* is the proportion of carcasses detected during searches as estimated by searcher efficiency trials. The Young et al. (2003) mortality estimation includes adjustments for both searcher efficiency and carcass removal bias. I calculated the variance using the variance of product formula (Goodman 1960) and the variance of ratio formula (Cochran 1977) as shown in Johnson et al. (2003). The variance of t and p is:

$$Var\,(t \times p) = [var(t) \times p^2] + [var(p) \times t^2] - [Var(t) * var(p)]$$

From this, the variance of M is:

$$Var\,(m) = \left[{}^{N^2 \times I^2 \times C^2}/_{k^2 \times t^2 \times p^2}\right] \times \left[\left({}^{Var(t \times p)}/_{t^2 \times p^2}\right) \times \left({}^{Var(c)}/_{c^2}\right)\right]$$

I estimated mortality for all avian size classes combined, due to limited sample size.

I censored 21 turbines from spatial and temporal distribution analysis that did not have mortality detections to reduce zero-inflation; thus, only turbine-related mortalities were included in the models. I used both parametric and non-parametric statistics because some of the data was heteroscedastic and not normally distributed. I generated binomial models to assess spatial and temporal variation in carcass detections with the carcass detections as the response variable and the mesa of detection as the binomial denominator in spatial analysis, and the season of each detection as the binomial denominator in temporal analysis. Wind turbine generator was included in each model as a covariate, and I included season as a repeated measure in the temporal distribution model.

I assessed seasonal and size class effects on searcher efficiency using a two-way factorial chi-squared test of deviance with successful location of trial carcasses as the response variable, and trial season and size class of carcass as binomial denominator. Carcass persistence departed significantly from a normal distribution (Shapiro-Wilk W test; $P < 0.0001$), so I completed a full-rank transformation of carcass persistence data and conducted an Analysis of Variance followed by a Tukey's multiple comparison of means to assess the influence of size class and season on the response variable, carcass persistence in days. I used Program R statistical package for (R, Vienna, Austria). I report results as means ±SEM , and applied a significance level of 0.05 throughout. All tests are two-tailed.

RESULTS

Standardized Carcass Searches

I conducted a total of 1,442 standardized carcass searches at sample turbines and 110 standardized carcass searches at anemometer towers (Table 1). Search times ranged from 22 minutes to 124 minutes ($\bar{x} =$ 40.98 minutes, SEM $= 5.26 \times 10^{-4}$). During the study period, searchers detected 30 avian mortalities comprising 9 identifiable species. Searchers detected 25 carcasses during standardized carcass searches (Appendix B-1), and detected 5 carcasses incidental to standardized carcass searches (Appendix B-2). Of the 25 carcasses detected during standardized carcass searches, turkey vultures comprised 36 percent and northern bobwhite and greater roadrunner each comprised 20 percent of mortalities. Red-tailed hawk, blue jay, northern mockingbird, mourning dove, great horned owl, and an unknown avian species were each detected once during standardized searches (Table 2). Searchers detected three species incidental to standardized carcass searches: turkey vultures (2 mortalities), mourning dove (2 mortalities) and barn owl (*Tyto alba*, 1 mortality, Table 3). None of the species detected are federal or state listed threatened or endangered.

Seasonal carcass detections were significantly different (χ^2 = 20.87, d.f. = 2, P = 0.0001). Mortalities were highest during the fall season and lowest during the spring and summer seasons. Carcass detections did not significantly differ between the three linearly-distinct mesas (χ^2 = 1.92, d.f. = 2, P = 0.38). However, searchers detected 69 percent (9 mortalities) of likely-collision mortality carcasses on the East Mesa. Of those 9 mortalities detected on the East Mesa, 6 mortalities were detected at a single wind turbine (WTG 51E, Table 4). Searchers detected mortalities near 14 of the 28 turbines (53.6 percent) and at one of the three anemometer towers (i.e. closest structure to mortality, Figure 2). The average distance of avian mortalities (including all 30 mortality detections) to the nearest structure was 27 meters (SEM = 4.40 meters, Figure 3).

Including all carcass detections, raptors comprised 47 percent of mortalities (14 mortalities). Of the 14 raptor carcasses located, 11 were of turkey vultures. The other 3 mortalities included a red-tailed hawk, great horned owl and barn owl. Searchers located the great horned owl during a standardized carcass search at anemometer tower 1 on the East Mesa during the fall 2007. Review of the collected feathers indicates that the mortality was likely caused by gunshot. The barn owl was found incidentally beneath an unsampled turbine in the winter 2006-7. It is unclear whether the carcass was due to collision mortality. The red-tailed hawk and turkey vulture carcasses had injuries consistent with collision with wind turbines. Upland gamebirds (27 percent, 8 mortalities) and near passerines (17 percent, 4 mortalities) were the only taxa groups with more than 10 percent of mortality detections.

Bias Corrections

I used a total of 26 large, 22 medium and 20 small avian trial carcasses in searcher efficiency trials. Overall, searcher efficiency significantly differed among size classes ($P < 0.05$) with searchers detecting 76 percent of the large carcasses, 50 percent of the medium carcasses, and 42 percent of the small carcasses (Table 5). Detection rates did not significantly differ between seasons ($P = 0.35$), but were highest during the winter for large carcasses (100 percent), in the summer for medium carcasses (60 percent) and in the winter for small carcasses (60 percent, Figure 4).

During the 4 seasonal carcass removal trials, I utilized 108 trial carcasses, representing 30 avian species. Carcass persistence significantly differed between size classes (Two-way Factorial ANOVA $F = 14.24$, d.f. = 2, 96, $P = 3.89 \times 10^{-6}$). Large carcasses persisted on average for 12 days (SEM= 1.96 days), medium carcasses for 7 days (SEM = 1.69 days), and small carcasses for 3 days (SEM = 0.85 days). Large carcasses persisted for significantly longer than medium carcasses ($P = 0.01$) and small carcasses ($P = 1.9 \times 10^{-6}$). Medium carcasses persisted for significantly longer than small carcasses ($P = 0.04$). Carcass persistence significantly differed between fall and spring seasons ($P = 0.003$), but was consistent for the other seasons (Table 6).

Mortality Estimation

I estimated avian collision mortality utilizing the thirteen carcasses deemed likely to be collision mortalities, an average search interval of 10 days, and 28 sample turbines. To estimate annual mortality for all avian species, I reviewed the detected species and pooled the medium and large-size bias corrections. I excluded small size bias corrections as I did not detect any carcasses of this size during standardized searches. I determined the pooled avian searcher efficiency to be 63 percent and the pooled avian carcass persistence to be 9.5 days. I estimate mortality for all avian species at Red Canyon Wind Energy Center to be 0.50 individuals per MW per year (SE = 0.024).

DISCUSSION

Spatial and Temporal Distribution

There was no statistical indication of spatial distribution of mortality detections across the three distinct mesas within the site. Based on the carcasses detections likely to be collision mortalities, the probability of occurrence on the west mesa was 4 percent; however, the probability of occurrence on the central and east mesa is higher at 10 and 12 percent, respectively. The mesas were relatively equal in representation in the analysis, as 2 turbines were each from the west and central mesa and 3 were located on the east mesa. However, the low sample size of mortality detections restricts further analysis of mesa and turbine characteristics to mortality. Hoover and Morrison (2005) concluded that red-tailed hawks exhibited stationary soaring on windward hillsides within a wind energy development, which coincided with mortality detections on the same slopes. Turbines along the central and east mesa are located along the windward western slopes, and it is possible avian individuals are utilizing the slopes in a similar manner.

Mortality detections were higher during the fall. The study area is located in the Central Flyaway and receives an influx of migratory species during the fall and spring seasons. The increased mortality detections of migratory species, i.e. turkey vultures, red-tailed hawks and blue jays, during this time may be related to the high number of individuals present on-site.

Bias Corrections

Size classes significantly influence searcher efficiency. Searchers did have greater success locating a large-bodied raptor carcass with a large surface area over a small-bodied wren with less surface area. Previous post-construction mortality studies combine medium and large-bodied species into a single size class, which would bias results low for large-bodied avian mortality given the significant difference in searcher efficiency. Additionally, many species native to the Caprock region are cryptically colored. A small-bodied wren with cryptic coloration would be additionally difficult to find over a larger-bodied raptor.

Carcass persistence significantly differed among size classes. A small-bodied bird would be relatively easy for an avian or mammalian scavenger to remove versus a larger-bodied bird. Additionally, insect scavengers would require more time to remove the larger-bodied bird. Although carcass persistence remained relatively consistent throughout the study period, carcasses persisted significantly longer during the spring season than the fall season. Wind energy development seeks to leave the smallest footprint as possible post-construction, thus development may create habitat for mammalian and avian scavengers through land conservation. During the fall and spring period when avian species are migrating to and from wintering grounds, mammalian species are preparing for winter periods of low activity and spring breeding as well. During these periods, individuals would be seeking out prey items more regularly. The wind energy development supports ravens, turkey vultures, bobcats, coyotes, badgers, and foxes that would utilize any available prey.

Mortality Estimation

In comparison to other wind energy developments, the number of species detected during this study was low. Turkey vultures were the most frequently detected species, similar to the high frequency of griffon vultures (*Gyps fulvus*) at E3 and PESUR wind farms, Tarifa, Spain (Barrios and Rodriguez 2004). Griffon vultures and turkey vultures are ecologically similar in being large-bodied, carrion-feeding raptors. Barrios and Rodriguez (2004) found a positive correlation between vulture mortality and the use of slopes within the wind park for lift during winter periods. Additionally, the authors identified a pattern similar to that seen at Red Canyon Wind Energy Center. In Spain, 57 percent of mortality occurred at two rows of turbines accounting for 15% of the development. At Red Canyon Wind Energy Center, 67 percent of mortalities occurred on the east mesa, specifically 3 turbines that account for 5 percent of the development. A possible explanation for the frequency and distribution of turkey vulture carcass detections is that they communally roost in large numbers (Kirk and Mossman 1998). This is corroborated by anecdotal evidence of field personnel who observed large groups of turkey vultures flying near turbines where high mortality detections occurred, so future studies should investigate the possibility of a communal roost within the development. Turkey vultures are a widespread and numerous species (Sauer et al. 2007), and the low mortality estimate for Red Canyon suggests a limited effect on the population.

The annual avian mortality estimate observed at the Red Canyon Wind Energy Center (0.50 individuals per MW per year) is lower than the average avian mortality reported for newer generation wind energy developments in the United States (3.05 individuals per MW per year; Erickson et al. 2004). Given the large search effort, adaptive approach to search interval, high searcher efficiency, and high carcass persistence onsite, I am confident that searchers located the majority of avian collision mortalities present. When compared to other newer generation wind energy developments, Red Canyon Wind Energy Center has a limited direct effect on avian species.

Care should be taken in applying the mortality estimate of Red Canyon Wind Energy Center outward to other developments along the Caprock Escarpment. At a local level within the wind energy center, avian mortality is low. However, the large number of wind energy developments and wind turbine generators that have not been studied along the Caprock Escarpment make it is difficult to determine the long-term population level impacts of wind energy generation to avian species.

CONCLUSION

This study is one of the first post-construction mortality monitoring studies conducted on a wind energy development in Texas, and within the Southwestern United States as a whole. Similar to other studies on avian collision mortality, I found some evidence of temporal distribution of mortality tied to fall migration periods. Because I did not determine statistically significant spatial distributions, the patterns of mortality detection suggest turbine location characteristics may influence mortality.

The impact of the Red Canyon Wind Energy Center on local avian species appears to be low, based by the low mortality estimate. However, as wind energy development continues along the Caprock Escarpment, future study will be needed to determine the cumulative impact of such development on local avian species. While Texas offers wind resources that make energy generation profitable within this region, the location of developments within a migratory corridor should be continually monitored.

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Table 3: Total effort for standardized carcass searches from September 2006 through September 2007.

Year	Month	No. Turbines Searched [a]	Anemometers Searched	No. Plot Searches [b]
2006	September	29[c]	3	58
	October	28	3	59
	November	28	3	62
	December	28	3	79
	2006 Total			258
2007	January	28	3	44
	February	28	3	62
	March	28	3	155
	April	28	3	124
	May	28	3	124
	June	27	3	330
	July	27	3	254
	August	27	3	171
	September	27	3	30
	2007 Total			1294
	Overall Total			1552

[a] No. turbines that are searched at least 80m in all directions
[b] Inclusive of anemometer and turbine searches
[c] Inclusive of a turbine searched during training periods

Table 4. Summary of avian mortality composition based on mortalities detected in standardized search plots from September 2006 through September 2007.

Species	Fall	Winter	Spring	Summer	Total	Percent Composition
Turkey Vulture *Cathartes aura*	6	1	1	1	9	36
Northern Bobwhite *Colinus virginianus*	2	1	2	0	5	20
Greater Roadrunner *Geococcyx californianus*	4	1	0	0	5	20
Mourning Dove *Zenaida macoura*	1	0	0	0	1	4
Unknown Species	1	0	0	0	1	4
Red-tailed Hawk *Buteo jamaicensis*	1	0	0	0	1	4
Blue Jay *Cyanocitta cristata*	1	0	0	0	1	4
Northern Mockingbird *Mimus polyglottus*	1	0	0	0	1	4
Great Horned Owl *Bubo virginianus*	1	0	0	0	1	4
Total	18	3	3	1	25	100

Table 5. Summary of avian species composition based on mortalities detected incidental to standardized carcass searches from September 2006 through September 2007.

Species	Fall	Winter	Spring	Summer	Total	Percent Composition
Mourning Dove *Zenaida macoura*	2	0	0	0	2	40
Turkey Vulture *Cathartes aura*	2	0	0	0	2	40
Barn Owl *Tyto alba*	0	0	1	0	1	20
Total	2	0	1	0	5	100

Table 6. Number of avian mortalities detected in standardized search plots per turbine from September 2006 through September 2007, inclusive of all species detected.

Turbine	No. Mortalities	Turbine	No. Mortalities
WTG 1	0	WTG 34	2
WTG 3	0	WTG 35	3
WTG 5	1	WTG 38	1
WTG 7	2	WTG 39	1
WTG 9	0	WTG 42	0
WTG 11	1	WTG 44	0
WTG 13	0	WTG 45	2
WTG 15	1	WTG 46	0
WTG 17	0	WTG 48	1
WTG 19	1	WTG 51	6
WTG 21	0	WTG 53	0
WTG 22	0	WTG 56	1
WTG 25	0		
WTG 26	0	Anemometer 1	0
WTG 28	1	Anemometer 2	1
WTG 32	0	Anemometer 3	0

Table 7. Results of avian species searcher efficiency trials conducted from September 2006 through September 2007.

Size Class	Season	No. Placed	Percent Found
Large Birds	Fall[a]	8	57
	Winter	6	100
	Spring	6	83
	Summer	6	67
	Overall	26	76
Medium Birds	Fall[a]	4	50
	Winter	6	40
	Spring	6	50
	Summer	6	60
	Overall	22	50
Small Birds	Fall[a]	2	0
	Winter	6	60
	Spring	6	20
	Summer	6	50
	Overall	20	42
All Birds	Overall	68	57

[a] Fall season was randomly assigned size class, other seasons were evenly set at 6 per size class (total of 12 per searcher).

Table 8. Results of avian species carcass removal trials conducted September 2006 through September 2007.

Size Class	Season	No. Placed	Mean stay (days)
Large Birds	Fall	9	12
	Winter	9	8
	Spring	9	8
	Summer	9	18
	Overall	36	12
Medium Birds	Fall	9	1
	Winter	9	8
	Spring	9	12
	Summer	9	9
	Overall	36	7
Small Birds	Fall	9	0
	Winter	9	4
	Spring	9	4
	Summer	9	3
	Overall	36	3
All Birds	Overall	108	7

Figure 1. Location of sampled wind turbine generators at Red Canyon Wind Energy Center.

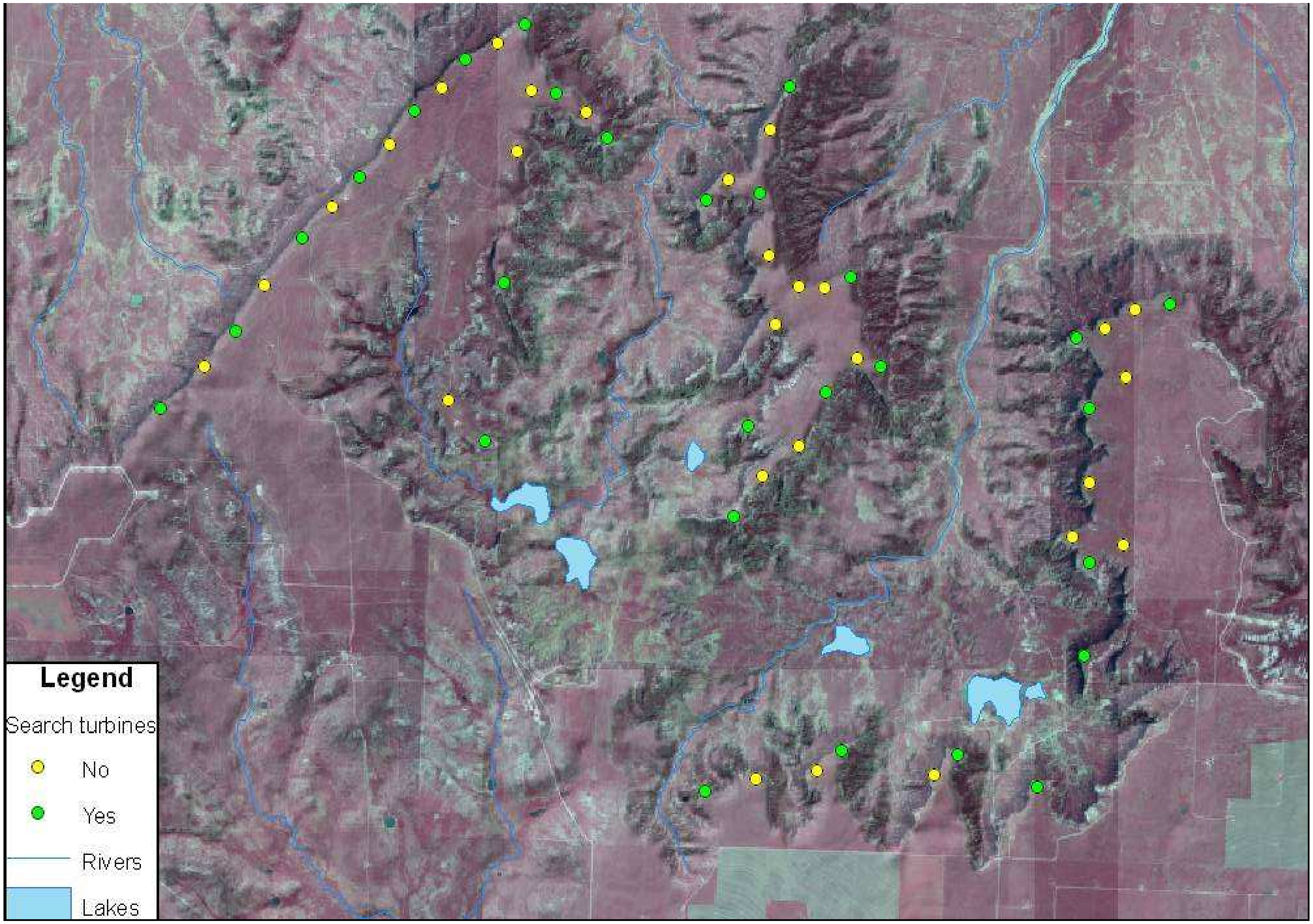


Figure2. Distribution of avian mortalities detected at Red Canyon Wind Energy Center.

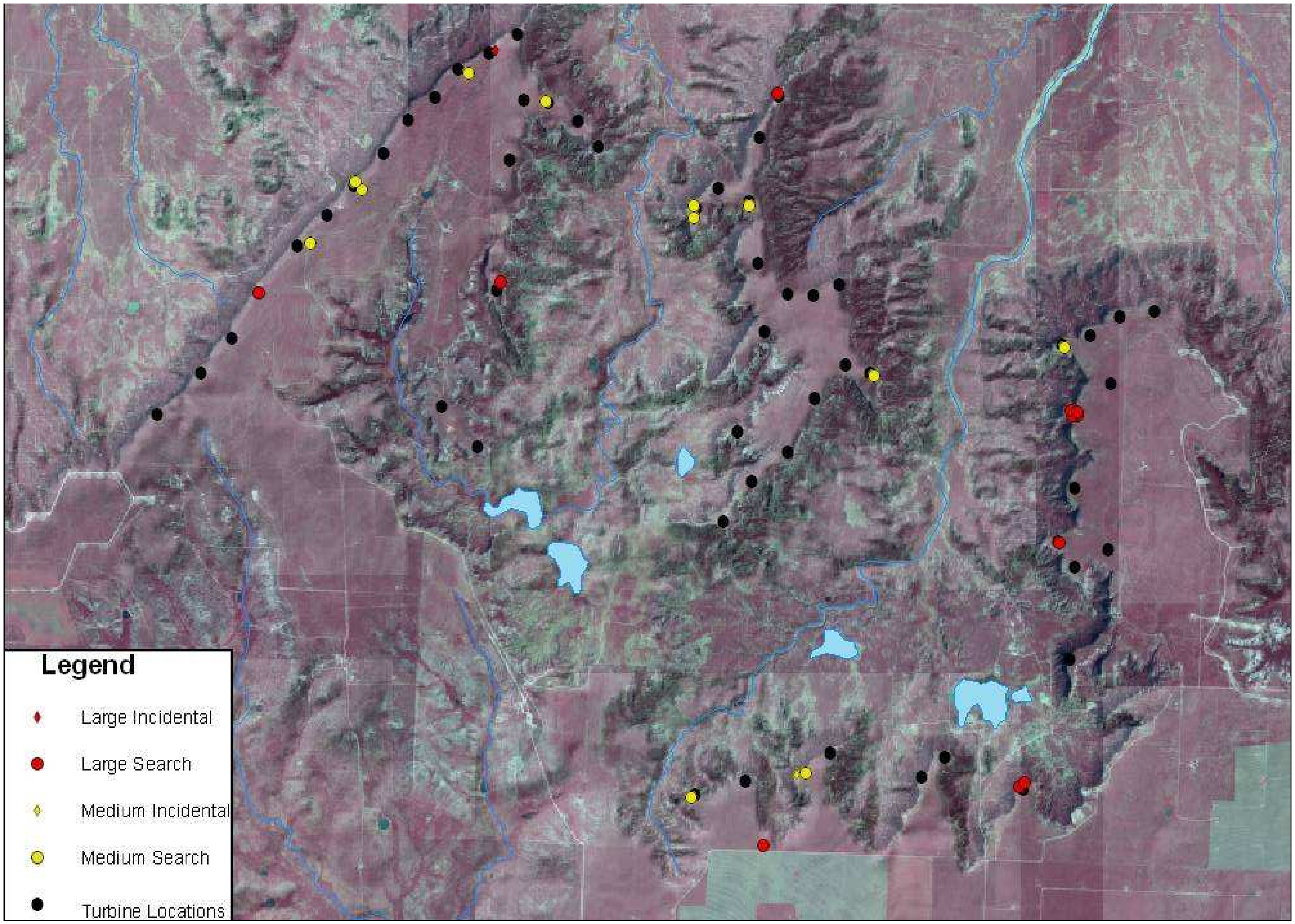


Figure 3. Distribution of distance from wind turbine generators to avian mortality detections.

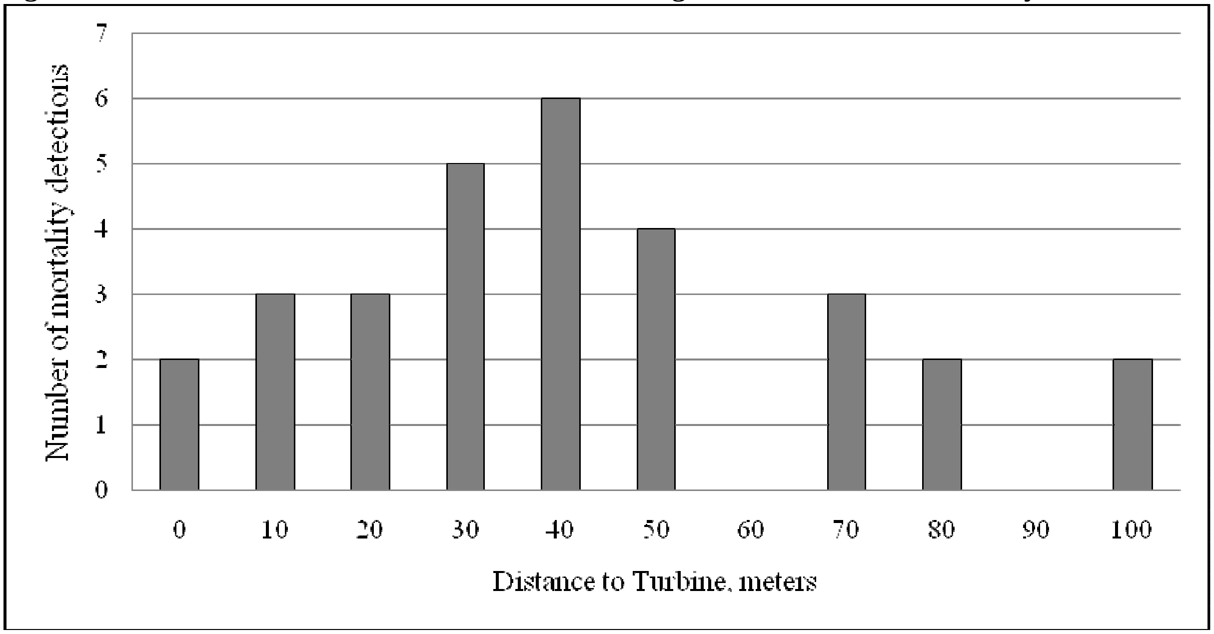
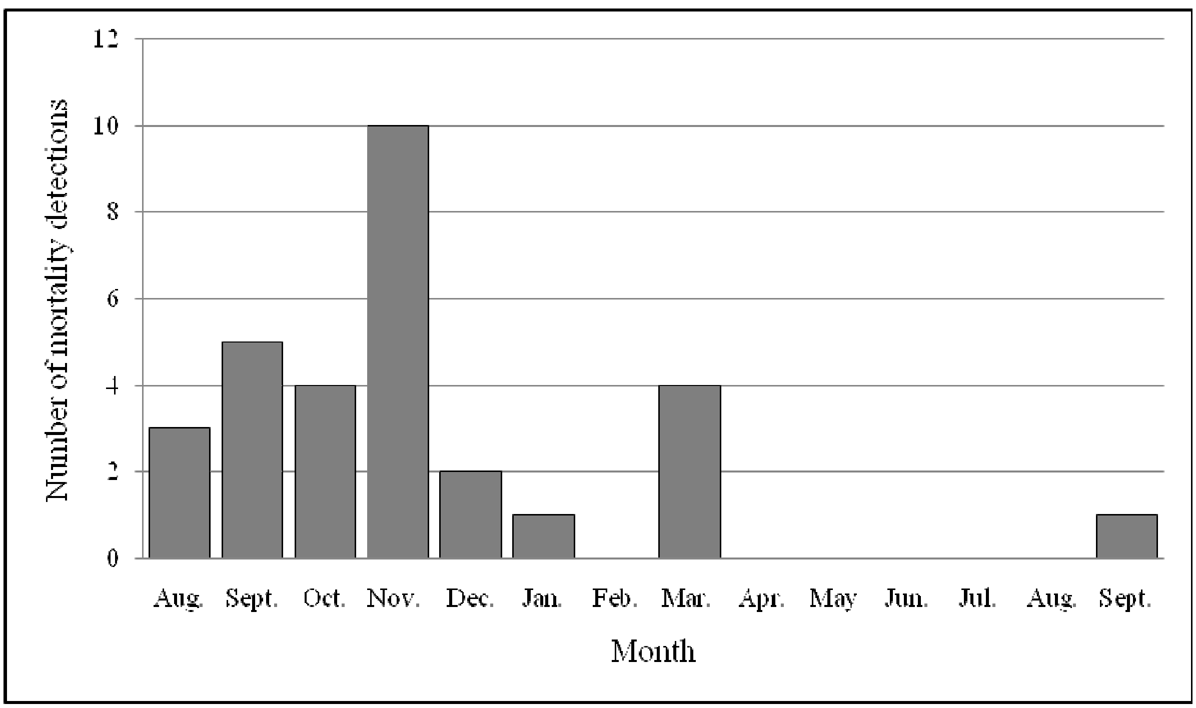


Figure 4. Temporal distribution of avian mortalities detected at Red Canyon Wind Energy Center.



CHAPTER 3: BAT MORTALITY AT A UTILITY-SCALE WIND ENERGY DEVELOPMENT ALONG THE CAPROCK ESCARPMENT

ABSTRACT

Wind energy has been utilized commercially in the United States since the 1970s. Texas has the most installed wind energy generation capacity in the United States, yet no empirical data are available to assess the impact to local bat populations. I assessed the incidence and frequency of mortality, modeled estimates of mortality and identified the spatial and temporal distribution of mortality at a utility-scale wind energy development consisting of 56 turbines southeast of Lubbock, Texas. From September 2006 to September 2007, I conducted standardized carcass searches (n=1,551) at sample turbines. To enhance accuracy of mortality estimations, I assessed removal rates of carcasses by scavengers and the efficiency of searchers in finding carcasses in bias correction trials concurrent to mortality searches. During standardized carcass searches, observers detected 47 bat carcasses of which 94 percent were Brazilian free-tailed bats (*Tadarida brasiliensis*). There was no indication of spatial distribution across the three linearly-distinct mesas. "Season of Occupancy" mortality estimates suggest the impact of wind turbines on local bat species at the Red Canyon Wind Energy Center is higher than the national average (46.1 individuals per MW per year, SE =140.29) with Brazilian free-tailed bats being the most frequent species detected.

Key Words: collision mortality, Texas Panhandle, wind energy, *Tadarida brasiliensis*, bias corrections, bat impacts

Wind energy development has increased in recent years due to renewed interest in renewable energy resources. Additionally, technological advances have made wind energy relatively competitive against more conventional forms of energy generation (Redlinger et al. 2002). Wind energy generation is ongoing in 25 states and the American Wind Energy Association (AWEA) predicts that 6% of the nation's energy supply will be from wind resources by 2020 (AWEA 2005). Generally considered environmentally friendly, recent studies have indicated that wind energy development is associated with negative impacts on avian and bat species. Two types of impacts have been identified: 1) direct mortality due to collisions with wind turbine generators, and 2) indirect impacts due to avoidance, habitat disturbance, and displacement (National Wind Coordinating Committee 2004).

Thirteen published studies have been conducted to determine the impacts of wind energy development on bat species, focusing on migratory, tree-roosting species, or the Eastern United States. To date, no published study has been conducted in the Southwestern United States, specifically in Texas, to determine the impact to local bat species (Arnett et al. 2008). Currently, the state of Texas leads the nation in installed wind energy generation with approximately 4,300 MW (AWEA 2007) and has the second highest wind energy generation potential. A study conducted at a wind energy development in western Oklahoma indicated that Brazilian free-tailed bats (*Tadarida brasiliensis*) are a species of possible concern given high population numbers in the Southwestern United States (Piorkowski 2006). Little is known about the bat populations in the Texas Panhandle, a region which contains the state's highest quality wind resource (Texas State Comptroller Office 2008). As development of wind energy within this region and similar areas of Texas increases, there is a pressing need for studies to be completed to assess the impact of wind energy development on local bat species.

I conducted a post-construction mortality study at a utility-scale wind energy development in the Southern Texas Panhandle to assess the incidence and frequency of bat mortality, model estimates of mortality rates, and identify the spatial and temporal distribution of bat mortality within a wind energy development.

STUDY AREA

The study area was the Red Canyon Wind Energy Center located in Borden, Garza and Scurry Counties in the southern portion of the Texas Panhandle (32º 53' N, 101º 8'W). The site is located along the edge of the Caprock Escarpment, a distinct palisade-like escarpment identified by the Ogallala group of sediments (Matthews 1969). The escarpment forms a border between the High Plains and the Rolling Central Plains. Annual precipitation is 47.4 centimeters with the highest amounts occurring in the spring and fall seasons. Average annual temperature ranges from 8˚C to 24˚C with June being the warmest month averaging 32˚C and December being the coolest month averaging -3˚C (NCDC 2004). The historical plant climax community on the top of the caprock consists of mixed grass, forbs, and shrubs. Dominant shrub species present are redberry juniper (*Juniperus pinchotti*), mesquite (*Prosopis glandulosa*), catclaw mimosa (*Mimosa nuttalli*), prickly pear (*Opuntia polycantha*), and hackberry (*Celtis retiulata*). The most common grasses are little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indiangrass (*Sorgastrum nutans*), and grama species (*Bouteloua* spp.) (Bell 2004). The study area is under rotational grazing management for cattle. The current plant community consists primarily of shrub stands with infrequent patches of grasses.

Development of the site was completed in May 2006 with the construction of 56 General Electric 1.5 MW wind turbine generators (WTG) and related facilities, including distribution lines, meteorological towers, transformers, roads, and an operation and management facility. The turbines are linearly arranged on three distinct mesas (Figure 5). Turbines have a hub height of 70 meters and a rotor diameter of 70 meters, resulting in rotor-swept area of 35 to 105 meters above ground. Turbines have a wind direction sensor within the hub that maneuvers the turbine into the wind, resulting in a 360-degree directional yaw. Thus, turbines have a spherical rotor-swept area of approximately 179,594 m^3 in which collision mortality may occur.

METHODS

Standardized Carcass Searches

I conducted carcass searches each week for 52 weeks, beginning in September 2006, on a systematic sample of 28 of the 56 turbines (Appendix A-1). In addition to myself, there were two additional trained observers. Beginning with the first numbered turbine, I chose every other turbine. When the turbine string was not truly linear, i.e. turbines followed caprock peninsulas; I chose the end turbine for sampling. I divided the study period into four 13-week seasons: 1 September – 30 November 2006 (Fall), 1 December 2006 – 28 February 2007 (Winter), 1 March – 31 May 2007 (Spring), and 1 June – 31 August 2007 (Summer). I initially searched all areas within a 200 meter x 200 meter square plot centered on sample turbines using a strip transect approach with transects located 7 meters apart. I did not search areas within 5 to 10 meters of the caprock edge due to safety concerns. I searched sample turbines every 14 days for the fall and winter seasons. I also searched 3 anemometer towers 5 times per season during this time.

At the end of the winter field season, I determined a 14 day search interval was too infrequent to account for short carcass persistence rates onsite (see discussion of carcass removal trials below). Further, I did not detect carcasses further than 59 meters from the sample turbines ($\bar{x}$= 16.0). Thus, beginning with the spring field season, I decreased the search plot area to a 160 meters x 160 meters and increased searches to every 7 days. During the summer season, I further increased searches to every 3 days. During the spring and summer season, I searched meteorological towers weekly.

For each carcass detected, I took digital photographs and completed a casualty report. Casualty reports included: time and date of collection, turbine number, UTM coordinates of the location, common and scientific names of species found, temperature, pertinent weather conditions, and photograph number (Appendix B-3). When possible, I recorded the age and sex of the carcass, following the criteria presented in Anthony (1988) and Racey (1988), and evidence of trauma or of scavenging. I recorded the condition of each carcass found using the following categories: “intact” included carcasses that were completely intact with little or no evidence of decomposition or scavenging, “partial” carcasses showed signs of scavenging or a dismembered carcass of greater than 50% intactness, and “wing spot” indicated a single wing with at least 50% of the wing intact. I retained intact carcasses as voucher specimens and labeled each with a unique number associated with the casualty report that indicated date of find, turbine number where located, searcher, and species.

Bias Corrections

The ability of searchers to detect carcasses is influenced by individual searcher skills, the characteristics of individual bat species (e.g. body size, color), and carcass removal due to scavenging prior to searches. I conducted searcher efficiency and carcass removal trials to account for such biases and to improve the accuracy of mortality estimation. Bias correction trials were conducted seasonally to account for differences in vegetation and scavenger-predator characteristics. For bias correction trials, I used carcasses provided by the South Plains Wildlife Rehabilitation Center and collected during surveys at the RCWEC. I limited carcasses used to Brazilian free-tailed bats (*Tadarida brasiliensis*) and red bats (*Lasiurus blossevillii*), species native to the Caprock Escarpment Region.

I conducted searcher efficiency trials to estimate the number of animals that go undetected by searchers and to determine each searcher's ability to find carcasses. Searcher efficiency trials were conducted at sample turbines. I conducted 3 trials per searcher per season in a double-blind manner with proctors placing efficiency trial carcasses at random locations in search plots. I considered trials successful when searchers located trial carcasses. When searchers did not detect trial carcasses, I considered the trial unsuccessful only if trial carcasses could be recollected by proctors (i.e. trial carcasses had not been removed by a scavenging animal prior to the search). I did not include trials were carcasses were not recollected by proctors in analysis.

I conducted carcass removal trials to estimate the onsite persistence of carcasses before removal by scavengers. Carcass removal trials were conducted underneath turbines not sampled in standardized carcass searches. I conducted 3 carcass removal trials per mesa per season to account for differences among mesas and seasons related to geophysical characteristics and scavenger-predator composition or abundances. Based on anecdotal evidence (Gritski, pers. comm..), I decided to place carcasses during a time when visual cues to scavengers, such as ravens or crows, would be less likely. All carcasses were placed during either early morning hours no later than 2 hour post-sunrise or before 2 hours pre-sunset to avoid immediate removal. During each trial on each mesa, I placed a total of 3 carcasses (1 per turbine) at randomly generated distances and directions from turbines. I recorded the UTM location of each carcass and the tracking number of the carcass. I observed carcasses at days 1, 2, 3, 7, 14, 21, and 28 with observations made as to the decomposition rate and evidence of scavenging (Young et al. 2003). At the end of each carcass removal trial period, I removed all remaining carcasses or evidence of the carcasses.

Statistical Analysis

I used both parametric and non-parametric statistics because some of the data was heteroscedastic and not normally distributed. I generated Poisson models to assess spatial and temporal variation in carcass detections with the carcass detections as the response variable and the mesa of detection as the response variable in spatial analysis, and the season of each detection as the response variable denominator in temporal analysis. Wind turbine generator was included in each model as a covariate, and I included season as a repeated measure in the temporal distribution model. To assess spatial distribution of carcass detections, I conducted a chi-squared analysis of deviance. I conducted a pairwise t-test with non-pooled standard deviations when a difference was detected.

I assessed seasonal effects on searcher efficiency using a two-way factorial chi-squared analysis of deviance with successful location of trial carcasses as the response variable, and trial season as the response variable. Carcass persistence departed significantly from a normal distribution (Shapiro-Wilk W test; $P < 0.0001$), so I completed a full-rank transformation of carcass persistence results and conducted an analysis of variance followed by a Tukey's multiple comparison of means to assess the influence of size class and season on the response variable, carcass persistence in days. I used Program R statistical package for (R, Vienna, Austria). I report results as means ± SEM , and applied a significance level of 0.05 throughout. All tests are two-tailed.

I assigned turbines to three mortality categories based on elevation, aspect, percent of turbine site that was Caprock Escarpment edge (Miller, unpublished thesis 2008). Low mortality turbines were southeast-facing turbines with greater than 865 meters elevation and less than 34 percent Caprock edge within the turbine site, medium mortality turbines were south-facing turbines with elevations between 853 – 865 meters and between 34 – 38 percent Caprock edge within the turbine site, and high mortality turbines were southwest-facing turbines with less than 853 meters elevation and greater than 38% Caprock edge within the turbine site. I estimated mortality for each turbine category using the formula (Young et al. 2003):

$$M = \frac{N \times I \times C}{k \times t \times p}$$

where N is the total number of turbines within each mortality category, I is the average interval between search efforts, C is the number of carcass found during a defined search period (e.g. season, year), *k* is the number of turbines searched, *t* is the mean persistence time of carcasses onsite as estimated by carcass removal trials, and *p* is the proportion of carcasses detected during searches as estimated by searcher efficiency trials. The Young et al. (2003) mortality estimation includes adjustments for both searcher efficiency and carcass removal bias. No bat carcasses were detected during standardized carcass searches in the winter season (one carcass detected incidental to searches). Based on no carcass detections, I excluded the winter season bias corrections for mortality estimation to account for low species presence/activity during this time. I term this restricted mortality estimate "season of occupancy." To estimate season of occupancy mortality rates, I pooled the turbine category mortality estimates. I calculated the variance using the variance of product formula (Goodman 1969) and the variance of ratio formula (Cochran 1977) as shown in Johnson et al. (2003). The variance of *t* and *p* is:

$$Var(t \times p) = t^2 x V(p) + \; p^2 \times V(t) - \; V(t) \times V(p)$$

From this, the variance of *M* is:

$$Var(m) = \frac{N^2 \times I^2 \; \times C^2}{k^2 \times t^2 \times p^2} \times \left[\frac{V(t \times p)}{t^2 \; \times p^2} + \frac{V(C)}{C^2}\right]$$

RESULTS

Standardized Carcass Searches

I conducted a total of 1,442 standardized carcass searches at sample turbines and 110 standardized carcass searches at anemometer towers (Table 9). Search times ranged from 22 minutes to 124 minutes ($\bar{x}$= 40.98 minutes, SEM = 5.26 x 10^{-4}).

During the study period, searchers found 56 bat mortalities, 47 of which were detected during standardized carcass searches and nine found incidental to the searches (Appendix B-3, B-4). Of the 47 bats found during standardized searches, Brazilian free-tailed bats (*Tadarida brasiliensis)* comprised 94 percent, hoary bats (*Lasiurus cinereus*) comprised 4 percent, and red bats (*Lasiurus borealis)* comprised 2 percent (Table 10). The 9 mortalities detected incidentally to standardized carcass searches included Brazilian free-tailed (5 mortalities), hoary bats (3 mortalities) and western pipistrelle (*Pipistrellus hesperus*) (1 mortality, Table 11). None of these bat species are federally or state listed as threatened or endangered.

I found mortalities beneath 24 of the 28 (86 percent) search turbines. The maximum number of mortalities detected at any one turbine during standardized carcass searches was 6 mortalities at WTG 44 and 46 on the East Mesa (Table 12). The average distance of bat mortalities located during standardized carcass searches to the nearest turbine was 16 meters (SEM = 1.95 meters, Figure 6). Carcasses were detected equally throughout the wind energy center (Figure 10, $\chi^2 = 4.97$, d.f. = 2, P = 0.08). I found bat carcasses primarily during the fall with a peak in mortality detections occurring in October (Figure 9). Carcass detections were significantly different between the fall and winter seasons (P = 0.004), between fall and spring seasons (P = 0.01), and between winter and summer seasons (P = 0.02).

I aged and sexed the 56 bat carcasses following the criteria presented in Anthony (1988) and Racey (1988) when possible. For Brazilian free-tailed bats, 41 percent were adults, 43 percent were juveniles, and 16 percent were unidentifiable to age. For hoary bats, 40 percent were adults, 40 percent were juveniles, and 20 percent were unidentifiable to age. The single red bat discovered was a juvenile male, and the western pipistrelle was unidentifiable to age or sex (Figure 7). Of the Brazilian free-tailed bats, 53 percent were male, 10 percent were female, and 37 percent were unidentifiable to sex. Of the hoary bats, 60 percent were male, 20 percent were female, and 20 percent were unidentifiable to sex (Figure 8).

Bias Corrections

I used a total of 24 bat carcasses of three species in searcher efficiency trials. Overall, searchers detected 23 percent of bat trial carcasses (Table 13). Excluding the winter season searcher efficiency, searchers detected 27 percent of trial carcasses. Detection rates for bat species were significantly different between seasons (χ^2 =10.20, d.f. = 4, P = 0.04) with highest detections occurring during the summer season at 50 percent. During the four seasonal carcass removal trials, I used a total of 36 bat carcasses (Table 14). Overall, bat carcasses persisted 1 day (SEM = 0.16 days, (χ^2 =7.30, d.f. = 4, P = 0.12).

Mortality Estimate

I used the season of occupancy bias correction factors for mortality estimation, i.e., 26 percent season of occupancy searcher efficiency and 1 day carcass persistence. Search interval averaged 8 days. I classified 34 total turbines as low mortality (i.e. 0 – 1 carcass detections). I estimate the season of occupancy mortality for these 34 total turbines at 15.29 individuals per MW (SE = 88.29) for the low mortality turbines. I classified 13 total turbines as medium mortality (i.e. 2 – 3 carcass detections), and estimate season of occupancy mortality to be 45.00 individuals per MW (SE =259.32) for the medium mortality turbines. Nine turbines were classified as high mortality turbines (i.e. more than 4 carcass detections). I estimated season of occupancy mortality at 106.67 individuals per MW (SE =615.77) for the high mortality turbines. In total, I estimate the Red Canyon Wind Energy Center season of occupancy mortality to be 36.87 individuals per MW (SE =111.89).

DISCUSSION

Carcass Detections

Of the 45 species of bats that occur in North America, 11 species have been documented as collision mortalities at wind energy developments (Johnson 2005, Kunz et al. 2007). Seventy-five percent of mortalities reported are of foliage-roosting and tree-cavity dwelling species (Kunz et al. 2007). Brazilian free-tailed bats are cavity roosters, typically in karst or cave formations. The high number of mortality detections for Brazilian free-tailed bats, and the mortality estimate for the development, indicates that further study is necessary to assess the population level impact of wind energy development in the Caprock Escarpment Brazilian free-tailed colonies. Brazilian free-tailed bats provide natural pest control for agricultural producers, specifically over cotton production (Cleveland et al. 2006). Twenty percent of the nation's cotton production occurs in Texas, largely in the Panhandle region (United States Department of Agriculture 2007). As wind energy development increases along the Caprock Escarpment, there is a possibility of an unexpected economic impact to local agricultural producers.

The spatial distribution of annual mortality detections among mesas was not statistically significant. There appears to be biological relevance in turbine characteristic effects on carcass detections and mortality events (Miller, unpublished 2008). The distribution of mortalities suggests that turbine site characteristics influence the likelihood of collision mortality, illustrated by 34 percent of carcass detections occurring at 16 percent of turbines. I incorporated turbine characteristics that effect carcass detections (i.e. mortality events) to prevent overestimation of mortality under the Young et al. (2003) formula.

There was a significant difference in carcass detections during the fall and summer seasons. These periods coincide with periods of high activity for the Brazilian free-tailed bat (Davis et al. 1962). Though a small number of bats may overwinter in the Caprock Escarpment region, the influx of individuals present at turbine rotor-swept area during the fall migration periods increases the likelihood of collision mortality events (Kunz et al. 2007). I suggest further investigation of the correlation between periods of bat species high activity periods and mortality events at the Red Canyon Wind Energy Center.

Bias Corrections

Of the 22 publicly available post-construction studies, only 8 have utilized bat carcasses to quantify bias corrections with the remaining 14 utilizing small avian carcasses as surrogates. The use of small avian carcasses in bias correction trials introduces error in that scavenging animals may be drawn to avian carcasses to a different extent than that of bat carcasses. I utilized carcasses of species native to the Caprock Escarpment either found during standardized carcass searches or obtained from a local wildlife rehabilitation facility and am confident the bias correction results are accurate representations for this region. I provide general comparison to other regions, but caution direct comparison given the different intensity and frequency of bias correction trials.

Searcher Efficiency

The searcher efficiency rate for the study period (27 percent) was on the low end of the other post-construction monitoring projects under similar study protocols, which range from 25% to 75% (Arnett et al. 2008). During the study period, the region experienced a higher than average precipitation. Between September 2006 and September 2007, the region received approximately 88.4 centimeters of precipitation. Vegetation height and density was unusually high and it became difficult for searchers to detect trial bat carcasses. Thus, efficiency at Red Canyon is more similar to that at wind energy developments in the forested Eastern United States (25 - 42%).

Searcher efficiency is influenced by the intensity of trials and the trial carcass size. First, I used a total of 24 bat carcasses for the same number of efficiency trials. The small trial number increases the likelihood of low searcher efficiency, as a small number of carcasses undetected by searchers will result in a disproportionately low searcher efficiency rate. Second, the carcasses obtained from the local wildlife rehabilitation center were of malnourished and injured bats, and thus were smaller and may have been more difficult to detect that carcasses found on-site. The searcher efficiency could be incorrectly biased low by the use of such bat carcasses. This is supported by the fact that searchers were still able to detect carcasses regardless of low searcher efficiency rates.

Carcass persistence

The carcass removal rate observed during my study was high (within 1 day) in comparison to the 1.9 - 12 days reported for other 22 studies (Arnett et al. 2008). The underlying cause of the high carcass removal rates has yet to be fully determined. However, I hypothesize the difference in vegetative community and geophysical characteristics influence carcass persistence. In contrast to other studies in which wind turbines are located over open grasslands, pastures, or hayfields, the turbines at Red Canyon Wind Energy Center are situated over native brushland habitat. Additionally, the development is located along the Caprock Escarpment, which provides diverse topography compared to the general flat and featureless topography of other wind developments. The native scavenging community remains relatively intact post-construction. These environmental features provide habitat for numerous vertebrate animals that are prone to scavenge when the opportunity occurs, and may influence scavenging. I directly observed or detected scavenging evidence of a variety of avian and mammalian species, including ravens, turkey vultures, bobcats, coyotes, skunks, and foxes.

The use of small avian carcasses introduces bias in that scavenging animals may be drawn to small avian carcasses to a greater or lesser extent than bat carcasses. For example, many bat species are colonial roosters and may have a strong odor associated with conspecifics and roosts. A stronger odor may facilitate detection by scavenging animals. By using bat carcasses exclusively for bat carcass removal trials, I am confident the bat carcass removal rates are accurate depictions of scavenging and other factors at the study site.

Mortality Estimate

Several factors influence the mortality rate estimation, including the search interval, the searcher efficiency rate, and the carcass removal rate. The 14-day search interval between standardized carcass searches I chose prior to study commencement accommodated the large search plot area and the number of sample turbines. Due to the high carcass removal rate, I modified the protocol to a 7-day search interval and reduced search plot area to accommodate more frequent searches of the sample turbines beginning in the spring season. A further reduction to a 3-day search interval was made during the summer field season. To account for changed search interval, I averaged the search interval across the study period. The carcass removal rate (1.0 day, Table 5) continued throughout the study period. The high carcass removal rate combined with the long search interval biases the mortality estimation low, as carcasses are likely removed prior to searcher detection.

The annual bat mortality rate estimate, restricted to season of occupancy, observed at the RCWEC (36.87 mortalities per MW per season of occupancy), is above the reported average bat mortality rate reported for new generation wind projects in the United States (2.1 mortalities per MW per year, Arnett et al. (2008)). Though bat mortality estimates at new generation wind projects are variable (Cryan 2006), a useful comparison can be made to results of post-construction monitoring at nearby wind energy projects with similar vegetation. Piorkowski (2006) reported a mortality estimation of 0.79 – 1.14 mortalities per MW per year at a wind energy center in Oklahoma, a number greatly lower than the RCWEC estimate. It is important to note that the bias correction trials conducted in Oklahoma were outside the Anderson et al. (1999) guidelines, specifically the use of artificial carcasses and use of carcass persistence rates from published literature.

Given the observed spacing of mortality across the development, I utilized turbine characteristic categories to assess mortality estimates for low, medium and high mortality turbines. Although turbine site characteristics did not greatly vary, i.e. elevation change of approximately 20 meters, there was a significant effect on mortality. I suggest further study to refine this method for use at this Caprock Escarpment wind energy development, as well as other developments within the region.

CONCLUSION

This study is one of the first post-construction mortality monitoring studies conducted on wind energy development in Texas and the Southwestern United States. Contrary to previous studies, I found biologically relevant spatial and significant temporal distribution in mortality detections. The current mortality estimate formula as offered by Young et al. (2003)

does not incorporate unequal likelihood of collision mortality. Geophysical characteristics of turbine sites influence the presence of collision-prone species at rotor-swept area. I incorporated the turbine site characteristics, based on mortality categories, into the mortality estimate. The results presented above offer a basis for the development of better mortality estimates for use along the Caprock Escarpment and the recognition of unique characteristics that might influence collision mortality estimates.

Potential negative impacts between wind energy development and bat species are relatively new areas of study. Although Texas offers wind resources that make energy development profitable, the Southern Panhandle and Caprock Escarpment is a region with large populations of bat species detected in low numbers in previous post-construction mortality monitoring studies. Future research within the region to identify the long-term environmental impacts of wind energy development should investigate population level impacts of collision mortality, specifically to the Brazilian free-tailed bat.

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Table 9. Total effort for standardized carcass searches from September 2006 through September 2007.

Year	Month	No. Turbines Searched [a]	Anemometers Searched [a]	No. Plot Searches [b]
2006	September	29	3	58
	October	28	3	59
	November	28	3	62
	December	28	3	79
	2006 Total	113	12	258
2007	January	28	3	44
	February	28	3	62
	March	28	3	155
	April	28	3	124
	May	28	3	124
	June	27	3	330
	July	27	3	254
	August	27	3	171
	September	27	3	30
	2007 Total			1294
	Overall Total			1552

[a] # turbines that are searched at least 80m in all directions
[b] Inclusive of anemometer and turbine searches

Table 10. Summary of bat mortality composition based on mortalities detected in standardized search plots from September 2006 through September 2007.

Species	Fall	Winter	Spring	Summer	Total	Percent Composition
Brazilian Free-tailed *Tadarida brasiliensis*	31	0	3	10	44	94
Hoary Bat *Lasiurus cinereus*	0	0	0	2	2	4
Red Bat *Lasiurus blossevillii*	1	0	0	0	1	2
Total	33	0	3	12	47	100

Table 11. Summary of bat species composition based on mortalities detected incidental to standardized carcass searches from September 2006 through September 2007.

Species	Fall	Winter	Spring	Summer	Total	Percent Composition
Brazilian Free-tailed *Tadarida brasiliensis*	4	0	1	0	5	56
Hoary Bat *Lasiurus cinereus*	1	1	1	0	3	33
Western Pipistrelle *Pipistrelle hesperus*	1	0	0	0	1	11
Total	6	1	2	0	9	100

Table 12. List of turbines and numbers of bat mortalities detected in standardized search plots from September 2006 through September 2007.

Turbine	# Mortalities	Turbine	# Mortalities
WTG 1	1	WTG 34	1
WTG 3	2	WTG 35	1
WTG 5	0	WTG 38	1
WTG 7	1	WTG 39	2
WTG 9	1	WTG 42	1
WTG 11	1	WTG 44	6
WTG 13	4	WTG 45	2
WTG 15	1	WTG 46	6
WTG 17	1	WTG 48	2
WTG 19	1	WTG 51	3
WTG 21	3	WTG 53	1
WTG 22	1	WTG 56	0
WTG 25	2		
WTG 26	0	Anemometer 1	0
WTG 28	0	Anemometer 2	0
WTG 32	2	Anemometer 3	0

Table 13. Results of bat species searcher efficiency trials conducted from September 2006 through September 2007.

Season	# Placed	Percent Found
Fall	6	33
Winter	6	0
Spring	6	0
Summer	6	50
Overall	24	23

Table 14. Results of bat species carcass removal trials conducted from September 2006 through September 2007.

Season	# Placed	Stay (days)
Fall	9	0
Winter	9	1
Spring	9	1
Summer	9	1
Overall	36	1

Figure 5. Location of sampled wind turbine generators at Red Canyon Wind Energy Center.

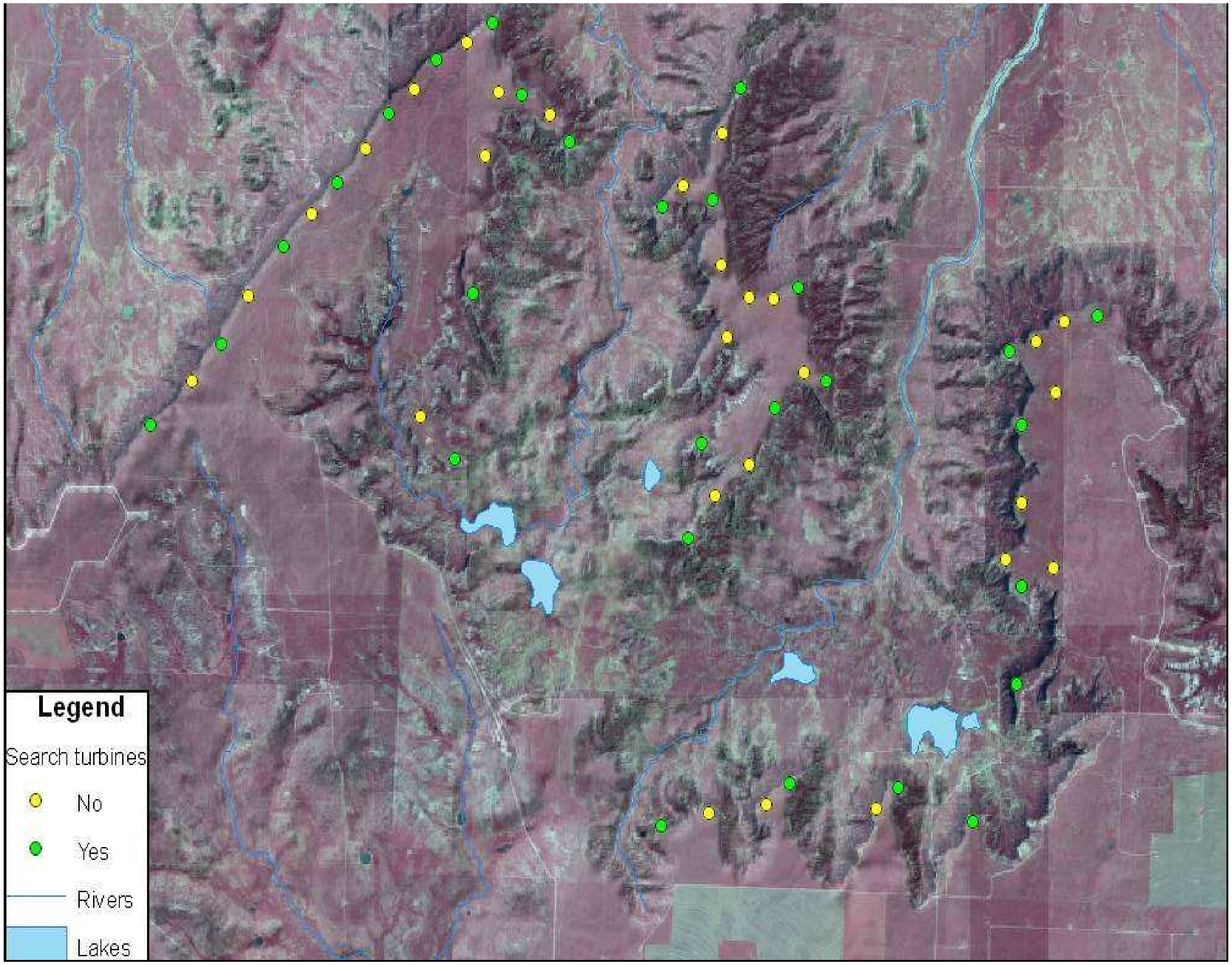


Figure 6. Distribution of distances from turbines to carcasses for bat mortalities detected September 2006 through September 2007.

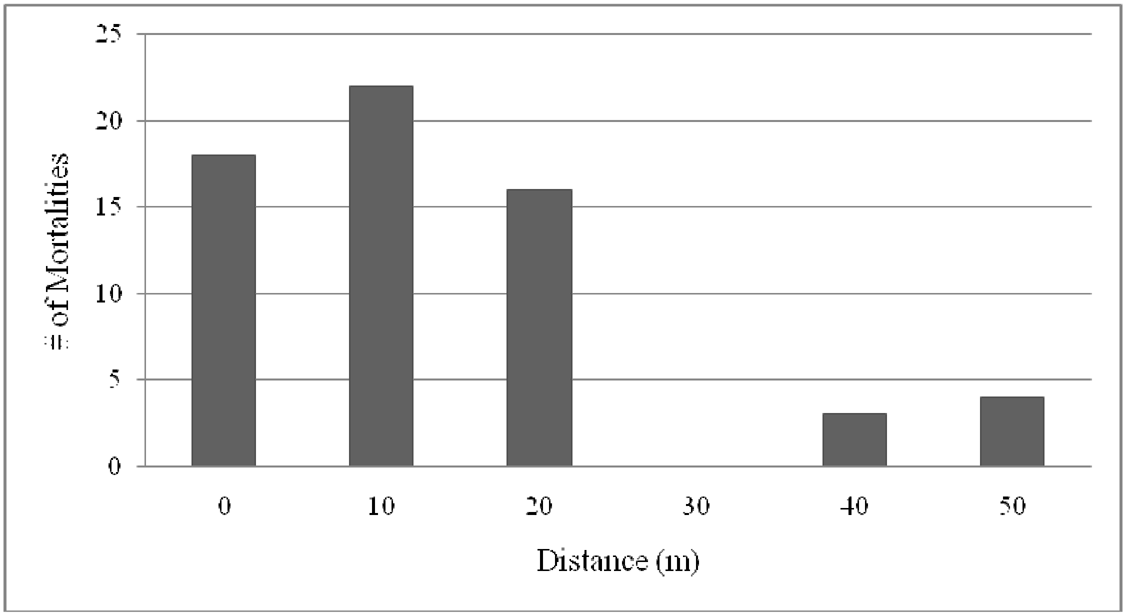


Figure 7. Age composition by species of bat mortalities detected from September 2006 through September 2007.

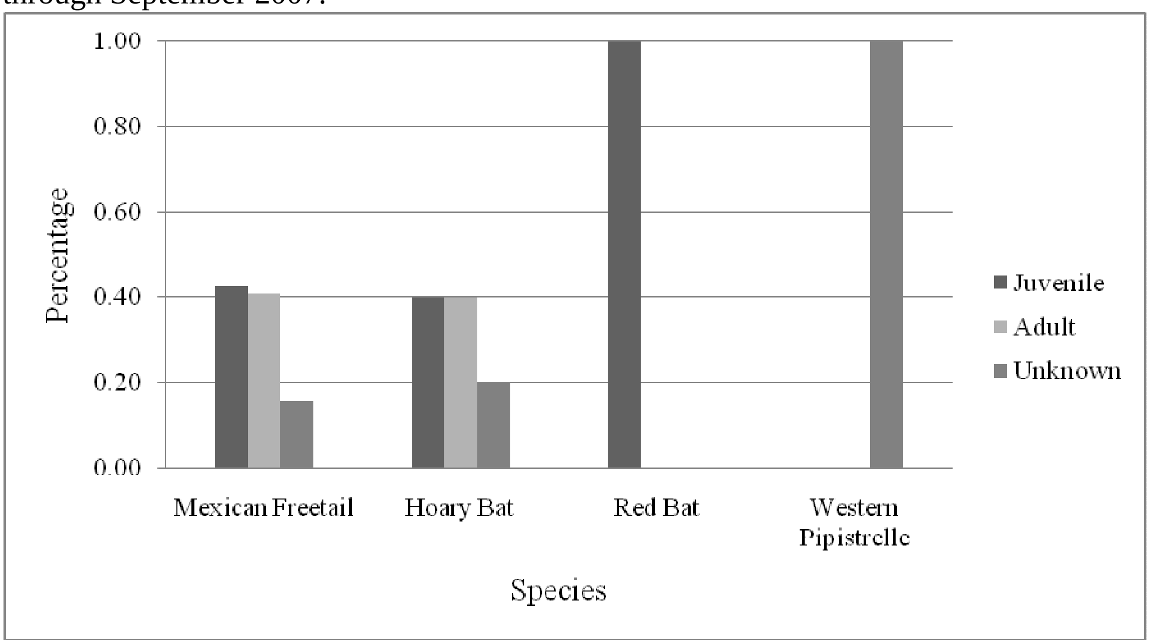


Figure 8. Sex composition by species of bat mortalities detected from September 2006 through September 2007.

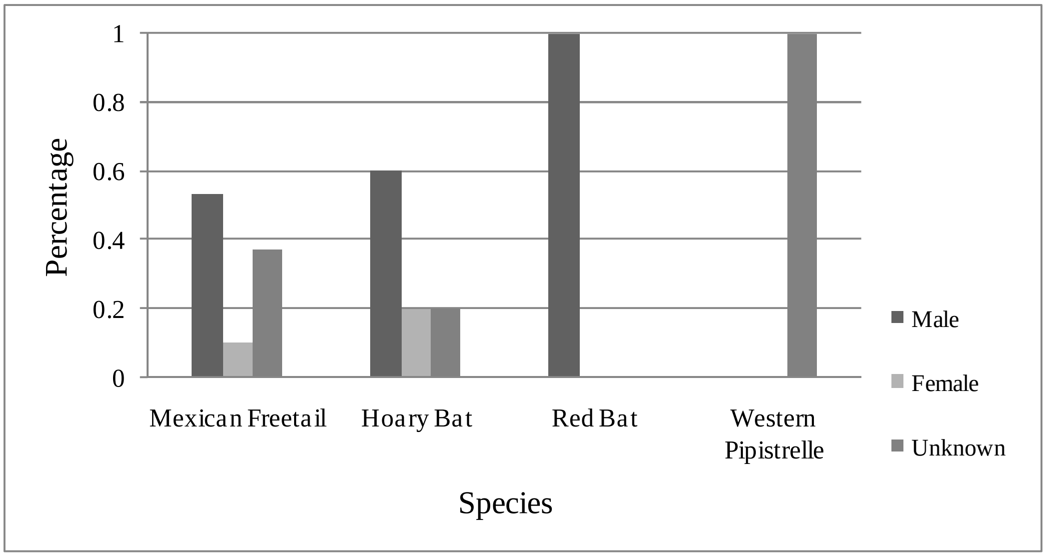


Figure 9. Distribution of all bat mortalities detected from September 2006 through September 2007 by month, beginning September 2006 through September 2007.

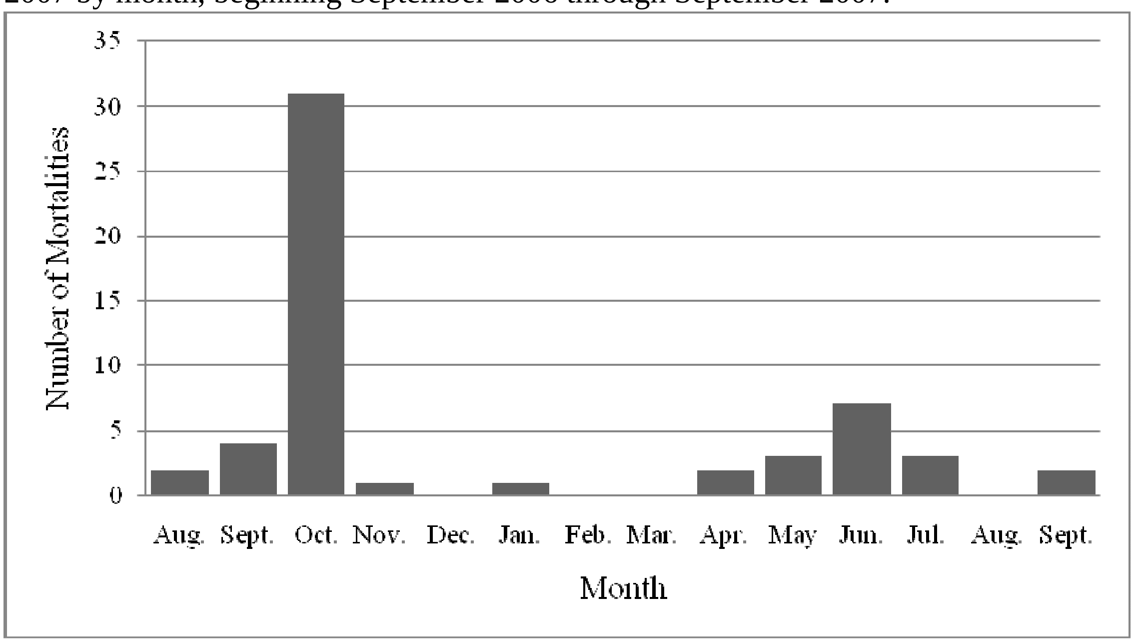
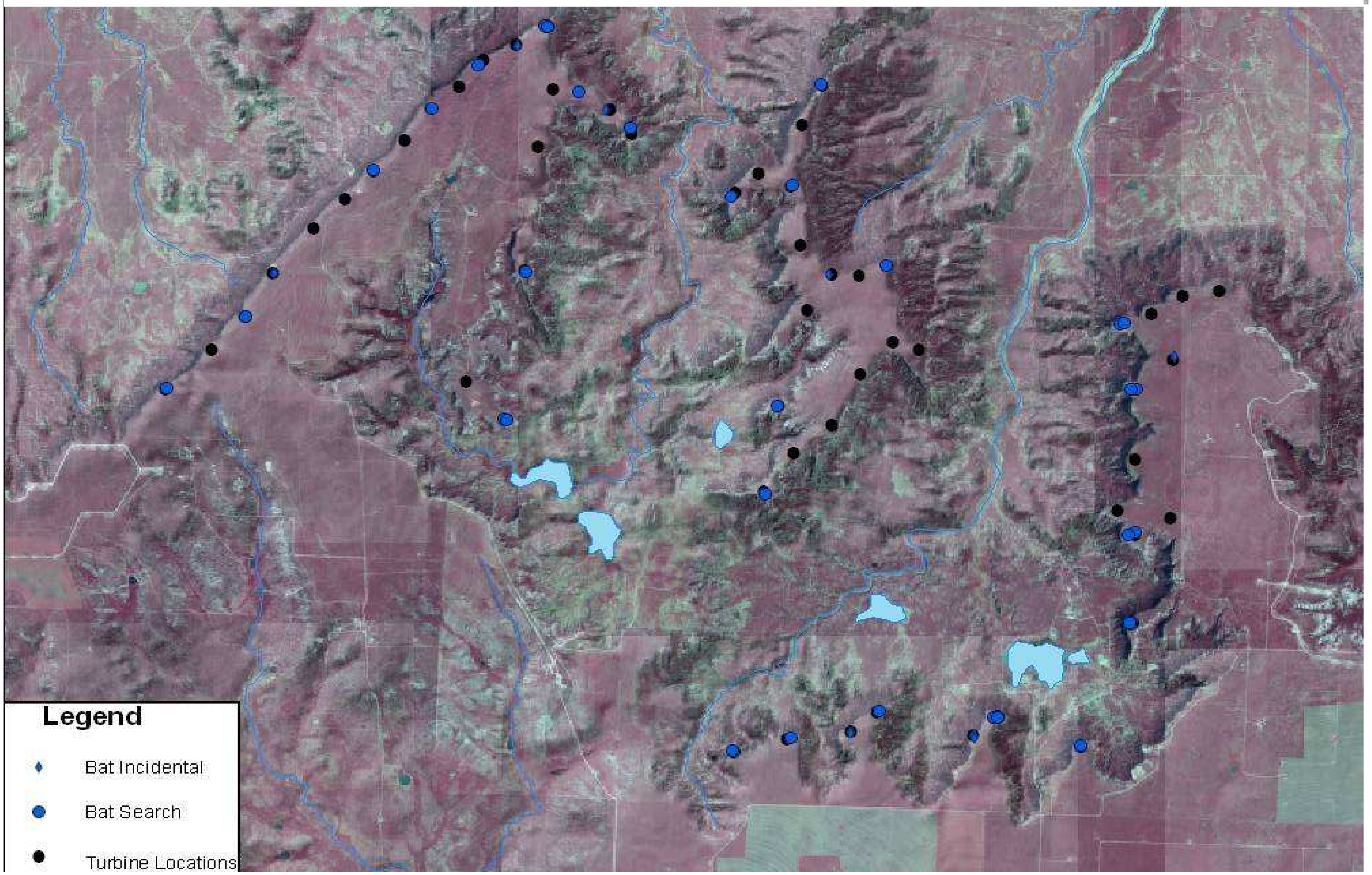


Figure 10. Distribution of bat mortalities detected from September 2006 through September 2007 at the Red Canyon Wind Energy Center



CHAPTER 4: GEOPHYSICAL CHARACTERISTICS THAT EFFECT BAT MORTALITY ALONG THE CAPROCK ESCARPMENT

ABSTRACT

Wind energy has been utilized commercially in the United States since the 1970s. Texas has the most installed wind energy generation capacity in the United States, yet no empirical data are available to assess the impact to local bat populations. Furthermore, Texas wind energy development occurs along the geologically unique Caprock Escarpment. I determined the geophysical characteristics of turbine sites and modeled the characteristics that influence bat species mortality at a utility-scale wind energy development southeast of Lubbock, TX. I determined that percent of turbine site boundary that is Caprock edge effects mortality. Investigation into bat species populations along the Caprock Escarpment, and identification of high use areas, would facilitate refinement of the model.

Key Words: wind energy, direct impacts, spatial modeling, bat species, turbine site characteristics

Wind energy development has increased in recent years due to renewed interest in renewable energy resources. Additionally, technological advances have made wind energy relatively competitive against more conventional forms of energy generation (Redlinger et al. 2002). Wind energy generation is ongoing in 25 states and the American Wind Energy Association (AWEA) predicts that 6% of the nation's energy supply will be from wind resources by 2020 (AWEA 2005). Generally considered environmentally friendly, recent studies have indicated that wind energy development is associated with negative impacts on avian and bat species. To date, no study has been conducted in the Southwestern United

States, specifically in Texas, to determine the negative impact to local bat species (Arnett et al. 2008). Currently, the state of Texas leads the nation in installed wind energy generation (AWEA 2007) and has the second highest wind energy generation potential. Thirteen studies have been conducted to determine the impacts of wind energy development on bat species, giving similar mortality estimates for on migratory, tree-roosting species and the Eastern United States. These studies indicate that bat mortality at wind energy developments is of greater magnitude than avian mortality (Durr and Bach 2004, Kunz et al. 2007, Arnett et al. 2008). Mitigation of bat direct impacts is limited due to limited knowledge of how and why bats are being killed by wind turbine generators (Larkin 2006). For this reason, intensive study of bat species migration patterns and behaviors at wind energy developments has been suggested (Arnett et al. 2008).

Geophysical characteristics of wind turbine sites may influence mortality. Ideally, post-construction mortality monitoring data could be correlated with the geophysical characteristics of wind turbine sites. Post-construction monitoring studies to assess bat mortality follow similar protocols (Anderson et al. 1999), but varying levels of search effort, small sample sizes in bias corrections of different methodology, use of avian species as surrogates for bat species in bias corrections, and low accounting of variation among habitats make definitive conclusions difficult. Previous attempts to develop such a model (Mistry and Hatfield 2006) have failed due to lack of complete and continuous data.

Concurrent to a continuous, year-long study assessing incidence and frequency of bat mortality, I quantified geophysical and ecological characteristics of wind turbine generator sites within my study site, modeled those characteristics as they relate to bat mortality, and assessed the predictive ability of the resultant model.

STUDY AREA

The study area was the Red Canyon Wind Energy Center (RCWEC) located in Borden, Garza and Scurry Counties in the southern portion of the Texas Panhandle (32º 53' N, 101º 8'W). The site is located along the edge of the Caprock Escarpment, a distinct palisade-like escarpment identified by the Ogallala group of sediments (Matthews 1969). The escarpment forms a border between the High Plains and the Rolling Central Plains. Annual precipitation is 47.4 centimeters with the highest amounts occurring in the spring and fall seasons. Average monthly temperature ranges from 8˚C to 24˚C, with June being the warmest month averaging 32˚C and December being the coolest month averaging -3˚C (NCDC 2004). The historical plant climax community on the top of the caprock consists of mixed grass, forbs, and shrubs. Dominant shrub species present are redberry juniper (*Juniperus pinchotti*), mesquite (*Prosopis glandulosa*), catclaw mimosa (*Mimosa nuttalli*), prickly pear (*Opuntia polycantha*), and hackberry (*Celtis retiulata*). The most common grasses are little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indiangrass (*Sorgastrum nutans*), and grama species (*Bouteloua* spp.) (Bell 2004). The study area is under rotational grazing management for cattle. The current plant community consists primarily of shrub stands with infrequent patches of grasses.

Development of the site was completed in May 2006 with the construction of 56 General Electric 1.5 MW wind turbine generators (WTG) and related facilities, including distribution lines, meteorological towers, transformers, roads, and an operation and management facility. The turbines are linearly arranged on three distinct mesas (Figure 11). Turbines have a hub height of 70 meters and a rotor diameter of 70 meters, resulting in rotor-swept area of 35 to 105 meters above ground. Turbines have a wind direction sensor within the hub that maneuvers the turbine into the wind, resulting in a 360-degree directional yaw. Thus, turbines have a spherical rotor-swept area of approximately 179,594 m^3 in which collision mortality may occur.

METHODS

Standardized Carcass Searches

I conducted carcass searches for 52 weeks, beginning in September 2006, on a systematic sample of 28 of the 56 turbines (Appendix A-1). Beginning with the first numbered turbine, I chose every other turbine. When the turbine string was not truly linear (i.e. turbines followed Caprock peninsulas), I chose the end turbine for sampling. I divided the study period into four 13-week seasons: 1 September – 30 November 2006 (Fall), 1 December 2006 – 28 February 2007 (Winter), 1 March – 31 May 2007 (Spring), and 1 June – 31 August 2007 (Summer). I searched all areas within a 200 meter x 200 meter square (4 ha) plot centered on sample turbines using a strip transect approach with transects located 7 meters apart. I did not search areas within 5 to 10 meters of the caprock edge due to safety concerns. I searched sample turbines every 14 days for the fall and winter seasons. I also searched 3 anemometer towers 5 times per season during this time.

At the end of the winter field season, I determined a 14 day search interval was too infrequent to account for short carcass persistence rates onsite (Miller and Boal 2008). Further, I did not detect carcasses further than 59 meters from the sample turbines (μ = 16.0). Thus, beginning with the spring field season, I decreased the search plot area to a 160 meters x

160 meters (2.6 ha) and increased searches to every 7 days. During the summer season, I further increased searches to every 3 days. During the spring and summer season, I searched meteorological towers weekly. I ranked the 28 sample turbines into three categories based on carcass detections pooled across season: each "low" mortality turbine had zero to one total carcass detections in the study period, "medium" mortality turbines had two to three total carcass detections in the study period and "high" mortality turbines had four or more carcass detections in the study period. I ranked sample turbines categorically to account for bi-modal distribution of carcass detections (i.e. few turbines had either two or three carcass detections), in analysis.

To test the developed model's accuracy, I repeated the standardized carcass searches at 14 turbines beginning October 2007 (Fall 2007). I began searches 5 October, continued searches for six weeks and ended searches on 12 November. In addition to myself, five trained observers searched turbines. The 14 turbines were chosen as a sub-sample of the original 28 sample turbines based on carcass detections from the first study period. I chose the five turbines with the greatest carcass detections (3, 4, and 6 carcass detections), the four turbines with zero bat mortality detections and a random selection of five of the remaining 19 turbines with either 1 or 2 mortality detections (Table 1). Searches were conducted over a four-day period each week. Day 1 carcass searches removed any carcasses detected within the search area. For the next 3 days, each sample turbine was searched once a day. Observers searched turbines 24 times in total.

Site Characteristics

Bat Presence-Absence

Thermal imagery studies conducted at wind energy developments in West Virginia demonstrated that bats actively interact with turbine blades (Horn et al. 2008). Further, several hypotheses have been posed suggesting that bats are attracted to wind turbine generators (Kunz et al. 2007, Horn et al. 2008, Cryan and Brown 2007). To account for bat activity at RCWEC, I conducted acoustic monitoring twice a week over a nine-week period beginning in May 2006 at the 28 original sample turbines.

To account for bat species presence-absence, I conducted active acoustic monitoring surveys using Pettersson D100 heterodyne bat detectors (Pettersson Elektronik AB, Sweden). The bat detectors were set to the 20 – 30 kHz frequency band, accounting for the peak frequency recorded for Brazilian free-tailed bats (Ratcliffe et. al. 2004) and the characteristic frequency recorded for hoary bats (O'Farrell et al. 2000). I located survey points 80 meters northeast of wind turbines (to decrease the interference associated with wind turbines) and sampled for seven minutes. Surveys began 30 minutes prior to sunset, and continued for three hours post-sunset. During each survey, I counted the number of bat calls and number of bat passes. I counted bat passes (defined here as two or more successive calls), to account for bats remaining in the survey area. I determined the average call per effort night and the average pass per effort night for each of the 28 sample turbines.

Geophysical Characteristics

I determined eleven geophysical and turbine-specific characteristics for each of the 56 turbines within the wind energy center. To describe turbine site characteristics, I defined a 200 meter radius circle centered on the wind turbine generator to be the "turbine site". I chose the 200 meter (12.5 ha) radius circle to account for over two times the length of the turbine blades (70 meter blade diameter) and the original 200 m x 200 m search area used in the standardized carcass searches. I used the geographic information system program ArcGIS 9.3 for determination of physical site characteristics (ESRI, Redlands, California). I used the digital elevation model (DEM) for Borden, Garza, and Scurry Counties (Texas Natural Resource Information System 2006). from which I generated an aspect layer, a slope layer and a contour layer for the wind energy center. I categorized the aspect polygon layer into 10 categories, including flat, based on 45º sections. I categorized the slope layer based on natural breaks in the degree distribution. The contour layer consisted of 20 meter contours beginning with a 0 meter base contour. I clipped the aspect and slope layers to the turbine site to generate summary statistics for each site.

I determined the mean aspect, the maximum slope, the mean slope, the shortest linear distance to the caprock edge and the percent of site boundary that was caprock edge. I used the Point Distance tool in the ArcGIS toolbox to determine the Euclidean distance to the nearest turbine. Using the information provided by FPL Energy, I identified the elevation of each turbine, the linear mesa that the turbine was located on, and whether the turbine had a FAA lighting feature.

Statistical Analysis

I generated a Poisson model using total 2006 – 2007 carcass detections as the response variable, and the thirteen geophysical characteristics and presence-absence index as response variables. I conducted stepwise regression on the generated model to determine the predictive variables that best correlated to bat mortality for the stepwise regression, I conducted a backward-elimination beginning with the base model including all thirteen variables. The regression analysis removed variables based on improvement in Akaike's Information Criterion (Burnham and Anderson 2002) score for the model. I conducted a post-hoc inspection of the best-fit model to assess predicted values and coefficients for biological suitability and relevance. I validated the model using the carcass detections from Fall 2007. Statistical analysis was conducted in Program R (R Development Core Team 2007).

RESULTS

Standardized Carcass Searches

I conducted a total of 1,442 standardized carcass searches at sample turbines and 110 standardized carcass searches at anemometer towers during the 2006-7 study period. I found carcasses beneath 24 of the 28 (86 percent) search turbines. The maximum number of carcasses detected at any one turbine during standardized carcass searches was 6 mortalities each at two turbines on the East Mesa (Table 15). The average distance of bat mortalities located to the nearest turbine was 16 meters (SEM = 1.94meters, Figure 12).

During Fall 2007 study period, I conducted a total of 336 carcass searches at the 14 sub-sample turbines. I found carcasses under 7 of the 14 sub-sample turbines (50 percent). The maximum number of carcasses detected at any one turbine during a single standardized carcass search was 2, which was located at WTG 21 and WTG 51, though the greatest total of carcasses was found under a single turbine was 9 (Table 16). The average distance bat carcasses to the nearest turbine was 18 meters (SEM = 3.58).

Site Characteristics

Inclusion of all thirteen variables did not significantly effect carcass detections (ANOVA F = 2.14, d.f. = 11, 15, P = 0.13); however, lighting (ANOVA F = 6.15, d.f. = 1,15, P = 0.03) and elevation (ANOVA F = 6.21, d.f. = 1, 15, P = 0.02) are significant partial coefficients. The backward-elimination stepwise regression indicates the best-fit model includes elevation of turbine (t = 2.35, P = 0.03), aspect (t = 2.20, P = 0.04), percent of turbine site boundary that is caprock edge (t = 2.52, P = 0.02), and lighting (t = 2.18, P = 0.04). Bat mortality (i.e. carcass detection) is a function of decreasing elevation, increasing aspect (i.e. becoming more western), percent of caprock edge within the turbine site and turbine lighting (ANOVA F = 4.83, d.f. = 4, 22, P = 0.006). Review of the correlation matrix indicates high correlation between percent of turbine site boundary that is caprock edge and lighting; inclusion of lighting into the model may be due to chance alone.

For each mortality category, I determined descriptive values for each of the best-fit variables. High mortality turbines (i.e. greater than four carcass detections) are southwest-facing turbines less than 853 meters in elevation with greater than 38 percent caprock edge within the turbine site boundary. Medium mortality turbines (i.e. two to three carcass detections) are south-facing turbines between 853 and 865 meters in elevation with between 34 and 38 percent of the site boundary as caprock edge. Low mortality turbines (i.e. zero to one carcass detections), are southeast-facing turbines greater than 865 meters in elevation that have less the 34 percent of the site boundary as caprock edge.

I validated the best-fit model generated by the 2006-2007 data with the carcass detections at the sub-sample 14 turbines in fall 2007. The 2006 – 2007 predictive model did not correctly predict the observed fall 2007 carcass detections; thus, I conducted an additional stepwise regression analysis to determine the best-fit model for the fall 2007 carcass detections. The best-fit model for Fall 2007 carcass detections at the 14 sample turbines included only percent of turbine site boundary that is caprock edge (t = 1.65, P = 0.13); however, neither the percent of the turbine site boundary that is caprock edge or overall model significantly effected carcass detection (ANOVA F =2.71, d.f. = 1, 12, P =0.013).

DISCUSSION

For the 2006 - 2007 study period, carcass detection (i.e. mortality) is a function of decreasing elevation. Study of incidence and frequency of mortality at Red Canyon Wind Energy Center indicates that there is no difference in carcass detections between the three linearly distinct mesas, although a high percentage of carcass detections occurred on the East Mesa (Miller and Boal 2008). A slight elevational gradient exists across the wind energy center; elevations decrease 15 meters in a west to east direction. However, the effect of elevation was relatively small. Although statistically significant, it is difficult to conclude that elevation is biologically relevant to carcass detection.

For the 2006 – 2007 study period, carcass detection (i.e. mortality), is a function of increasing aspect (i.e. turbines with a more western aspect) have greater mortalities. Turbines at RCWEC are linearly arranged along three distinct mesas, and are placed in a manner to capture the most wind. Generally, the wind at the RCWEC comes from southwestern-western direction. There are two possible explanations for the relationship between a more western aspect and carcass detection. First, turbines with a more western aspect would capture more wind, turn more frequently as a result and increase the likelihood of collision mortality as a result of turning more frequently. Secondly, bat species may utilize the wind currents to reduce effort in flight, encounter turbines that are faced in a more western aspect, and increase likelihood of collision mortality at those turbines. However, studies at other wind energy developments with high bat collision mortality indicate highest mortality occurs on low wind nights (Arnett et al. 2008). To further investigate the relationship between wind patterns, aspect of turbine sites, and collision mortality, and assessment of energy output of wind turbine generators and the relationship to collision mortality should be initiated. At the time of analysis, this information was not available to me. Under my search protocol, it is difficult to determine the exact weather patterns at the time of collision mortality. However, average energy output of the wind turbine generator can serve as a surrogate and the relationship between wind pattern, turbine site aspect, and collision mortality can be refined.

Carcass detection (i.e. mortality) is a function of percent of the turbine site boundary that was Caprock edge. Wind turbine generators with the high percent of site boundary that was Caprock edge tended to be turbines on the end of linear strings or discontinuous turbines with no turbines nearby. These turbines also are the turbines that generally received FAA lighting structures, a fact illustrated by the high correlation between the percent Caprock edge in the turbine site boundary and turbine lighting. Brazilian free-tailed bats were the highest percentage of species detected as collision mortalities during the study period (Miller and Boal 2008). Brazilian free-tailed bats are cavity roosters which use caves and crevices (Davis et al. 1962). Large colonies of free-tailed bats are found along the northern portions of the Caprock Escarpment walls (Tuttle 2003). Those turbines with high percentage of site boundary that is Caprock edge may have an increased likelihood of collision mortalities as a result of bat species utilizing the Caprock Escarpment walls as roost sites. However, little is known about the roosts sites within southern Caprock Escarpment region. To further refine the relationship between potential roost sites along the Caprock Escarpment, percent of turbine site boundary that is Caprock edge, and collision mortality, a survey of bat populations and identification their roosts within the region maybe beneficial.

The 2006 - 2007 study year carcass detections were affected by turbine elevation, aspect of turbine site, percent of turbine site boundary that was Caprock edge, and the lighting of the turbine. In contrast, the fall 2007 carcass detections were affected only by percent of turbine site boundary that was Caprock edge. Temporal variation in mortality category, that is high mortality turbines based on 2006 - 2007 carcass detections becoming low mortality turbines in Fall 2007, suggets that mortality patterns may be temporally variable. Concurrent acoustic monitoring at the Red Canyon Wind Energy Center in fall 2007 indicated a high activity of bats on-site (Miller and Boal 2007). The temporal variation in mortality cannot be explained by geophysical, turbine-specific site characteristics alone; rather, the temporal variation in mortality could be a factor of bat ecology that is unaccounted for by this study. The consistency of the effect of the percent of turbine site boundary that is Caprock edge on carcass detection, as discussed above, is suggestive of biological relevance. Further investigation of bat species use of the Caprock Escarpment region, including presence of roost sites, can refine the model.

CONCLUSION

In conjunction with a collision mortality study, this study is one of the first post-construction monitoring studies conducted on a wind energy development in Texas and the Southwestern United States. I determined the geophysical characteristics of turbine sites within a utility-scale wind energy center along the Caprock Escarpment and assessed the effect of those characteristics on bat mortality based on carcass detections. Based on the combined 2006 -

2007 study year and fall 2007 season models, it appears that percent of the turbine site boundary that is Caprock edge effects bat mortality. The temporal variations in turbine mortality category and predictor variables indicate a need for further investigation into bat species mortality at wind energy developments within this region.

Potential negative impacts between wind energy development and bat species are relatively new areas of study. While Texas offers wind resources that make energy development profitable, the Southern Panhandle and Caprock Escarpment is a region with large populations of bat species detected in low numbers in previous post-construction mortality monitoring studies. The model developed above would be a useful tool in planning and development of future wind energy sites along the Caprock Escarpment. Future research within the region to identify the long-term environmental impacts of wind energy development should identify high use areas and utilize the observed relationship between site characteristics and negative impacts.

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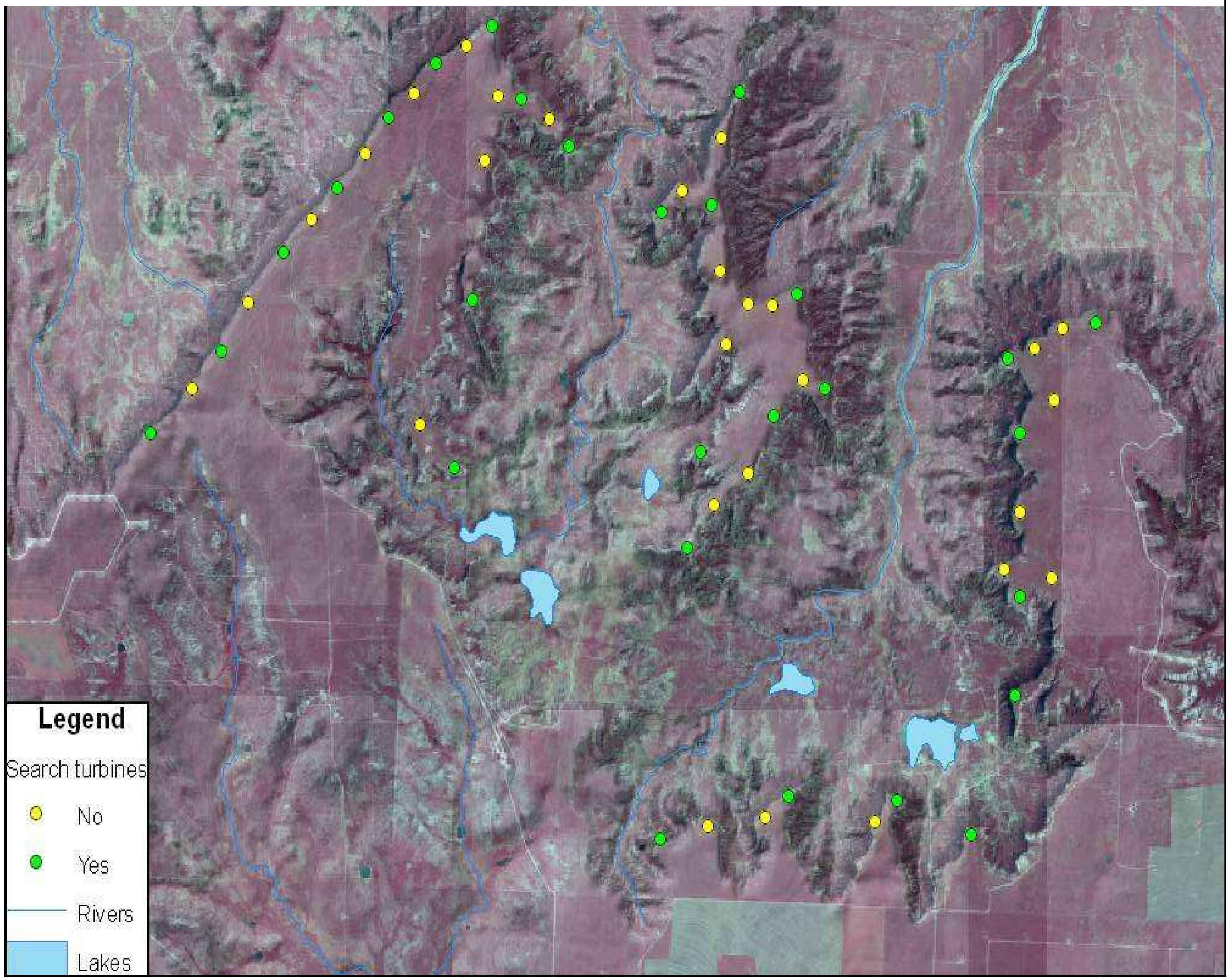
Table 15. List of turbines and numbers of bat mortalities detected in standardized search plots from September 2006 through September 2007.

Turbine	# Mortalities	Turbine	# Mortalities
WTG 1	1	WTG 34	1
WTG 3	2	WTG 35	1
WTG 5	0	WTG 38	1
WTG 7	1	WTG 39	2
WTG 9	1	WTG 42	1
WTG 11	1	WTG 44	6
WTG 13	4	WTG 45	2
WTG 15	1	WTG 46	6
WTG 17	1	WTG 48	2
WTG 19	1	WTG 51	3
WTG 21	3	WTG 53	1
WTG 22	1	WTG 56	0
WTG 25	2		
WTG 26	0	Anemometer 1	0
WTG 28	0	Anemometer 2	0
WTG 32	2	Anemometer 3	0

Table 16. List of turbines and numbers of bat mortalities detected in standardized search plots from October to December 2007.

Turbine	# Mortalities
WTG 5	1
WTG 11	1
WTG 13	1
WTG 19	0
WTG 21	9
WTG 22	1
WTG 26	0
WTG 28	0
WTG 34	0
WTG 42	0
WTG 44	1
WTG 46	0
WTG 51	4
WTG 56	0
Total	18

Figure 11. Location of sampled wind turbine generators at Red Canyon Wind Energy Center.



APPENDICES

APPENDIX A-1. List of Red Canyon Wind Energy Center turbines sampled during the standardized searches from September 2006 through November 2007.

Count	Turbine ID	Mesa	Turbine Position
1	WTG 1	West	E
2	WTG 3	West	M
3	WTG 5	West	M
4	WTG 7	West	M
5	WTG 9	West	M
6	WTG 11	West	M
7	WTG 13	West	E
8	WTG 15	West	M
9	WTG 17	West	E
10	WTG 19	West	E
11	WTG 21	West	E
12	WTG 22	Central	E
13	WTG 25	Central	E
14	WTG 26	Central	E
15	WTG 28	Central	E
16	WTG 32	Central	E
17	WTG 34	Central	E
18	WTG 35	Central	D
19	WTG 38	Central	E
20	WTG 39	East	E
21	WTG 42	East	E
22	WTG 44	East	E
23	WTG 45	East	E
24	WTG 46	East	E
25	WTG 48	East	E
26	WTG 51	East	D
27	WTG 53	East	E
28	WTG 56	East	E

[A] Turbine Position: E=end-row, D=discontinuous, M=mid-row

APPENDIX A-2. Sample Completed Avian Casualty Report.

Casualty Report		
Date:	09-03-07	
Time:	0945	
Type of Find:	Search	
Specimen Number[a]:	090307-38C-AM-tuvu-01	
Tower Number:	38C	
GPS Coordinates:	E 0292768	N 3651356
Bearing to Turbine:	134	
Distance to Turbine:	31m	
Condition:	Scavenged	
Age/Sex:	Unknown, unknown	
Estimated Time on Site:	> 2 days	
Scavenging Evidence:	Lower torso removed, insects present	
Temperature:	73 F	
Weather Conditions:	Clear, light wind	
Photographs:	A, B	
Deposition:	Removed from site	
Notes:	Impact at mid-torso? Appears sheered in half	

[a] AM = Amanda Miller

APPENDIX A-3. Sample Completed Bat Casualty Report

Casualty Report		
Date:	091406	
Time:	0845	
Type of Find:	Search	
Specimen Number[a]:	091706-22C-AM-mxft-01	
Tower Number:	22C	
GPS Coordinates:	E 292277	N 3647505
Bearing to Turbine:	6	
Distance to Turbine:	23m	
Condition:	Partial	
Age/Sex:	Unknown/unknown	
Estimated Time on Site:	> 7 days	
Scavenging Evidence:	Ants present	
Temperature:	73 F	
Weather Conditions:	Clear, light wind	
Photographs:	A, B, C	
Deposition:	Collected	
Notes:	Impact at mid-torso? Appears sheered in half	

[a] AM = Amanda Miller

APPENDIX B – 1. List of avian mortalities detected during standardized carcass searches from September 2006 through September 2007.

Specimen Number[a]	Date	Species	Deposition
091706-48E-AO-unsp-01	9 /17/2006	Unknown Bird	Collected
091706-51E-AO-tuvu-01	9 /17/2006	Turkey Vulture	Collected
092306-34C-CR-modo-01	9 /23/2006	Mourning Dove	Collected
092906-39E-AO-nobo-01	9 /29/2006	Northern Bobwhite	Collected
100606-34C-AO-grro-01	10/6 /2006	Greater Roadrunner	Collected
101306-28C-AO-grro-01	10/13/2006	Greater Roadrunner	Collected
101306-51E-AO-rtha-01	10/13/2006	Red-tailed Hawk	Collected
102006-19W-AO-tuvu-01	10/20/2006	Turkey Vulture	Collected
110306-35C-CR-grro-01	11/3 /2006	Greater Roadrunner	Collected
110306-35C-CR-grro-02	11/3 /2006	Greater Roadrunner	Collected
111006-56E-CR-tuvu-01	11/10/2006	Turkey Vulture	Removed
111806-5W-AO-nomo-01	11/18/2006	Northern Mockingbird	Collected
111806-7W-AO-nobo-01	11/18/2006	Northern Bobwhite	Collected
111806-AN2-AO-ghow-01	11/18/2006	Great Horned Owl	Collected
112506-45E-AO-tuvu-03	11/25/2006	Turkey Vulture	Collected
112506-51E-AO-tuvu-01	11/25/2006	Turkey Vulture	Collected
112506-51E-AO-tuvu-02	11/25/2006	Turkey Vulture	Collected
112506-51E-AO-blja-01	11/25/2006	Blue Jay	Collected
120806-45E-CR-tuvu-01	12/08/2006	Turkey Vulture	Collected
121406-35C-CR-grro-01	12/14/2006	Greater Roadrunner	Collected
011207-11W-AO-nobo-01	01/12/2007	Northern Bobwhite	Collected
030307-15W-MD-nobo-01	03/03/2007	Northern Bobwhite	Collected
030907-51E-MD-tuvu-01	03/09/2007	Turkey Vulture	Collected
031007-7W-AO-nobo-01	03/10/2007	Northern Bobwhite	Collected
090307-38C-AM-tuvu-01	09/03/2007	Turkey Vulture	Collected

[a] AO/AM = Amanda Miller, CR = Colton Rose, MD = Mark Davis

APPENDIX B – 2. List of avian mortalities detected incidental to standardized carcass searches from September 2006 through September 2007.

Specimen Number[a]	Date	Species	Deposition
083106-41E-AO-modo-01	08/31/2006	Mourning Dove	Collected
083106-41E-AO-modo-02	08/31/2006	Mourning Dove	Collected
083106-4W-AO-tuvu-01	08/31/2006	Turkey Vulture	Removed
090706-18W-AO-tuvu-01	09/08/2006	Turkey Vulture	Removed
031007-12W-AO-baow-01	03/10/2007	Barn Owl	Collected

[a] AO/AM = Amanda Miller, CR = Colton Rose, MD = Mark Davis

APPENDIX B – 3. List of bat mortalities detected during standardized carcass searches from September 2006 through September 2007.

Specimen Number[a]	Date	Species
091706-22C-AO-mxft-01	9 /17/2006	Brazilian Free-tail
091706-48E-AO-mxft-02	9 /17/2006	Brazilian Free-tail
091706-48E-AO-mxft-03	9 /17/2006	Brazilian Free-tail
091706-53E-AO-mxft-01	9 /17/2006	Brazilian Free-tail
100606-11W-CR-mxft-05	10/6 /2006	Brazilian Free-tail
100606-13W-CR-mxft-02	10/6 /2006	Brazilian Free-tail
100606-13W-CR-mxft-03	10/6 /2006	Brazilian Free-tail
100606-13W-CR-mxft-04	10/6 /2006	Brazilian Free-tail
100606-21W-AO-mxft-07	10/6 /2006	Brazilian Free-tail
100606-34C-AO-mxft-01	10/6 /2006	Brazilian Free-tail
100606-7W- CR-mxft-06	10/6 /2006	Brazilian Free-tail
100706-15W-AO-mxft-01	10/7 /2006	Brazilian Free-tail
100706-35C-CR-mxft-02	10/7 /2006	Brazilian Free-tail
101206-44E-AO-mxft-03	10/12/2006	Brazilian Free-tail
101206-44E-AO-mxft-04	10/12/2006	Brazilian Free-tail
101206-44E-AO-mxft-05	10/12/2006	Brazilian Free-tail
101206-44E-AO-mxft-06	10/12/2006	Brazilian Free-tail
101206-44E-AO-mxft-07	10/12/2006	Brazilian Free-tail
101206-45E-AO-mxft-08	10/12/2006	Brazilian Free-tail
101306-32C-AO-mxft-01	10/13/2006	Brazilian Free-tail
101306-32C-AO-mxft-02	10/13/2006	Brazilian Free-tail
101306-39E-AO-mxft-07	10/13/2006	Brazilian Free-tail
101306-39E-AO-mxft-08	10/13/2006	Brazilian Free-tail
101306-42E-AO-mxft-09	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-01	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-02	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-03	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-04	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-05	10/13/2006	Brazilian Free-tail
101306-46E-AO-mxft-06	10/13/2006	Brazilian Free-tail
102006-3W-CR-mxft-01	10/20/2006	Brazilian Free-tail
110306-9W-AO-reba-01	11/03/2006	Red Bat
040607-25C-AO-mxft-01	04/06/2007	Brazilian Free-tail
051707-25C-AO-mxft-01	05/17/2007	Brazilian Free-tail
051707-3W-AO-mxft-02	05/17/2007	Brazilian Free-tail
060507-38C-MD-mxft-02	06/05/2007	Brazilian Free-tail
060507-53E-AO-mxft-01	06/05/2007	Brazilian Free-tail
060807-13W-MD-mxft-01	06/05/2007	Brazilian Free-tail
061007-17W-AO-mxft-03	06/10/2007	Brazilian Free-tail
061007-19W-AO-mxft-02	06/10/2007	Brazilian Free-tail
061007-21W-MD-mxft-01	06/10/2007	Brazilian Free-tail
061107-45E-MD-hoba-01	06/11/2007	Hoary Bat
070307-1W-AM-mxft-02	07/02/2007	Brazilian Free-tail
070307-21W-AM-mxft-01	07/03/2007	Brazilian Free-tail
071007-44E-AM-mxft-01	07/10/2007	Brazilian Free-tail
090107-51E-MD-hoba-01	09/01/2007	Hoary Bat
090107-51E-MD-mxft-01	09/01/2007	Brazilian Free-tail

[a] AO/AM = Amanda Miller, CR = Colton Rose, MD = Mark Davis

APPENDIX B – 4. List of bat mortalities detected incidental to standardized carcass searches from September 2006 through September 2007.

Specimen Number[a]	Date	Species
083106-41E-AO-wepi-01	08/31/2006	Western Pipistrelle
083106-4W-AO-mxft-01	08/31/2006	Brazilian Free-tail
010507-43E-AO-hoba-01	01/05/2007	Hoary Bat
100506-12W-AO-mxft-01	10/05/2006	Brazilian Free-tail
100606-52E-AO-hoba-01	10/06/2006	Hoary Bat
101206-43E-AO-mxft-01	10/12/2006	Brazilian Free-tail
101206-43E-AO-mxft-02	10/12/2006	Brazilian Free-tail
042807-16W-AO-mxft-01	04/28/2007	Brazilian Free-tail
051107-30C-AO-hoba-01	05/11/2007	Hoary bat

[a] AO/AM = Amanda Miller, CR = Colton Rose, MD = Mark Davis

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