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Bird and Bat Collision Risks & Wind Energy Facilities

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Preface

Over the past few years, the Inter-American Development Bank (IDB) has seen its portfolio of wind power projects increase substantially, and this trend is expected to continue. This report is intended to provide expert guidance to the IDB regarding wind-wildlife risk issues, and to ensure that environmental impact considerations are sufficiently incorporated into IDB's wind energy projects. Guidance is provided in 3 specific areas, corresponding to the 3 chapters of this report, as follows:

Efficacy of bird and bat impact minimization/mitigation measures (Chapter 1). This chapter is intended as a review of the effectiveness of various measures that have been implemented at wind energy facilities to reduce wildlife fatalities. The emphasis of this chapter is on synthesizing empirical evidence supporting the effectiveness of the different measures, and the applicability of each measure to IDB's wind energy projects. This chapter was prepared by Julia Willmott (birds), E. Allison Costello (bats), and Caleb Gordon.

Efficacy of preconstruction collision risk prediction models (Chapter 2). This chapter is intended as an evaluation of the value of preconstruction collision risk modeling, as a tool to predict bird and/or bat fatality rates at wind energy facilities prior to construction. The emphasis of this chapter is on empirical support for the prediction accuracy of existing models, as demonstrated by validation studies in which preconstruction predicted fatality rates are compared with observed postconstruction fatality rates. This chapter was prepared by Greg Forcey and Caleb Gordon, with input from a variety of wind-wildlife modeling experts who responded to a wind-wildlife collision risk modeling accuracy survey questionnaire developed for this review.

Postconstruction fatality monitoring protocols for birds and bats (Chapter 3). This chapter is intended to provide a standardized protocol and methodology for the monitoring of bird and bat fatalities of wind energy projects in operation. Essential considerations in developing this protocol include scientific validity, robustness, and comparability of data across projects, and also feasibility for application to IDB's wind energy projects. This chapter was prepared by Caleb Gordon and Sean Casto, with helpful discussion and commentary on an earlier draft provided by Drs. Amanda Hale and Victoria Bennett of Texas Christian University.

Contents

List of Tables

Acronyms and Abbreviations

APWRA	Altamont Pass Wind Resource Area
BACI	before-after control-impact
CEC	California Energy Commission
FAA	Federal Aviation Administration
IDB	Inter-American Development Bank
MMO	Marine Management Organization
MDB	multilateral development bank
NAS	National Academy of Science
NWCC	National Wind Coordinating Collaborative
NYDEC	New York Department of Environmental Conservation
ODNR	Ohio Department of Natural Resources
OMNR	Ontario Ministry of Natural Resources
PGC	Pennsylvania Game Commission
PWEA	Polish Wind Energy Association
SCRAM	spatial collision risk assessment model
USFWS	U.S. Fish and Wildlife Service

1 Effectiveness of Mitigation Measures for Reducing Direct Mortality of Birds and Bats at Wind Energy Facilities, and Recommendations for Application to Latin America

1.1 Introduction

Both birds and bats are known to have fatal collisions (or near collisions) with turbines at wind energy facilities. Bird collision rates are typically very low, an average of 2.96 birds/MW/year in the U.S. (NAS 2007), although under some circumstances for some bird taxa, higher rates or collision patterns of conservation concern are possible. Collision rates for certain bat taxa are known to exceed normal bird collision rates, in some regions outnumbering bird fatalities 10 to 1 (Barclay et al. 2007).

Ever since wildlife collision risk was identified as an issue at wind energy facilities, measures to reduce, avoid, and mitigate these impacts have been sought. Solutions are typically driven by understanding of the factors that contribute to the susceptibility of particular bird and bat taxa to collision mortality. The focus of this chapter is to evaluate the effectiveness of bird and bat collision mitigation measures that are currently available, and to assess their effectiveness for application to Latin American wind energy facilities. The emphasis of this evaluation is on empirical support for the effectiveness of various measures, as opposed to purely hypothetical or unsubstantiated effectiveness.

1.2 Curtailment of Wind Turbine Operation

1.2.1 Birds

Bird collision mortalities at wind farms are typically very low (see section 1.1), hence the curtailment of wind turbine operation to reduce bird collision mortality has not been widely recommended, tested, or implemented worldwide. As with bats, bird collision mortality problems are highly species-specific (NAS 2007), and can typically only be reliably identified with post-construction mortality monitoring (Ferrer et al. 2012). In several specific cases where potentially significant bird collision mortalities have been detected or predicted at wind energy facilities, various operational curtailment strategies have been implemented as a means of reducing bird collision mortality. Such cases include the La Venta II facility in Oaxaca, Mexico, several wind facilities along the Gulf of Mexico coast in Texas, the Altamont Pass wind energy facility in California, the El Zayt Gulf facility in Egypt, and various facilities in Spain. Of these, data that can be used to assess the effectiveness of the operational curtailment are only available for Spain and California.

The La Venta II facility in Oaxaca, Mexico has always implemented operational shutdowns of all turbines during episodes when large numbers of migrating raptors are observed approaching the wind facility, and post-construction fatality monitoring data have demonstrated zero, or negligible collision mortality rates for migratory raptor species at this site (Patraca 2010, Comision Federal de Electricidad 2008, 2009, 2011). However, there are no post-construction fatality rate data either from this facility prior to the implementation of the operational curtailment strategy, or from other nearby facilities that do not implement operational curtailment of wind turbines for migrating raptors, hence it is not clear how many raptor deaths are being avoided by the operational curtailment implemented at the La Venta II facility, if any.

In fact, the possibility of significant susceptibility of migrating raptors to wind turbine collisions in the Americas currently remains purely speculative and hypothetical, as no such impacts have yet been documented. In the US National Academy of Science's (NAS) 2007 review of the environmental impacts of wind power generation in the US, post-construction bird/bat fatality data were included for 2 wind facilities located along ridge tops in the Appalachian mountains, within the most significant raptor migration corridor in the eastern US. These 2 facilities produced among the lowest measured raptor collision rates of any US wind facilities, with 0.00 and 0.02 raptor fatalities estimated per megawatt per year at Buffalo Mountain, Tennessee and Mountaineer, West Virginia, respectively. While these results are suggestive of generally low collision susceptibility for migrating raptors, these studies were not designed specifically to examine migratory raptor impacts, and further study is needed to shed light on this issue.

At the Altamont Pass Wind Resource Area (APWRA) in California, where potentially significant mortality has been documented in Golden Eagles and a handful of other resident raptor species (Orloff and Flannery 1992), some experimentation with temporary (monthly) wind turbine shut-downs has been conducted (Smallwood 2010). Post-implementation analysis has suggested that collision rates were lowered in some of the months with partial shutdowns, although the variable shutdown design made this trend difficult to quantify and was only relevant for some species. For example, there was no net collision mortality benefit for Red-tailed Hawk, and the conclusion drawn was that because monthly patterns of fatality rates vary among species, no particular seasonal shutdown of turbines would uniformly benefit all species (Smallwood 2010).

In Spain, where wind turbine mortality rates observed for Griffon Vulture have caused concern, operational curtailment strategies targeted specifically at certain turbines, landscape features, and time periods identified as problematic through post-construction fatality studies, have proven effective at reducing collision mortality for this species (Camiña 2011; Muriel et al. 2011; Ferrer et al. 2012; Martinez et al. 2012; de Lucas et al. 2012). Studies in Castellon, Spain, involved a 50-turbine shutdown of turbines placed directly in front of a foraging site (landfill). Cessation of turbine operation resulted in a 50% to 60% reduction in observed vulture mortality (Martinez et al. 2012). In a study in northern Spain where 33 out of 267 (12%) turbines identified as having comparatively higher vulture collision rates were shut down, observed vulture collision mortality dropped by approximately 36% (Camiña 2011).

In the Tarifa region of southern Spain, the complexion of the issue is somewhat different, as this region has seen the development of a large number of utility-scale wind energy facilities within 1 of the most important bird migratory corridors in Europe, where the bulk of the Iberian Peninsula's Griffon Vulture population joins hundreds of thousands of other Palearctic-Paleotropical migrating birds to pass across the Mediterranean Sea across the Straits of Gibraltar as they travel semiannually between Europe and Africa. One emergent result from post-construction studies of bird mortality at wind farms in the Tarifa region is that even though many bird species migrate through this region in large numbers, very few bird species are killed at Tarifa wind energy facilities at potentially significant rates. Ferrer et al. (2012) presented data from 1to 3 years of every-day, every-turbine fatality monitoring conducted at 20 wind energy facilities, collectively containing 252 wind turbines in this region, and demonstrated that the overall bird mortality rate was low, 1.33 birds per turbine per year. Griffon Vulture (138 fatalities) and Calandra Lark (45 fatalities) were the only species with more than 25 observed fatalities in this study, despite heavy migrant bird passage of many bird species recorded at these farms during the study (291,278 birds passing through in 7,267 total observation hours, or 40.08 birds/hour average for the entire study). The low observed mortality rates for high-volume Tarifa migrant species such as White Stork and Black Kite clearly demonstrate the species-specificity of migrant bird susceptibility to wind turbine collisions.

An experimental Griffon Vulture fatality reduction study conducted in the Tarifa region has produced the only example worldwide of a highly effective operational curtailment strategy for reducing bird collisions with wind turbines (de Lucas et al. 2012). This study employed a before-after, control-impact (BACI) design, and encompassed 13 wind energy facilities in the Tarifa region, containing a total of 296 turbines. They developed a highly targeted operational curtailment strategy in which operation of the 10 turbines that had been identified through post-construction monitoring as producing the highest Griffon Vulture mortality was curtailed only during the highest risk season (fall migration: October and November), and only during the highest risk wind conditions (days with higher than average easterly wind speeds). By implementing this operational curtailment strategy, Griffon Vulture collision mortality was reduced by 55%, with a sacrifice of only 0.07% of total annual electricity generation.

Recommendations for Latin American Wind Energy Facilities

1) Implement post-construction monitoring to determine where operational curtailment might be necessary to reduce problematic bird mortality rates. One of the most distinct emergent patterns from studies of bird mortality at wind energy facilities worldwide is that collision susceptibility is highly taxon-specific. Furthermore, overall bird mortality rates are low worldwide, and very few species are affected at greater than trace levels. Even where potentially concerning bird collision impacts with wind turbines have been hypothesized to occur within Latin America, such as with Nearctic-Neotropical migrant raptors moving semiannually through the great Central American migration corridor, no impacts have yet been documented. Before effective mortality reduction or mitigation solutions can be developed for Latin America, post-construction collision monitoring must be conducted to describe the nature and extent of any bird collision mortality impacts that are discovered. This information will direct the search for any operational curtailment, or other mortality reduction/mitigation measures that might be necessary.

2) If any significant wind turbine collision impacts are discovered at Latin American wind facilities, develop highly targeted operational curtailment strategies and conduct experiments to evaluate their effectiveness. De Lucas et al.'s (2012) study on Griffon Vultures at wind facilities in the Tarifa region of Spain demonstrated the value of using a fine-toothed analysis of post-construction mortality data to develop a highly targeted, species-specific operational curtailment strategy, and then using experimentation to document the effectiveness of the strategy. If any potentially significant collision mortality impacts are discovered for birds at Latin American wind energy facilities, post-construction monitoring data should be used in a similar manner to develop operational curtailment strategies that are likely to be effective at reducing collisions with wind turbines for the affected species, and similar experimental studies should be conducted to assess the effectiveness of these strategies.

1.2.2 Bats

A variety of recent studies have indicated that increasing the cut-in speed[1] of wind turbines, and elimination of "freewheeling[2]" below cut-in speeds, can result in significant reductions in the mortality of Vespertilionid bats in the genera *Lasiurus* and *Lasionycteris*. Baerwald et al. (2009) conducted an experimental study in southwestern Alberta, Canada during the peak of fall hoary and silver-haired bat migration activity and demonstrated that fatality rates for these species could be reduced by between 50% and 70% by increasing the cut-in speed from 4.0m/s to 5.5 m/s. In a similar experiment conducted at the Casselman wind energy facility in Somerset County, Pennsylvania, Arnett et al. (2011) demonstrated that bat fatalities (primarily *Lasiurus* and *Lasionycteris*) could be reduced by 72% by increasing the cut-in speed from 3.5 m/s to either 5.0 or 6.5 m/s, with no significant difference observed between the 5.0 m/s and 6.5 m/s treatments. At the Fowler Ridge wind energy facility, located in primarily agricultural habitat in Indiana, Good et al. (2011) produced a 50% reduction in bat mortality (primarily *Lasiurus* and *Lasionycteris*) by increasing the cut-in speed from 3.5 m/s to 5.0 m/s, and a 78% reduction in bat mortality by further increasing the cut-in speed to 6.5 m/s.

Even higher reductions in bat mortality were achieved at the Fowler Ridge facility when blades were feathered rather than allowed to "freewheel" below the cut-in speed, with 36.3%, 56.7%, and 73.3% bat fatality reductions at cut-in speeds of 3.5 m/s, 4.5 m/s, and 5.5 m/s, respectively, compared to the control group of turbines that were allowed to freewheel (Good et al. 2012). Young et al. (2011) also demonstrated the benefits of blade feathering in an experimental study during the fall bat migration season at the Mount Storm wind energy facility in West Virginia, producing 73% and 50% reductions in bat mortality (primarily *Lasiurus* and *Lasionycteris*) when blades were feathered rather than allowed to freewheel below the cut-in speed (4.0 m/s) during the first half or the second half of the night, respectively.

There is little evidence of the effectiveness of operational curtailment for reducing wind turbine related mortality in bats outside of the genera *Lasiurus* and *Lasionycteris*. This is primarily because mortality rates of bats at US wind energy facilities are typically very

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[1] Cut-in speed is the lowest wind speed at which the rotor blades are generating electricity for the grid.

[2] Freewheeling is when turbines are not generating electricity (i.e. below cut-in speed) but blades are still positioned to catch the wind, hence some rotor spinning may occur at wind speeds lower than the cut-in speed. At the Fowler Ridge facility, it was noted that Vestas turbines exhibit a higher degree of freewheeling than do GE or Clipper turbines, and this was hypothesized as an explanation for higher bat mortality observed at Vestas Turbines at this facility (Good et al. 2012). Freewheeling is eliminated when blades are feathered at wind speeds below the cut-in speed, which entails orienting the blades such that they do not catch the wind and cause the rotor to spin.

low for all other bats in North America (Kunz et al. 2007). Molossid bats in the genus *Tadarida* represent 1 possible exception to this pattern, as 1 study from Oklahoma suggested that mortality rates could be significant for bats in this primarily tropical and warm temperate genus. To the extent that collision susceptibility in *Tadarida* bats is a problem, there is no information available on whether or not the types of operational curtailment strategies that have proven effective for *Lasiurus* and *Lasionycteris* would be effective for *Tadarida*. In fact, the marginal cut-in speed increases that have proven successful for reducing mortalities of *Lasiurus* and *Lasionycteris* bats may be unlikely to succeed because *Tadarida* and other Molossid bats tend to be stronger and faster flyers than are *Lasiurus* and *Lasionycteris*. Whereas *Lasiurus* and *Lasionycteris* activity drops off sharply at moderate wind speeds, resulting in a significant reduction in exposure to spinning rotors operating under marginal cut-in speed increases, Molossids, including *Tadarida*, tend to remain active at moderate wind speeds (Normandeau Associates, unpublished data), hence marginal cut-in speed increases would not result in significant reductions in exposure of these bats to spinning wind turbine rotors.

Recommendations for Latin American Wind Energy Facilities

1) <u>Implement post-construction monitoring to determine where operational curtailment might be necessary to reduce problematic bat mortality rates</u>. One of the most distinct emergent patterns from North American studies of bat mortality at wind energy facilities is that collision susceptibility is highly taxon-specific. Although the reasons for this are not well-understood, it is clear that different species, even within the same family (Vespertilionidae, for most bats in the US), have very different levels of collision susceptibility (Kunz et al. 2007). The Latin American bat fauna has a much higher diversity, and a vastly different taxonomic complexion than the US bat fauna. The Phyllostomidae, a family virtually absent from the US, dominates bat faunas in much of Latin America, and wind turbine susceptibility of species in this family is virtually unknown. Neotropical bat faunas contain several other families that are also rare within, or absent from the US, and for which collision susceptibilities are virtually, or completely unknown, including the Molossidae, Emballonuridae and Mormoopidae. Based on this, it is very difficult to extrapolate from the U.S. to Latin America with respect to wind farm bat collision mortality problems and solutions. Before effective mortality reduction or mitigation solutions can be developed for Latin America, post-construction collision monitoring must be conducted to describe the nature and extent of any bat collision mortality impacts that are discovered. This information will direct the search for any operational curtailment, or other mortality reduction/mitigation measures that might be necessary.

2) Feather the blades of wind turbine rotors when wind speeds are below the cut-in speed. North American studies have demonstrated that bat mortality is significantly reduced when this technique is implemented, primarily for *Lasiurus* and *Lasionycteris*. Although wind turbine collision susceptibility is highly taxon-specific, and the benefits to Latin American bats from this technique are, therefore, unknown, this technique does not result in any loss of electricity generation, hence it is a relatively low cost impact mitigation technique, and it is likely to produce some reduction in mortality for at least some taxa of Latin American bats.

3) If any significant wind turbine collision impacts are discovered at Latin American wind facilities, conduct experiments to determine whether marginal increases of cut-in speed would be effective at reducing mortality in the affected taxa. North American studies have demonstrated the value of experimental studies for developing solutions to reduce mortality in collision susceptible taxa significantly by implementing marginal increases in wind turbine cut-in speeds. If any potentially significant collision mortality impacts are discovered for bats at Latin American wind energy facilities, experimental studies with marginal cut-in speed increases similar to those conducted in North America are the most promising strategy for developing effective and efficient solutions for implementation in Latin America.

1.3 Lighting Regimes

1.3.1 Birds

Lights attract nocturnal migrant songbirds, particularly in conditions of poor visibility, which may result in the disruption of the birds' migrating behavior, and death (Gauthreaux and Belser 1999; Manville 2000). Major bird kill events have been reported at lighted communication towers (Avery et al. 1976, 1977, Manville 2000, 2001). Much smaller scale bird mortality events believed to be related to lights have been documented at several wind farms, usually associated with bright, steady-burning lights being left on at substations on nights with inclement weather conditions during peak bird migration times. (Kerlinger and Kerns 2003; Kerns and Kerlinger 2004).

Research into bird mortality rates in relation to lighting types at wind energy facilities and on structures associated with wind energy facilities has been conducted over many years, covering a wide variety of different types of lighting that meet US Federal Aviation Administration (FAA) requirements for obstruction beacons, including steady-burning white lights, steadily burning red incandescent L-810 lights, red flashing FAA obstruction beacons, and white flashing lights or strobe lights on turbines, towers, and other structures (Erickson et al. 2000a, 2000b; Johnson et al. 2000b; Johnson et al. 2002; Kerlinger 2002; Erickson et al. 2003a, 2003b; Kerlinger 2004; Gehring et al. 2006; Fiedler et al. 2007). Steady-burning lights placed on wind turbines produce higher bird mortality rates than do the red flashing FAA obstruction beacons used on most wind turbines today (Kerlinger et al. 2007). In a more recent study, Kerlinger et al. (2010) demonstrated that turbines with flashing red lights produced the lowest bird mortality rates of any FAA-approved design, yielding bird mortality levels indistinguishable from those of unlit turbines.

1.3.2 Bats

There are no studies of which the authors are aware that demonstrate statistically significant differences in bat mortality between turbines lit with FAA-approved obstruction lighting and unlit turbines. Some bat species are known to congregate and forage around various sources of light (e.g., streetlamps, athletic field lights), and it has been hypothesized that illuminated turbines may attract bats, increasing collision risk (Arnett et al. 2008). At the Mountaineer wind energy facility, in West Virginia, Kerns et al. (2005) found no difference in bat mortality rates between lit and unlit turbines. Kerns et al. (2005), and Brown and Hamilton (2006) described similar results for wind energy facilities in Pennsylvania, and Alberta, Canada, respectively. Similarly, Jain found no significant differences in bat fatality rates at lit vs. unlit turbines at wind energy facilities in Iowa (Jain 2005) and New York (Jain et al. 2007). It has been speculated that blinking red and white FAA lights emit strong ultrasonic pulses that may serve as an attractant to bats in the area (Arnett et al. 2008), but this has not been tested.

Recommendations for Latin American Wind Energy Facilities

1) <u>If placing aviation obstruction lighting on wind turbines is required or desired, use blinking red lights such as those currently used at many U.S. wind facilities, and approved by the US FAA.</u> The use of such lights is not likely to increase bird or bat collision risk relative to unlit turbines.

2) <u>Institute wind facility operational procedures to minimize the nocturnal use of steady burning white lights at substations, operations and maintenance buildings, or anywhere else at wind energy facilities.</u> The proper implementation of such policies is particularly important during peak bird migration periods to reduce the potential for causing fatalities of nocturnally migrating birds that become attracted to the lights.

1.4 Ultrasonic and Audible Deterrents

1.4.1 Birds

Audible devices to scare or warn birds have been used at airports, television towers, utility poles, and oil spills to deter birds from entering potentially hazardous areas. Ultrasound has been proven not to work in repelling birds (Erickson et al. 1992). Studies of auditory warning devices have found that birds become habituated to these devices and fail to respond, although habituation is slower with auditory devices that utilize bird alarm and distress calls (Thompson et al. 1968; Johnson et al. 1985; Bomford and O'Brien 1990; Morrison 2005). There are no studies that recommend using audio devices to warn birds away from wind turbines, and no studies that correlate audio warning devices in wind energy facilities with lower collision mortality.

1.4.2 Bats

Because bats rely on sensitive hearing in the ultrasonic range, it has been hypothesized that bats could be deterred from entering the airspace surrounding a wind turbine if ultrasound signals were broadcast from the turbine. Deterrence of bats by broadcasting ultrasound has been demonstrated in a laboratory setting and in a small-scale field setting. However, the application of an ultrasound deterrent on a large scale has been more challenging. Currently, there is not an acoustic deterrent for bats that is effective over a large enough area to deter bats from entering the rotor swept zone of a wind turbine, let alone a wind energy facility. An inherent challenge in broadcasting ultrasound over a large area, is the propensity of high frequency sound to attenuate rapidly over short distances. Because of this physical property of ultrasound, ultrasound-emitting bat deterrent devices do not hold a great deal of promise as a bat collision fatality reduction technique at wind energy facilities.

Mackey and Barclay (1989) investigated the influence of broadcasting ultrasound on bat activity and concluded that bat activity was reduced in the presence of the ultrasound, possibly because of increased difficulty in hearing the echoes of prey items, resulting in a decrease in foraging efficiency. It is likely that bats are not as efficient at maneuvering and capturing prey items in the presence of ultrasound because it may force them to shift their call frequencies to avoid frequency overlap and echo masking (Ulanovsky et al. 2004). Broadcasting a high intensity sound at a frequency to which bats are sensitive could generate an uncomfortable and disorienting space that bats may elect to avoid. An acoustic deterrent may work by directly diverting bats away from a turbine as they approach, or by inducing a learned aversion from a previous exposure. However, research done to date has failed to demonstrate that deterrents could be successful in reducing bat mortality at utility scale wind energy facilities, primarily because of the difficulties in getting the broadcasted ultrasound to affect a large enough airspace to keep the bats away from the turbines.

Spanjer (2006) used lab tests with captive *Eptesicus fuscus* (big brown bats) to test the response of these bats to ultrasound broadcasted from an 8-speaker deterrent device. Results showed that bats tended to avoid the deterrent when it was producing ultrasound, but not when the device was silent. However, avoidance was not absolute and appeared to be less pronounced when a prey item was present near the deterrent. There was some evidence of habituation, but overall, bats seemed to remain deterred by the ultrasound for the duration of the experiment.

Szewczak and Arnett (2006) tested a prototype of an ultrasound broadcasting acoustic bat deterrent device (AT800) at 8 pond sites in California and Oregon. Each pond site was monitored for 3 nights, with the first 2 nights having no experimental treatment to determine baseline bat use. Bat activity was monitored using a nightshot camcorder. On the third night, the AT800 was turned on and bat activity was monitored. Bats flying within the vicinity of the AT800 seemed affected by the ultrasound, with fewer bats flying in the AT800 affected area during the nights with broadcasted ultrasound. This study recommended increasing the amplitude of the broadcasted ultrasound to achieve a greater deterrent zone. Additionally, the authors recommended that future experiments examine the potential habituation of bats to the ultrasound by conducting the testing for multiple nights subsequent to the initial night of ultrasound broadcasting after the baseline activity levels have been documented.

Szewczak and Arnett (2008) expanded on these results in an additional round of field trials with additional nights of monitoring once the ultrasound broadcasting treatment was initiated. The results of this field study confirmed previous findings that the broadcast of ultrasound can create an uncomfortable environment for bats, and deter bats from occupying a treated airspace. The effect observed was immediate, as bat activity reduced to 10% of control levels within the treated airspace on the first night of treatment. This field trial also indicated that bats did not habituate to the ultrasound, as over the 5 to 7 days of monitoring, bats entering the treated airspace declined. The authors speculated that bats randomly encountered the treated airspace and elected to avoid it subsequently. Over the 7-day course of the experimental treatment, bat activity declined to 4% of the control levels, less than half of the first night of treatment. While this study supported the notion that areas treated with ultrasound can deter some species of bats, the authors cautioned that the effectiveness in implementing this practice to encompass a large enough area of airspace to minimize bat mortality at wind energy facilities would require further improvement. The single source of ultrasound broadcast with the current amplitude level (~120 dB at 1 m) could only affect bats up to a range of approximately 12 to 15 m, which is less than half of the length of commonly used turbine blades.

Ultrasound-emitting bat deterrent devices were first tested on an operational wind turbine at the Maple Ridge wind energy facility in Lowville, New York, US, where bat fatalities had been previously reported. This study used a larger, more powerful version of the AT800 than that used in the Szewczak and Arnett (2006, 2008) studies. Each deterrent device had 3 emitters that were placed equidistant from one another around the circumference of the tower, creating an omnidirectional broadcast effect. Deterrent devices were mounted on the towers of 2 turbines and bat fatality rates from the 2 treatment turbines were compared with fatality rates at 2 control turbines that did not have deterrents. The deterrents used emitted randomized and continuous ultrasound in various frequencies from 20 to 80 kHz. Broadband ultrasound containing randomized pulses was used because this technique is thought to be effective in jamming chirped radar (similar to signals used by bats), because it quickly generates waveforms that are misinterpreted by bats' time/frequency process, causing bats to generate rapid and random sequences of false detections, which obscure any detection of the surrounding environment. Thermal infrared imaging was used to monitor the airspace adjacent to the towers for bat activity at the treatment and control turbines. During the first 10-night experiment, there was a significantly lower number of bat passes at the deterrent turbines compared with the control. However, during the second 10-night experiment, no significant differences were detected between the treatment turbines and the control turbines.

The most promising results for the deterrence of bats from wind turbines by ultrasound-emitting deterrent devices were obtained by Arnett et al. (2011), who deployed units containing 16 transducers that emitted continuous broadband ultrasound from 20 kHz to 100 kHz in a 2-year study at a wind energy facility in Pennsylvania. Ultrasonic acoustic deterrents were installed on 10 turbines (8 individual deterrent devices to the nacelle per turbine), while 15 turbines were designated as control turbines. Results suggested that 21% to 51% fewer bats were killed on deterrent turbines compared with control turbines during the monitoring period with approximately twice as many hoary bats killed per control than deterrent turbine, and nearly twice as many silver-haired bats killed per control than deterrent turbine. However, when before-after comparisons were taken into account, these represented only a 20% decrease in fatality with deterrence. The authors were encouraged by the findings but cautioned that additional tests of deterrent devices that take into account inherent differences in fatality rates among turbines should be conducted to better understand differences in fatalities among different species. It should also be noted that the devices used in this study were quite large, costly, and complex, rendering the application of this particular design, or larger designs for great ultrasound broadcast power fairly challenging.

Nicholls and Racey (2009) tested whether bats could be deterred from airspace using unidirectional or rotating broadcasts of radar signals and achieved 13.3% to 38.6% reductions in bat foraging activity within 30 m of the radar unit. These results suggest that there is little potential for the use of radar signal broadcast as an effective bat deterrent strategy at wind energy facilities, as the range of effectiveness is short and the effectiveness is low, particularly given the cost and complexity of this technology.

Recommendation for Latin American Wind Energy Facilities

1) The use of sound, ultrasound or radar signal broadcasting devices to deter birds or bats from approaching wind turbines at Latin American wind energy facilities is not recommended. Such devices have not yet been demonstrated to work over the distances that would be necessary to generate significant collision mortality reduction for either birds or bats at Latin American wind energy facilities.

1.5 Blade Painting

1.5.1 Birds

Ultraviolet Paint

Birds are known to detect visual wavelengths that include the UV spectrum (Jacobs 1992). Birds use this ability to avoid predators, and to locate and select mates and food (Andersson 1996; Andersson et al. 1998; Honkavaara et al. 2002). To test if this ability could assist birds in detecting and avoiding turbine blades, Young et al. (2000) examined the effects of painting wind turbine blades with 60% UV-reflective paint on bird use and mortality at the Foote Creek Rim wind energy facility in Carbon County, Wyoming. No statistically significant differences were found between fatality rates for the UV and non-UV turbines, although overall passerine fatality rates at the UV turbines were 2 times higher than at the non-UV turbines. Raptor fatality rates were very similar (0.0029, 0.0031) between UV and non-UV turbines. Based on these results, it may be beneficial to select paint colors which do not have strong UV reflectance peaks for turbine installations (Long et al. 2011).

Mixed-color Blade Painting

Motion smear has been cited as 1 of the problems affecting birds' abilities to see moving turbine blades, hence visually contrasting patterns painted onto wind turbine blades have been hypothesized as a means to reduce bird collision impacts. In an experiment consisting of a randomly selected sample of 25 turbines with blades painted an alternating pattern of red and white and 50 control turbines at the APWRA, results indicated fewer bird fatalities at turbines with painted rotors, but with the caveat that the small sample size precluded any definitive conclusions (Howell et al. 1991). Further experiments have been conducted informally in the APWRA (Altamont Winds Inc. 2006) to ground-truth laboratory research that identified that a single, solid-black blade paired with 2 blank blades would be the most visible visual deterrent to birds (Hodos et al. 2001; Hodos 2003). Initial informal results indicated that raptor fatalities may be able to be reduced by up to 50%, using this blade painting pattern (B. Damon, pers. comm.). However, further research is needed to determine whether or not this is an effective technique for reducing bird collision mortalities at wind farms.

1.5.2 Bats

A decrease in bat mortality as a result of blade painting has yet to be demonstrated at an operational wind facility. Hypotheses regarding mechanisms of bat mortality include the possibility that bats may be attracted to turbines based on their visual appearance, either because of bats' searching strategies for roosts or for prey, suggesting that different blade colors or patterns could impact bat fatality rates. Indeed, there has been some evidence reported of bats foraging around turbines (Horn et al. 2008), and Long et al. (2011) demonstrated that turbine paint color could influence insect attraction to turbines, potentially leading to the attraction of bats to turbines, and increased bat fatality rates. Long et al. (2011) suggested that painting turbines a color that insects find less attractive may reduce the amount of insects at the turbine, and therefore, reduce bat fatality rates. However, additional research is needed in this area before blade painting can be used as a tool for reducing bat fatality rates at wind energy facilities.

Recommendation for Latin American Wind Energy Facilities

1) The use of UV-reflective paint on wind turbines at Latin American wind energy facilities should be avoided. While the effects of using such paint are not very well characterized, it may result in increased mortality of birds and/or bats, either directly by visually attracting these animals to the turbines, or indirectly by attracting their insect prey, resulting in increased bird and/or bat foraging activity in proximity to the turbines.

1.6 Anti-perching Structures and Turbine Design

1.6.1 Birds

Early studies on wind turbines with lattice towers in the U.S. suggested that raptors perching on wind turbines resulted in higher collision fatalities, leading to experimental studies of the effectiveness of installing perch deterrent devices on lattice towers, which demonstrated reductions in bird mortality of up to 54% when such devices were used

(Nelson and Curry 1995; Orloff and Flannery 1996). Subsequently, it was hypothesized that the use of tubular, monopole towers instead of lattice towers could further reduce bird collisions by further reducing perching opportunities for birds, and tubular towers are now more common at wind energy facilities worldwide than are lattice towers. A handful of studies have indicated that bird collisions are actually higher at monopole towers than at lattice towers (Thelander and Rugge 2000; Smallwood and Thelander 2005; Smallwood et al. 2007; Smallwood 2010). However, Morrison et al. (2007) reviewed literature on this subject and concluded that placement of turbines relative to slope, which was often confounded with tower design in early studies in the western US, was the primary contributing factor for bird collision susceptibility, rather than tower design, *per se*. Other research suggests that larger, taller, higher nameplate capacity turbines cause fewer collision mortalities per megawatt for most bird species, with Golden Eagles standing as a notable exception to this pattern. In the APWRA, Golden Eagle fatality rates increased with increasing turbine size over 2 size ranges of turbines, first with turbines ranging in size from 40 KW to 200 KW, and then again with turbines ranging in size from 330 KW to 1 MW (Smallwood 2010).

1.6.2 Bats

There is a paucity of data available for examining the influence of turbine design on bat mortality, but some authors have suggested that larger, taller turbines kill more bats than do smaller, shorter ones. Barclay et al. (2007) arrived at this conclusion based on a 14-fold observed difference in bat mortality rate between 2 wind energy facilities in Alberta, Canada. Although these facilities did, indeed use different wind turbine technologies, 1 with 50 m towers and the other with 65 m towers, they were also located approximately 40 km apart, and 1 was significantly closer to a potential migratory route along the Rocky Mountains, hence the observed variation in fatality rates is just as likely to be attributable to simple across-site geographic variation as it is to the difference in turbine technology between these 2 facilities. Arnett et al. (2008) demonstrated higher bat fatality rates at turbines with 78 m towers than at turbines with 65 m towers at the Buffalo Mountain wind energy facility in Tennessee. However, bat fatality rates were lower at the taller turbines when results were compared on a per-megawatt, rather than a per-turbine basis. Perhaps the most compelling evidence of an increase in bat mortality rate with an increase in turbine size was produced by Johnson et al. (2003) at Buffalo Ridge, Minnesota, where almost 7-fold higher per-megawatt bat fatality rates were measured at larger turbines. However, this study compared 2 turbine sizes that are both significantly smaller than most of the models currently on the market (340 kW turbines on 37 m towers and 750kW turbines on 50 m towers), hence it is not clear how bat fatality rates vary with turbine size and height in the range of modern utility scale wind turbines.

Recommendation for Latin American Wind Energy Facilities

1) <u>Discourage bird perching on wind turbines and associated structures.</u> The use of simple perch discouraging devices on wind turbines and associated structures is likely to provide a relatively low-cost means of reducing bird collision mortality at Latin American wind energy facilities. This is likely to have greater impact for lattice towers than for tubular towers.

2) <u>The installation of fewer, larger, higher capacity turbines is generally preferable to achieving the same total nameplate capacity by installing more, smaller, lower individual capacity turbines.</u> It should be noted that bats and some birds may represent exceptions to this rule, and post-construction monitoring should be implemented to shed light on the impacts of variation in turbine design characteristics on wind turbine collision mortality patterns for Latin American bird and bat taxa.

2 Accuracy of Preconstruction Collision Risk Model Predictions for Birds and Bats with Wind Turbines: A Review of Existing Evidence and Consideration of Applicability to Latin America

2.1 Introduction

This chapter presents the results of a review of technical literature and expert opinion intended to evaluate the value of preconstruction bird and bat collision risk models at wind energy facilities. In this evaluation, primary consideration was given to the accuracy of model predictions as measured by validation studies, where validation was defined as the comparison of model-predicted bird and bat fatality rates to rates that have been empirically derived from postconstruction carcass searches. Another essential criterion used to perform this evaluation was the applicability of models and modeling approaches to Latin American wind energy development scenarios.

Models are heuristic tools used in many scientific fields to understand how systems work and to predict system outcomes, in the form of model output data, based on a given starting condition defined by model input data. Models can be separated into 2 basic types depending on the way in which they are constructed. Empirical models are built starting with observed patterns and working backward toward reconstructing the processes that could plausibly have generated the patterns. The hope is that an empirical model that explains an exemplar data set will be applicable to other analogous situations to accurately predict outcomes, or output data, as a function of starting conditions, or input data. By contrast, mechanistic models are built starting with mathematical representations of the dynamics of the system of interest. The hope is that by successfully mimicking or encapsulating the system's dynamics within the equations of the model, the model will be able to accurately predict outcomes as a function of starting conditions of the system (Tham 2000).

Both types of modeling approaches have been extensively used in the context of wind-wildlife studies to predict bird and/or bat collision mortality patterns as a function of preconstruction input data on wildlife abundance, behavior, and wind facility characteristics (de Lucas et al. 2008). A justification for using predictive collision risk modeling in this way is that it can provide a basis for decision-making regarding permitting, mitigation, and micrositing prior to construction of the wind facility, when few other tools are available for making such decisions (Normandeau 2012). However, models that produce inaccurate predictions can lead to misguided decision making. All models are simplified versions of reality, and all models contain assumptions that can be violated in some circumstances. Such simplifications may or may not lead to prediction inaccuracy depending on how sensitive the model is to violation of its assumptions. For this reason, it is essential to assess the accuracy of models' predictions with validation studies. Models whose accuracy has been empirically demonstrated through extensive empirical validation provide a more robust basis for decision making than do models whose prediction accuracy has rarely or never been empirically validated.

For the purpose of this review, we make a distinction between collision risk models and conventional preconstruction wind-wildlife collision risk studies. Both approaches are frequently used to predict wildlife collision fatality patterns at wind energy facilities. We define collision risk models as models that consist of an explicit mathematical or algorithmic structure that generates output data in an automated fashion, purely as a function of input data and a discrete set of mechanisms that have been built into the model. Such models are typically simpler, more mathematical, automated, and their predictions are typically more quantitative than are those of conventional risk studies. Conventional risk studies rely on synthesis of comparative information from technical literature, (e.g., studies of known collision susceptibility of particular taxa), as well as site-specific data on the distribution and abundance of birds and bats at the proposed site (e.g., tier 3 site characterization studies, USFWS 2011a). Predictions are usually qualitative, and although this type of approach could be described as entailing conceptual models, the models are not explicitly presented in mathematical or algorithmic form, and are not automated, uniform, or systematic, hence we do not include such models in the definition of collision risk models discussed in the remainder of this review.

2.2 Methods

We conducted a comprehensive review of technical literature regarding wind-wildlife collision risk models. This review was focused on model validation studies, but we also compiled information on the basic structure, design, and assumptions of each model. Literature that was reviewed included both peer-reviewed and gray literature (e.g., government and consulting reports), as well as conference presentations and posters. In addition to the literature review, we conducted phone and email surveys of 7 collision modeling experts (Table 2–1) with a series of questions regarding collision model validation (Appendix 1). The synthesis that follows is based on the results of both the literature review and model expert surveys.

Table 2–1. Collision Modeling Experts that Responded to a Written Questionnaire Regarding Wind-wildlife Collision Risk Model Accuracy and Validation Studies.

Name of Expert	Affiliation	Collision Modeling Background
Richard Podolsky	Exponent Consulting	Developed a variant of the Tucker (1996) model and patented it as the ARC collision risk model
Ian Smales	Biosis Research	Developer of Biosis model, used on dozens of Australian wind projects
Bill Band	Formerly Scottish National Heritage	Developed the Band (Scottish National Heritage) collision model
Roel May	Norwegian Institute for Natural Research	Worked with Band Model developed by Scottish National Heritage on several wind projects
Rowena Langston	Royal Society for the Protection of Birds	Background using the Band collision model, and 1 of the leading wind-wildlife experts in the U.K.
Aonghais Cook	British Trust for Ornithology	Mostly used the Band model, but also familiar with the Biosis, ARC, and Hamer models
Victoria Bennett	Texas Christian University	Developed a computer simulation model to look at bat avoidance of automobiles along roads

2.3 Review of Existing Risk Models

A variety of wind-wildlife collision models have been developed by researchers over the past 2 decades. These models include both mechanistic and empirical models. Some were built specifically to address questions about a particular wind facility (e.g., Bolker et al. 2006), while others were developed for more general application. In this section, we present an overview of the general structure of the most widely used wind-wildlife collision models, and a comparative discussion of the strengths and weaknesses of each model.

2.3.1 Tucker Model

The Tucker (1996) model was the first published bird-wind collision risk model. This mechanistic model uses input data on bird anatomy, flight characteristics, avoidance rates, and turbine characteristics to output a turbine-specific collision probability. The basic structure of the Tucker model has been used to generate several related models (e.g., ARC model [Podolsky 2008] described below), and refinements continue to be made to the original modeling approach.

Advantages of the Tucker (1996) model include comprehensive inclusion of biological and structural variables into the model as inputs. Models are always an oversimplification of the true system, but including many variables minimizes this issue. The Tucker (1996) model also considers collision probability specific to different areas of the turbine blade as this can vary due to the speeds and size of the blades. Limitations to this model include lack of consideration of the monopole in collision calculations, no accommodation for differently sized birds and bats, and an absence of any habitat considerations that could affect exposure to the turbine blades.

The original Tucker (1996) model may have some application to collision modeling at wind facilities in Latin America, because the input data required is likely to be available, as long as sufficient technical expertise can be acquired. However, given the lack of habitat-based considerations that affect siting decisions, its outputs may have limited application in risk-based decision making. We suggest looking at some of the more modern variants of this model which consider additional factors in the collision calculation and are more empirical in nature (

Table 2–2 and

Table 2–3).

2.3.2 Band et al. Model

The Band Model, also known as the Scottish National Heritage Model, is the most well-known and openly documented wind-wildlife collision risk model. The Band model is an empirical model which presents a combined field study and modeling approach that can be used to predict collision mortality risk of birds at wind facilities (Band et al. 2007). The collision prediction has 2 key components that are used to estimate the number of annual bird collisions: (1) the number of birds flying through the rotor—stage 1, and (2) the probability of a bird flying through the rotor colliding with a blade—stage 2 (Band et al. 2007). Stage 1 data are collected through field observations, and a series of calculations are used to calculate the number of bird transits through the rotors. Stage 2 calculations are performed using geometry and a measure of avoidance to arrive at a final estimate of collision mortality for a wind farm.

Advantages of the Band collision model include relatively simple calculations and the use of site-specific field data to drive the estimates. Calculations are computed in a spreadsheet available from the author. The model has also been heavily scrutinized by many parties, has general acceptance in the collision modeling field, and is also openly documented. Despite its acceptance, the model does have limitations including inherent biases with field data collection (detection biases and flight height estimation biases), assuming birds have a simple cruciform shape, assuming turbine blades have no thickness, and assuming that bird flight velocity is the same regardless of upwind or downwind flight. The Band model also does not account for birds flying at different angles to the turbine blades. Chamberlain et al. (2005) provided a critique of the Band model and determined that while it was statistically sound, the lack of solid data on avoidance rates should encourage caution when interpreting model outputs. Seven years later, additional information on avoidance rates have filled that void to a limited degree, although the number of species where avoidance rate is known is still small, particularly in Latin America.

The Band model (or 1 of the variants described below) has the most application to collision modeling at potential Latin American wind farms. The model is openly documented, and calculations are simple based on a spreadsheet provided by the author. Avoidance rates and even mortality predictions can be validated with the proper field data collection if desired. Although there are limitations to this model, they are well documented and understood, and they can be considered when interpreting the model outputs (

Table 2–2 and

Table 2–3).

2.3.3 Podolsky Model

The ARC model (Podolsky 2008) is an extension and variant of the original model described by Tucker (1996) and as such uses similar model inputs, but offers several key advantages. The ARC model considers the monopole in the risk calculations as well as accounting for differences in the flight speed and size of different bird and bat species. The model can also incorporate attraction to, or avoidance of turbines by birds or bats.

Given the similarities to the Tucker (1996) model, the ARC model has similar advantages and has addressed some of the disadvantages of the Tucker model. The main limitation remains the lack of any habitat considerations that could influence the occupancy of an area by a species. This model is also proprietary, and although it is documented in a patent (Podolsky 2008), the calculations are not openly available as with Band et al. (2007).

Given the refinements and improvements in the ARC over the Tucker (1996) model, this model does have moderate applicability for wind facilities in Latin America. The model is known to over-predict collision mortality (Richard Podolsky, pers. comm.) so this caveat should be considered when considering the possibility of using this model (

Table 2–2 and

Table 2–3).

2.3.4 Bolker Model

The impetus for the empirical Bolker et al. (2006) model was to provide a means to predict collisions of birds at the proposed Cape Wind offshore wind facility in Nantucket Sound, Massachusetts. Like the Band model, the Bolker et al. (2006) model can be calculated using a spreadsheet that provides an easy user interface. Required input data include turbine and bird characteristics along with avoidance behavior to calculate and estimate of the number of bird encounters with wind turbines.

Advantages to using the Bolker et al. (2006) model include simple mathematical calculations that can be done in a spreadsheet and relatively few inputs needed to run the model. Limitations include lack of avoidance considerations, and no consideration of the tower or nacelle in encounter predictions.

The inability to apply model outputs (number of encounters) to risk-based decision making is a limitation that reduces its applicability to siting wind facilities in Latin America. In addition, the probability of surviving an encounter is largely unknown and varies greatly among species; therefore, this model's predictions of mortality are likely inaccurate (Bolker et al. 2006) (

Table 2–2 and

Table 2–3).

2.3.5 *Warren-Hicks* et al. *Model*

This model was developed by William Warren-Hicks, Lucy Vlietstra, and Caleb Gordon (Normandeau 2011). It is a variation of the Bolker et al. (2006) model that includes avoidance behavior at 3 spatial scales (avoiding the wind facility, avoiding the turbines inside the wind facility, and avoiding being struck by a blade inside of turbine rotor swept areas).

Avoidance parameters were derived from empirical data collected on Common Tern (*Sterna hirundo)* and Roseate Tern (*Sterna dougallii)* flight behavior and avoidance at the Massachusetts Maritime Academy Wind Turbine. While drawing from the Bolker et al. (2006) model, this model extension is designed to estimate mortality, as opposed to just encounters, which provides a better metric for risk-based decision making. Given that the outputs are geared more toward a decision-making framework, and that it includes avoidance rates which are known to be an important factor affecting wind-wildlife collision risk, this model has moderate applicability for wind farm siting in Latin America (

Table 2–2 and

Table 2–3). One important limitation of this model is that it requires extensive data gathering on birds' flight behavior in the vicinity of wind energy facilities.

2.3.6 Biosis Collision Model

The Biosis Research Party, Ltd., of Australia has developed its own proprietary collision model called the Biosis Research Deterministic Avian Collision Risk Assessment Model. The Biosis model is empirical and uses data on various metrics of bird use of a wind resource area to estimate collision risks to birds (Smales 2006). It has been used at dozens of wind facilities in Australia (e.g., Smales 2005; Smales et al. 2005) and has achieved high acceptance in this country among regulators. Unfortunately, the proprietary nature of this model makes it difficult to understand inner model components and how it works. A peer-reviewed journal article describing the model had been submitted at the time of this writing, but was not available for review for this project (Ian Smales, pers. comm.). This model has also seen little use outside of Australia, so its applicability to Latin American wind farm siting is difficult to determine (

Table 2–2 and

Table 2–3).

2.3.7 *Eichhorn* et al. *2012*

The Eichhorn et al. (2012) collision model is a spatially explicit simulation model designed to assess collision risk impacts on select species. The model uses simulated landscape and bird behavioral data to create an impact function, which describes how the risk varies across the landscape. Input data for this model include simulated land use, bird behavior, and turbine location and outputs include simulations of mortality rates at different distances between bird nests and wind turbines. The principal focus of this model is on the decrease in bird collision risk as distance from raptor nests to wind turbines increases. The applicability to Latin America is likely to be limited, although it may be applicable in cases where raptors or other bird species of particular conservation importance are nesting within, or in the vicinity of wind energy facilities (

Table 2–2 and

Table 2–3).

2.3.8 U.S. Fish and Wildlife Service Collision Model

As part of development of an environmental assessment for the West Butte wind energy project in Oregon, the U.S. Fish and Wildlife Service (USFWS) developed a Bayesian collision risk model for Golden Eagles (USFWS 2011b). Although developed for Golden Eagles, this model can also be applied to Bald Eagles and potentially other species by modifying some of the input parameters. The structure of this model includes 3 components: (1) input data from field studies and turbine measurements, (2) a collision avoidance estimate, and (3) an exposure rate. These components are modeled in a Bayesian framework and an annual collision prediction for the entire facility is outputted for the entire site.

Several advantages to the USFWS's Bayesian collision model include (1) allowing field data to inform the model, and (2) having the flexibility to be stratified by space and time. Disadvantages include (1) a lack of consideration for habitat features which could influence collision risk, (2) the mortality prediction is not spatially explicit, and therefore cannot be used to inform micrositing decisions, and (3) avoidance measures are not well characterized for many species, and small differences in avoidance inputs can result in large differences in predicted collision mortality. This can lead to significant uncertainty in the model predictions (Chamberlain et al. 2006). Applicability of the USFWS collision model to Latin American wind facilities is limited given the lack of species-specific avoidance rates for Latin American bird species. Although other species with similar behavioral characteristics could be used as surrogates, small differences in collision mortality between the surrogate and the species of interest could bias the collision estimates significantly higher or lower than the true value (Chamberlain et al. 2006) (

Table 2–2 and

Table 2–3).

2.3.9 Normandeau Spatial Collision Risk Assessment Model (SCRAM)

Normandeau Associates developed a spatial collision risk assessment model (SCRAM) that has been applied to model Bald Eagle collision risk at several U.S. wind energy facilities. The SCRAM model has 2 components: (1) a spatial model which estimates number of bird transits that occur over the course of a year and (2) a mechanistic model which estimates collision probability based on bird size and wind turbine specifications. The synthesis of the outputs between the spatial and mechanical models provides a spatially explicit risk prediction in the form of a grid that can be viewed within a GIS. The spatially explicit prediction for each grid cell can be summed over the entire study site to calculate the fatality prediction for eagles per year for the site (Normandeau Associates, unpubl. report).

Advantages of the SCRAM model include (1) considering turbine locations relative to habitat and environmental features, (2) using field data as inputs to inform the model the amount of time eagles spend at different flight heights, (3) a spatial prediction of risk which allows for informative micrositing to reduce collision risk, and (4) the model considers the life history of different ages and sexes of birds differently and accounts for differences in behavior among those classes. Disadvantages to the SCRAM model include (1) requirement of fine-grained geospatial habitat data, as well as species-specific data on habitat use and (2) a time-consuming modeling process. Applicability of the SCRAM model to Latin American wind facilities is limited based on the limited availability of high-resolution land use data from the region, as well as information on bird species’ habitat use patterns (

Table 2–2 and

Table 2–3).

2.3.10 Normandeau Spatial Landscape Collision Model

Normandeau Associates more recently developed a landscape-scale wind-wildlife collision risk model that predicts relative fatality risk across the upper Great Plains region for several selected species based on land cover, habitat use patterns, and known collision susceptibility information. This spatial collision model uses a hierarchical linear-mixed model with fixed (environmental variables) and random effects (study design variables) to predict bird and bat occurrence based on habitat. Occurrence predictions are combined with variables thought to influence exposure such as weather, topography, and behavior. The outputs of this model are maps of relative collision risk across the selected landscape, which are visual and useful for large scale planning but not for micrositing. Currently, this model has only been applied to select bird and bat species within the central United States (Normandeau 2012).

This model has several advantages including reliance on existing data from publically available data sets so costly field studies are not needed. The model also considers spatial relationships among environmental features that can influence collision risk for distinct species differently. A final advantage is that this model is 1 of the few that has been validated for select species within the central U.S., and validation would also be possible if it were applied to other species in other geographic regions. Limitations include the fact that mortality predictions are only relative and do not predict a number of birds or bats that will be killed at a given site. Relative predictions only indicate whether a prediction is higher or lower than a prediction from another area; predictions are not comparable among species. A second limitation is that the weighting of habitat and exposure variables must be done *ad hoc* as there is little empirical basis for determining how much each of these variables affect collision rates. Each species must also be modeled individually which can be time consuming depending on the number of focal species of interest. Applicability to wind farm development in Latin America is minimal because large scale geospatial data sets on land cover types and bird and bat distributions are required (

Table 2–2 and

Table 2–3).

2.3.11 Other Models

Other models that exist include a number of variations on 1 of the previously discussed models. The Folkerts model is similar to the Band model except that it can accommodate birds approaching the wind turbine at different angles and better accommodates marine environments as opposed terrestrial landscapes (MMO 2012). Collision risk estimates are normally within 15% of those estimated by the Band model (MMO 2012), but we could not find any studies comparing the accuracy of those estimates to mortality data.

Hamer Environmental has also developed its own proprietary collision model which expands on the Tucker (1996) model by accounting for the approach angle as a determinant of collision risk. The model also considers a variety of bird and turbine measurements and uses a Monte Carlo simulation which accounts for variation in flight paths among birds (Hamer Environmental 2012). This model is also proprietary, and further details about its structure and assumptions are not available.

Table 2–2. Comparative Overview of Key Advantages, Disadvantages, and Applicability of Wind-wildlife Collision Risk Models.

Model	Key Advantages	Key Limitations	Application in Wind Fatality Modeling	Validation	Applicability to Latin American Wind Siting
Tucker (1996)	Predictions specific to different areas on turbine blade Numerous bird and turbine parameters considered	Does not consider monopole No site-specific habitat considerations Not applicable to micrositing turbines Avoidance not included	Many variants of this model have been implemented (e.g., Podolsky) Radar Ridge, Washington	Has not been validated	Low—complex and mechanistic; outputs not useful for decision making
Podolsky (2008)	Simulates influences of parameters on collisions Numerous bird and turbine parameters considered	No site-specific habitat considerations Proprietary and not openly available Not applicable to micrositing turbines	Kaheawa Wind Facility (Podolsky 2005) Buzzards Bay Roseate Tern More than 12 others	Author claims his model over-predicts mortality, but no quantitative information available	Low to moderate—proprietary but model outputs useful for decision making

Model	Key Advantages	Key Limitations	Application in Wind Fatality Modeling	Validation	Applicability to Latin American Wind Siting
Band et al. (2007) (Scottish National heritage)	Openly documented and available to use Calculations easy to do in spreadsheet Considers many environmental and structural parameters Provides separate outputs for upwind and downwind flights	Crude incorporation of avoidance Assumes constant bird flight speed No habitat considerations Requires intensive field sampling Does not consider multiple flight angles Does not distinguish between number of flights and number of birds Not applicable to micrositing turbines	Dounreay, Caithness Wind Farm (Scotland) Clocaenog Forest Wind Farm Smøla Wind Power Plant Multiple sites mentioned in Whitfield (2009)	Validation of avoidance rates available from Scottish National Heritage website; no validation of raw collision predictions	Moderate—easy to use but often criticized for some assumptions Most openly documented so inputs and structure are easily understood
Bolker et al. (2006)	Relatively few model inputs needed Simple spreadsheet calculation	No risk-based decision making Does not include tower or nacelle Not applicable to micrositing turbines Simplistic assumption about avoidance	Cape Wind, Nantucket Sound	Has not been validated	Low—outputs not useful for risk-based decision making

Model	Key Advantages	Key Limitations	Application in Wind Fatality Modeling	Validation	Applicability to Latin American Wind Siting
Warren-Hicks et al. (Normandeau 2011)	Incorporates avoidance behavior to Bolker et al. (2006) model Provides uncertainty metric Risk-based decision making included	Requires field observations Habitat data not incorporated Not applicable to micrositing turbines	Estimation of Roseate Tern mortality at U.S. offshore wind facilities	Has not been validated	Moderate—outputs are useful for decision making
Smales (2006)	Widely used and accepted in Australia Frequently updated Considers both field data and turbine characteristics	Proprietary—not well described at the time of this writing	Approximately 30 Australian wind facilities and 1 in Fiji	2 sites in Australia—manuscript submitted but unavailable as of this writing	Useful if working with Biosis Research Party in Australia, but proprietary and unavailable otherwise
Eichhorn et al. (2012)	Includes spatial landscape information Estimates suitable buffer zones around turbines	Model inputs are simulated; does not appear to be designed to use empirical data	Single wind turbine in West Saxony, Germany (simulated location)	Some of the simulated model inputs validated against empirical data; no quantitative validation of mortality prediction	Minimal—much of the input data are simulated and outputs are not useful for risk-based decision making

Model	Key Advantages	Key Limitations	Application in Wind Fatality Modeling	Validation	Applicability to Latin American Wind Siting
USFWS Eagle Collision Model (USFWS 2011b)	Model uncertainty calculated Regulatory acceptance in U.S. Uses Bayesian inference to calculate mortality	Collision avoidance measures are difficult to estimate Does not identify high-risk turbines Not applicable to micrositing turbines	West Butte project in Oregon (Golden Eagle) Sugarland wind project in Florida (Bald Eagle)	Has not been validated	Low—model does not identify high risk areas and there is no regulatory acceptance outside U.S.
Normandeau SCRAM Model (unpublished)	Calculates site-specific bird mortality Considers turbine layout Identifies higher risk areas within site so applicable to micrositing	Habitat variable weights are not statistically determined Only applicable at site level Proprietary and not openly available	Rollins Wind Farm, Maine Osage Wind Farm, Oklahoma	Has not been validated	Low—spatial data inputs unlikely to be available

Model	Key Advantages	Key Limitations	Application in Wind Fatality Modeling	Validation	Applicability to Latin American Wind Siting
Normandeau Landscape Collision Risk Model (Normandeau 2012)	Robust statistical approach Map output is easy to interpret Incorporates habitat and weather into predictions Adaptable to other geographic areas Thoroughly documented in report	Relative predictions Applicable only to large scale siting Not applicable to micrositing turbines	Used for 3 bat and 6 bird species in the central U.S.	Model has performed moderately well to very well, but limited to species where mortality has been used in the study area	None—Spatial data inputs unlikely to be available Does not apply to single project scale, but only regional or landscape-level wind facility site selection

Table 2–3. Summary of the Structure and Components of Wind-wildlife Collision Risk Models

Model	Model Type[1]	Model Scale[2]	Spatially Explicit[3]	Bayesian[4]	Behavioral Avoidance[5]	Simulation [6]	Model Inputs	Model Outputs
Tucker (1996)	Mechanistic	Wind Turbine	No	No	Yes	No	Bird anatomy Flight characteristics Avoidance rates Turbine characteristics	Turbine-specific collision probability based on bird anatomical and flight characteristics
Podolsky (2008)	Empirical	Wind Facility	No	No	Yes	No	Bird anatomy Flight characteristics Avoidance rates Turbine characteristics Turbine layout	Site specific collision probability for each collision

Model	Model Type[1]	Model Scale[2]	Spatially Explicit[3]	Bayesian[4]	Behavioral Avoidance[5]	Simulation [6]	Model Inputs	Model Outputs
Band et al. 2007 (Scottish National Heritage)	Empirical	Wind Facility	No	No	Yes	No	Bird field data and flight characteristics Wind turbine dimensions	Number of birds in rotor swept area Collision probability with and without avoidance
Bolker et al. (2006)	Empirical	Wind Facility	No	No	Yes	No	Turbine Location Turbine Height Rotor Length Flight Angle Flight Height Flight Direction Avoidance	Average and maximum number of turbine encounters
Warren-Hicks et al. (Normandeau 2011)	Empirical	Wind Turbine	No	No	Yes	No	Turbine Dimensions Bird Observation Data	Number of turbine encounters

Model	Model Type[1]	Model Scale[2]	Spatially Explicit[3]	Bayesian[4]	Behavioral Avoidance[5]	Simulation [6]	Model Inputs	Model Outputs
Smales (2006)	Empirical	Wind Facility	No	No	Yes	?	Bird flight behavior Turbine characteristics Other parameters undocumented	Annual proportion of a species predicted to survive encounters with wind turbines
Eichhorn et al. (2012)	Mechanistic	Wind Facility	Yes	No	Yes	Yes	Landscape composition Bird locations and flight characteristics Wind turbine characteristics	Predicted mortality rate per turbine
USFWS Eagle Collision Model (USFWS 2011b)	Empirical	Wind Facility	No	Yes	Yes	No	Turbine specifications Point Count Data Exposure Rate Collision Avoidance	Species-specific annual mortality calculation

Model	Model Type[1]	Model Scale[2]	Spatially Explicit[3]	Bayesian[4]	Behavioral Avoidance[5]	Simulation [6]	Model Inputs	Model Outputs
Normandeau SCRAM Model (unpublished)	Empirical	Wind Facility	Yes	No	Yes	No	Land cover data, bird field data, wind turbine specifications	GIS grid predicting mortality
Normandeau Landscape Collision Risk Model (Normandeau 2012)	Empirical	Landscape-level	Yes	No	No	No	Breeding Bird Survey Christmas Bird Count eBird National Landcover Climate Data Topography Data	Statistical modeling outputs Predicted Abundance Maps Predicted Collision Maps

[1] Refers to 2 different classes of models, mechanistic and empirical. Mechanistic models attempt to describe the entire system by including the individual parts of the system as model parameters. Empirical models are developed based on observational data and modeling that data to predict an outcome

[2] Model scale refers to the scale at which the model was designed to operate.

[3] Spatially explicit models describe the distribution of collision risk across space using a map or GIS

[4] Bayesian models use prior information from previous studies as a starting point to initially inform the model.

[5] Behavioral avoidance is a key component in all project-specific collision models and small changes in the behavioral avoidance estimate can have large changes in the final collision prediction

[6] Simulation models create an artificial environment and model various scenarios as opposed to modeling a real world situation

2.4 Collision Model Validation

Validation of wind-wildlife collision risk models consists of comparing preconstruction fatality predictions with fatality rates that have been empirically determined postconstruction based on carcass searching studies. Such validation enhances the value of models by demonstrating the accuracy of their predictions. A widespread and pervasive problem with existing wind-wildlife collision models is that they have largely gone unvalidated. The scarcity of direct comparisons between preconstruction mortality predictions and postconstruction mortality data is alarming because much emphasis is placed on the preconstruction risk assessments when making permitting decisions about a project. One reason for this scarcity may be that postconstruction fatality estimates are usually proprietary information at most wind energy facilities, and this information is not publically available. Some avoidance rate validation has been done, but such studies only address the accuracy of 1 of the models' parameters, rather than the accuracy of the models' fatality rate predictions. Some fatality rate validation studies have been informally conducted by various researchers, but have not been published in peer-reviewed or gray literature. In this section, we review the existing wind-wildlife collision risk model validation studies to characterize the level of empirical support for the accuracy of these models' predictions.

2.4.1 Fatality Rate Validation

The Eichhorn et al. (2012) simulation model has allegedly been validated against 2 independent studies that collected data on Red Kites at wind facilities in Europe. Eichhorn et al. (2012) claimed that the predictions from the simulation corresponded well to what was observed in the field studies, but no quantitative evidence of model validation was reported.

Normandeau (2012) validated 4 of 9 spatial collision models for birds and bats in the central U.S. using data from publically available studies in the region. Models were validated by standardizing the mortality from the publically available studies to mortalities per turbine per year and comparing the counts to the predicted value from the model. These values were compared to the relative risk of collision from the spatial model using Spearman's rank correlations. Validation occurred for horned lark, hoary bat, eastern red bat, and silver-haired bat. Correlation between observed versus predicted mortality was the following: horned lark ($r = 0.56$), eastern red bat ($r = 0.89$), hoary bat ($r = 0.85$), and silver-haired bat ($r = 0.91$) (Normandeau 2012). These correlation coefficients are moderate to high especially for the bat species, indicating that the collision model predicted mortality well for the areas with publically available studies. It is important to note that this model predicts only relative collision risk across a landscape, not site-specific fatality rates; hence, this model cannot be used to predict bird or bat fatality rates at individual wind energy facilities.

The ARC model (Podolsky 2008) allegedly over-predicts wildlife collisions at wind facilities (Richard Podolsky, pers. comm.), although no quantitative validations have apparently been performed.

Finally, the Biosis model has also allegedly been validated against postconstruction monitoring data from 2 Australian wind facilities at Bluff Point and Studland Bay. The Biosis model predictions using 90% and 95% avoidance rates for Wedge-tailed Eagles and White-bellied Sea-Eagles were within the 95% confidence limits for the average annually mortality observed in the field (Ian Smales, pers. comm.).

2.4.2 Avoidance Rate Validation

Although few studies have looked directly at the number of mortalities as it relates to the collision prediction, other studies have looked at validating the avoidance rates used in the model against data collected in the field (e.g., Scottish National Heritage 2008). This approach does not validate the entire model, but it does provide evidential support for the robustness of models' avoidance rate parameter. May et al. (2010) examined point count data on bird observations and compared it to known fatalities of white-tailed eagles from weekly searches at the Smøla wind energy facility in Norway. This approach allowed some level of avoidance rate validation. The average avoidance rate for the Band model was 0.925; whereas, the avoidance rate derived from field observations was 0.938 (May et al. 2010). In a second study, May et al. (2011) evaluated avoidance rates from satellite telemetry data and found them to be similar (0.975) to previous estimates from field data. No further quantitative analysis was performed in these studies.

All of the validation work done on collision risk modeling has been performed onshore, and there have been no attempts to validate offshore collision predictions. Despite the lack of collision data, birds have been shown to avoid offshore turbines to the point that fewer than 1% of ducks and geese were close enough to turbines to be at risk of collision (Desholm and Kahlert 2005a, 2005b). Currently, many methods are currently being tested to assess collision offshore in Europe including acoustic monitoring, imaging, and radar (Collier et al. 2011, 2012) and a joint industry project is being developed in the U.K. to monitor collisions at offshore wind facilities and validate avoidance rates (Aonghais Cook, pers. comm.).

2.4.3 Discussion

The scarcity of validation studies for collision risk models results in a high level of uncertainty regarding the accuracy of model-predicted wildlife fatality rates. Sources of uncertainty are numerous and include survey data variability, validity of model assumptions, and insufficient knowledge of bird displacement, avoidance, and attraction effects. Band (pers. comm.) estimated the inherent inaccuracy of wildlife collision model fatality predictions on the basis of several specific sources of error including uncertainty regarding flight activity (± 50%), uncertainty due to simplifications in the collision model (± 20%), and other untested model design parameters (±15%). Because of this level of uncertainty, collision model outputs must be interpreted with caution. Undue weight is often given to preconstruction collision risk model outputs in spite of recommendations against doing so, and in spite of the general lack of postconstruction validation data (Rowena Langston, pers. comm.).

Despite the few studies that have attempted to validate collision risk model mortality predictions and avoidance rates, collision risk models potentially add significant value to preconstruction wildlife risk assessments. Collision risk models allow 1 to calculate the probability of a bird colliding in the absence of avoidance, which can be a surrogate metric on the vulnerability of a species as well as how collision risk can vary with turbine design. The quantitative approach also makes collision risk more comparable among wind facilities because numerical values are more easily compared than qualitative assessments (Aonghais Cook, pers. comm.). The quantitative approach also builds on data collected specifically at the site of interest as opposed to a qualitative approach which often makes assumptions on comparability among species and sites (Roel May, pers. comm.). Quantitative models are also transparent in that all the inputs and assumptions are clearly defined which facilities a heuristic approach to answering questions about collision risk. (Ian Smales, pers. comm.). Quantitative and even untested models are also useful because they show how validation studies should be carried out and they document rational decisions (Vance Tucker, pers. comm.).

Although collision models do add some value to preconstruction risk assessment, particularly where little other information is available, their outputs must be interpreted with caution until more extensive validation support for specific models is brought to bear.

2.5 Recommendations for Application to Latin America

Because of the general lack of validation support for the accuracy of collision risk models, the application of such models to preconstruction assessments of wildlife collision risk adds marginal value for decision-making, and should not be a high priority for Latin American wind energy development.

As an alternative, we recommend conducting streamlined conventional preconstruction wind-wildlife risk assessments that are highly empirical and synthetic in nature. Ferrer et al., (2012) recently demonstrated that even synthetic, empirically oriented preconstruction wind-wildlife collision risk assessments are subject to a great deal of error and prediction inaccuracy, and this is a valid justification for taking a simplified, streamlined approach. Nonetheless, such studies represent the best available option for identifying any potential "show-stoppers" or wind wildlife risk issues at the site that can only be minimized, avoided, or mitigated prior to wind farm construction (i.e. turbine siting or micrositing considerations), hence there is still significant value in performing them.

Preconstruction wind-wildlife risk assessments for proposed Latin American wind energy facilities should synthesize all available information from technical literature, existing wind-wildlife studies, and region-specific biological data sets, and combine it with targeted field data gathered at the proposed site to develop a fine-toothed, site specific assessment of wind-wildlife risk at the site. Such studies should be highly focused on identifying impacts to species of the greatest management concern, in particular to species on national or international endangered species lists such as the IUCN red list. Furthermore, such studies should focus on identifying where, and for which species impacts are potentially significant at the level of local populations or larger.

Because of the pronounced seasonal variation in animal behavior and local/regional distributions present in most Latin American bird and bat faunas, it is ideal for preconstruction field studies to incorporate reasonably intensive and continuous field data gathering over the course of an entire year. Because interannual variation is expected to be less pronounced than seasonal variation in most cases, a single year of data gathering will normally be sufficient for preconstruction wind-wildlife risk assessments.

This streamlined approach is recommended based on the recognition that in most cases, the most reliable and efficient way to address wildlife impact issues associated with wind energy development in Latin America will be to apply an adaptive management paradigm that rests on the foundation of a strong post-construction impact monitoring program. Such a program should serve as the basis for developing, implementing, and assessing the effectiveness of impact minimization, avoidance, and mitigation measures for any observed significant impacts of concern. The primary function of performing the preconstruction risk assessment is to address any wildlife impact considerations that cannot be effectively managed or addressed once the wind farm is already constructed (e.g. wind farm siting, or turbine micrositing considerations).

3 Postconstruction Wildlife Fatality Monitoring Protocols: A Review of Existing Methodologies and a Proposed Protocol for Latin American Wind Energy Facilities

3.1 Introduction

Mortality of birds and bats caused by collisions or near-collisions with turbine rotors is a prime consideration in environmental risk and impact studies of wind energy facilities worldwide (Anderson et al. 1999; Arnett et al. 2007; Drewitt and Langston 2006, 2008; NWCC 2010; Jordan and Smallie 2010). The extent, spatiotemporal distribution, and species composition of bird and bat fatalities at wind energy facilities varies widely across biogeographic regions, habitat types, topographic features, and other environmental variables (Smallwood 2007; Arnett et al. 2007; Jordan and Smallie 2010; Strickland 2010; USFWS 2012 and references therein). Postconstruction monitoring programs are often implemented to gather high value empirical data on bird and bat mortalities at wind energy facilities. Such programs provide valuable scientific insights into the species composition and rate of fatalities, and the spatiotemporal relationships between fatality rates and various siting and animal behavioral characteristics. This information, in turn, provides environmental managers with an essential basis for assessing compliance with environmental conditions of the permit and/or financing of the wind facility, need and success for mitigation measures, and conducting adaptive management.

Although postconstruction fatality monitoring programs normally share the common objective of characterizing bird and bat fatality rates at specific wind facilities, they vary widely in field and analytical methodology, intensity, and duration. This variation is often driven by differences in the requirements imposed by governmental regulatory agencies or finance institutions in different countries or states, as well as by budgetary constraints and availability of local field expertise. All these factors can cause variation in the scientific accuracy, robustness, and validity of results. Furthermore, this variation can reduce the comparability of fatality rate estimates across sites, which limits the ability of scientists and managers to understand and manage bird and bat fatality patterns at wind energy facilities.

The primary objective of this chapter is to provide a standardized Protocol for postconstruction monitoring of avian and bat fatalities that can be implemented in Latin American wind energy developments that are financed by the Inter-American Development Bank (IDB). This Protocol aims to strengthen IDB efforts towards a more effective supervision of wind projects and monitoring of impacts on the avian fauna. To serve this purpose, several critical considerations guided the development of this Protocol, as follows:

- **Scientific validity and robustness**. This Protocol integrates the most recent technical information from field studies on postconstruction fatality monitoring methodologies and fatality rate estimations in order to maximize the scientific validity and robustness of the results. A key consideration is comparability of results across studies.

- **Cost effectiveness and pragmatism**. This Protocol was designed to maximize feasibility and ease of implementation at Latin American wind energy facilities. All elements of the Protocol were selected and structured for optimum cost effectiveness and pragmatism, with methodological instructions described in sufficient detail to enable effective implementation in Latin American contexts.

- **Flexibility**. Latin America encompasses a wide variety of biological and socioeconomic environments. Furthermore, proposed wind energy development projects may vary significantly in size and other factors that affect the potential for projects to generate adverse impacts to birds and bats. This Protocol is designed with flexibility in mind to accommodate this variation with corresponding variation in postconstruction fatality monitoring methodologies, while still maintaining scientific validity and comparability of fatality rate estimates across studies.

Section 3.2 of this chapter provides a brief summary of existing technical literature on bird and bat postconstruction fatality monitoring protocols at wind energy project sites worldwide, and the diversity of scientific considerations and regulatory contexts that have shaped them. Section 3.3 provides recommended postconstruction fatality monitoring protocols for birds and bats for IDB-funded wind energy development projects in Latin America.

3.2 Synthesis of Literature on Postconstruction Fatality Monitoring Methodologies for Birds and Bats

3.2.1 Introduction

The development of postconstruction monitoring methodologies for bird and bat fatalities has paralleled the global expansion of wind energy development, as regulatory agencies and scientists continue to identify critical data needs and ways of improving the accuracy and cost effectiveness of postconstruction fatality monitoring studies. Reviews by Arnett et al. (2007), NAS (2007), and Strickland et al. (2011) summarize recent scientific lessons learned, and contain many of the emerging ideas for optimizing the scientific validity and robustness of bird and bat fatality rate estimates based on postconstruction carcass searching field studies.

One central idea that has emerged from these studies is that there is no single, correct study design for postconstruction fatality monitoring of birds and bats. The design of any environmental monitoring program, and bird and bat fatality monitoring at wind energy facilities is no exception, entails design tradeoffs and choices that can only be made by balancing scientific and environmental priorities with budgetary, environmental, and other constraints that determine the optimum intensity and design of a postconstruction monitoring study at a given site. One manifestation of the diversity of possible solutions is evidenced by the variation across guidelines that have been produced for postconstruction fatality monitoring studies for birds and bats for wind energy facilities by various European, North American, and Austral-Asian nations, summarized in Table 3–1. This variation largely reflects the different regulatory and sociopolitical contexts of the different entities that have produced these guidelines. In considering optimum postconstruction bird and bat fatality monitoring study designs for Latin America, where no national or state guidelines have yet been developed, it is important to remember that while some of the design choices that have been adopted in North America, Europe, and Australia may be equally applicable for Latin America, others may not. For example, study components designed to ensure compliance with specific legal statutes of particular countries, such as the U.S. Endangered Species Act or Migratory Bird Treaty Act, may not be optimal for studies in other countries where comparable laws do not exist. By contrast, study components derived from purely scientific considerations, such as optimal bias correction factors, may be equally applicable in any location—although unique aspects of the biological taxa and environments present in Latin America may alter the applicability of some of the postconstruction fatality monitoring protocol elements that have been developed primarily in temperate latitudes.

For wind energy projects financed throughout the world by multilateral development banks (MDBs), the most important driver of postconstruction fatality monitoring programs for birds and bats is often the environmental compliance conditions that are attached to the loan agreements taken by the project proponent, in consultation with the MDB. While most MDBs have general policies in place to ensure that the projects they finance do not result in undue adverse environmental and/or social impacts, most do not yet have specific guidelines for wind energy projects[3]. To date, none of the MDBs

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[3] with the exception of IFC, see Environmental, Health and Safety Guidelines - Wind Energy, dated 2007 which consist of a general guideline.

have prescribed specific postconstruction fatality monitoring methodologies for birds and bats. The World Bank has recently produced a report outlining a wide variety of available options for reducing the potential adverse ecological impacts of internationally financed wind energy projects (Ledec et al. 2011), but this report was neither structured, nor intended, as a guideline to provide standardized environmental study methodologies to be implemented by the developers of World Bank-funded wind energy projects.

The need for standardizing such methodologies across IDB-funded projects was the primary impetus for developing the protocols presented in this chapter. In the remainder of this chapter, we synthesize the current state of science and regulatory practice for postconstruction fatality monitoring protocols for bird and bats worldwide, broken down by specific protocol elements, with a focus on distinguishing which of the established or recommended study design choices derived from North American, European, and Australian science and practice are, and which are not, optimal for application to Latin America.

Table 3–1. Avian and Bat Postconstruction Monitoring Requirements or Recommendations from Various Regulatory Agencies (NS = not specified).

Location	Search Duration	Search Period	Search Frequency	Number of Turbines Searched	Search Area Extent	Transect Design	Searcher Efficiency Trials	Scavenging Correction Trials	Estimator	Additional Methods Required
New York, USA[1] Standard postconstruction studies	2 years minimum	April 15 through November 15	Daily searches at all turbines if small project At larger projects 10 turbines searched daily, and at least 33% of the total turbines searched weekly	For small projects, search all turbines if < 10 turbines At larger projects (> 10 turbines), 33% of turbines	≥ 1.5 x turbine rotor diameter Mapping of ground cover recorded every day. Mowing is recommended to increase searcher efficiency.	5 m apart	At least monthly with various sized carcasses. The number of carcasses used should not cause excess attraction to bring scavengers to the area.	At least monthly with various sized carcasses. The number of carcasses used should not cause excess attraction to bring scavengers to the area.	NS	Bird habituation, avoidance studies, and bat acoustical monitoring
New York, USA[1] Expanded postconstruction studies	2 years minimum	April 15 through November 15	Daily searches at all turbines if small project At larger projects 10 turbines searched daily, and at least 33% of the total turbines searched weekly	For small projects, search all turbines if < 10 turbines At larger projects (> 10 turbines), 33% of turbines	≥ 1.5 x rotor diameter Mapping of ground cover recorded every day. Mowing is recommended to increase searcher efficiency.	5 m apart	At least monthly with various sized carcasses. The number of carcasses used should not cause excess attraction to bring scavengers to the area.	At least monthly with various sized carcasses. The number of carcasses used should not cause excess attraction to bring scavengers to the area.	NS	Radar surveys, bat acoustic monitoring, and raptor migration surveys
Arizona, USA[2] Category 1 or 2—low risk	1 to 2 years minimum	April to October	Daily searches at all turbines and meteorological (met) towers if small project. At larger projects, daily searches at least 30% of the total turbines and met towers .	For small projects, all turbines and met towers At larger projects, at least 30% of the total turbines and met towers.	Diameter is ≥ to the maximum rotor tip height	NS—Parallel or circular transects are acceptable	Conducted systematically through survey period. Use of trained dogs is recommended. Small birds can be used as surrogates for bats.	Conducted systematically through survey period Small birds can be used as surrogates for bats.	Orloff and Flannery (1992)	Bat acoustic monitoring and mist netting between August to October.
Arizona, USA[2] Category 3 or 4—high risk	2 to 3 years minimum	April to October	Daily searches at all turbines and met towers if small project. At larger projects, daily searches at least 30% of the total turbines and met towers.	For small projects, all turbines and met towers At larger projects, at least 30% of the total turbines and met towers.	Diameter is ≥ to the maximum rotor tip height	NS—Parallel or circular transects are acceptable	Conducted systematically through survey period. Use of trained dogs is recommended. Small birds can be used as surrogates for bats.	Conducted systematically through survey period Small birds can be used as surrogates for bats.	Orloff and Flannery (1992)	Bat acoustic monitoring and mist netting between August to October.

Location	Search Duration	Search Period	Search Frequency	Number of Turbines Searched	Search Area Extent	Transect Design	Searcher Efficiency Trials	Scavenging Correction Trials	Estimator	Additional Methods Required
Ohio, USA[3]	1-year minimum with possible extension	April 15 to November 15 with an option for additional seasons	Daily searches	If < 10 turbines, all must be searched, If 10 to 40 turbines, ½ searched, minimum of 10 If > 40 turbines, ¼ searched, minimum of 20.	Search out to a distance equal to 2x blade length	5 m apart north-south oriented	> 200 individual searcher efficiency trials. Use of native species is recommended.	> 50 carcass trials per year should be conducted. Use of native species is recommended.	NS	Bat acoustic monitoring
Pennsylvania, USA [4]	2 years minimum Pennsylvania Game Commission (PGC) can reduce monitoring if justified. At higher risk sites, additional monitoring may be imposed.	April 1 to November 15	Daily searches	≥ 10 turbines will be sampled or ≤ 20% of the turbines (whichever is greater).	Rectangular 120 x 120 m plot recommended	NS	> 200 individual searcher efficiency trials. Use of native species is recommended.	> 50 carcass trials per year should be conducted. Use of native species is recommended.	Shoenfield (2004) estimator.	Bat acoustic monitoring
California, USA[5] Category 1—low risk	1 year	March to October	Every 3, 7, or 14 days, more or less frequent if pilot scavenger trials indicate high or low carcass removal.	30% of turbines, selected at random via stratification or systematically	Search diameter equal to maximum rotor tip height.	3 to 6 m apart	Searcher efficiency trials should be conducted on site to test observer detection unknowingly to the searcher. Conduct trials at regular intervals throughout the four seasons.	Carcass removal trials should use recently killed birds and be checked at least every day for a minimum of the first 3 days and thereafter at regular intervals to calculate percent recovery. Spread trial over the four seasons and be sure not to swamp the area with carcasses.	Provides suggested formula, but review Gauthreaux (1995), Orloff and Flannery (1992), Kerns and Kerlinger (2004), Ericson 2004, Shoenfeld (2004), and Smallwood (2006).	NS
California, USA[5] Category 2 and 3—high risk	2 years	March to October	Every 3, 7, or 14 days, more or less frequent if pilot scavenger trials indicate high or low carcass removal.	30% of turbines, selected at random via stratification or systematically	Search diameter equal to maximum rotor tip height.	3 to 6 m apart	Searcher efficiency trials should be conducted on site to test observer detection unknowingly to the searcher. Conduct trials at regular intervals throughout the four seasons.	Carcass removal trials should use recently killed birds and be checked at least every day for a minimum of the first 3 days and thereafter at regular intervals to calculate percent recovery. Spread trial over the four seasons and be sure not to "swamp" the area with carcasses.	Provides suggested formula, but review Gauthreaux (1995), Orloff and Flannery (1992), Kerns and Kerlinger (2004), Ericson 2004, Shoenfeld (2004), and Smallwood (2006).	NS

Location	Search Duration	Search Period	Search Frequency	Number of Turbines Searched	Search Area Extent	Transect Design	Searcher Efficiency Trials	Scavenging Correction Trials	Estimator	Additional Methods Required
US Fish and Wildlife Service, USA[12]	≥ 1 year—low risk sites ≥ 2 years—moderate risk sites ≥ 3 years—high risk sites	NS	NS—should be adequate to measure fatalities. For raptors—14 to 28-day interval, for small birds or bats—shorter. Should occur when species are present.	If < 10 turbines, search all turbines. Systematic subsample of larger projects.	Minimum plot width of 120 m for bats. 2x turbine height for birds.	~3 to 10 m transects. 6 m apart should be adequate	50 to 200 searcher efficiency trials recommended	50 to 200 carcass removal trials recommended	NS—recommends the most contemporary equations be used.	NS
Poland[6]	3 years including within 5-year postconstruction span.	During all phenologic periods when species are present	Every 10 to 18 days	All turbines at once (farms of up to 15 turbines); at least 15 turbines (farms of 15-50 turbines); 1/3 of turbines (farms > 50 turbines)	NS	NS	≥ couple of experiments allowing for estimating detectability of collision victims	≥ couple of experiments allowing for estimating rate of decay of carcasses.	NS	NS
Ontario, Canada[7] Category 1 or 2 wind sites—low risk	Minimum 2 years, additional 2 years may be required if significant mortality has occurred.	May 1 to October 31	2x per week at monitored turbines Raptor mortality monitoring at every turbine once per month.	All turbines at wind power projects ≤ 10 turbines. For wind power projects >10 turbines, a subsample of at least 30% of turbines (minimum 10 turbines)	50 m radius, representing the maximum area searched.	5 m apart	≥ 10 trials (totaling between 30 and 60 carcasses). A maximum of 3 trial carcasses should be placed at any one time to avoid bias and flooding the area with carcasses.	≥ 10 trials (totaling between 30 and 60 carcasses). A maximum of 3 trial carcasses should be placed at any one time to avoid bias and flooding the area with carcasses. Monitored every 3 to 4 days	Ontario Ministry of Natural Resources (OMNR) provides their own statistical analysis, as a modified version of Jain et al 2007.	NS
Ontario, Canada[7] Category 3 or 4 wind sites—high risk	3 years minimum, additional 2 years may be required if significant mortality has occurred.	May 1 to October 31	2x per week at monitored turbines Raptor mortality monitoring at every turbine once per month.	All turbines at wind power projects ≤ 10 turbines. For wind power projects >10 turbines, a subsample of at least 30% of turbines (minimum 10 turbines)	50 m radius, representing the maximum area searched.	5 m apart	≥ 10 trials (totaling between 30 and 60 carcasses). A maximum of 3 trial carcasses should be placed at any one time to avoid bias and flooding the area with carcasses.	≥ 10 trials (totaling between 30 and 60 carcasses). A maximum of 3 trial carcasses should be placed at any one time to avoid bias and flooding the area with carcasses. Monitored every 3 to 4 days	OMNR provides their own statistical analysis, as a modified version of Jain et al 2007.	NS
Alberta, Canada[8]	1 year minimum, additional years determined through consultation	NS	NS—frequency (e.g., weekly, biweekly), seasonality (e.g., year-round, spring and fall migration), will be determined through consultation	NS—extent (subsample or complete sample of wind farm) will be determined through consultation	Radius ≥ height of the turbine.	NS	NS	NS	Recommends (Kingsley and Whittam 2003 and references listed within) for study protocols and analysis.	Methods may require infrared, thermal imagery, radar, and acoustical monitoring equipment to assess bird and bat movements.

Location	Search Duration	Search Period	Search Frequency	Number of Turbines Searched	Search Area Extent	Transect Design	Searcher Efficiency Trials	Scavenging Correction Trials	Estimator	Additional Methods Required
Canada, Canadian Wildlife Service [9] Small project (< 10 turbines)	≥ 1 year minimum	Spring and Fall	At least every 2 weeks (perhaps as often as once or twice a week during periods of great interest or presumed risk More frequently in areas where there is a high rate of carcass removal by predators)	50% of turbines	Radius = 50 m around each turbine. As turbine height increases the search radius should also increase.	NS	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	See Johnson et al. (2002) for more details on calculating carcass removal and predator efficiency rates. See Anderson et al. (1999) and Morrison (1998)	Bird utilization rate
Canada, Canadian Wildlife Service [9] Medium projects (11 to 50 turbines)	≥ 1 year minimum	Spring and Fall	At least every 2 weeks (perhaps as often as once or twice a week during periods of great interest or presumed risk. More frequently in areas where there is a high rate of carcass removal by predators)	30% of turbines	Radius = 50 m around each turbine. As turbine height increases the search radius should also increase.	NS	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	See Johnson et al. (2002) for more details on calculating carcass removal and predator efficiency rates. See Anderson et al. (1999) and Morrison (1998)	Bird utilization rate; bird use and potential impact
Canada, Canadian Wildlife Service [9] Large projects (50 to 200+ turbines)	≥ 2 years minimum	Spring and Fall	At least every 2 weeks (perhaps as often as once or twice a week during periods of great interest or presumed risk. More frequently in areas where there is a high rate of carcass removal by predators)	30% of turbines	Radius = 50 m around each turbine. As turbine height increases the search radius should also increase	NS	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	Detection and carcass removal trials should be conducted, with varying sizes and species of carcasses	See Johnson et al. (2002) for more details on calculating carcass removal and predator efficiency rates. See Anderson et al. (1999) and Morrison (1998)	Bird utilization rate; bird use and potential impact

Location	Search Duration	Search Period	Search Frequency	Number of Turbines Searched	Search Area Extent	Transect Design	Searcher Efficiency Trials	Scavenging Correction Trials	Estimator	Additional Methods Required
Scotland [10]	Years 1, 2, 3, 5, 10, and 15 after construction	May 1 to October 31 November 1 to November 31st.	2x per week (3 and 4-day intervals) 1x per month for raptor mortality surveys from November 1st to November 30th.	All turbines at wind power projects ≤ 10 turbines. For wind power projects >10 turbines, a subsample of at least 30% of turbines (minimum 10 turbines) All turbines within the project location should be monitored once a month during the survey period for evidence of raptor mortalities.	Radius = 50 m	NS	Searcher efficiency biases should be tested throughout the study season. Bias trials should not use numbers greatly in excess of likely number of victims, as this can attract scavengers, biasing the scavenging the estimates. Use of trained dogs is recommended to improve searcher efficiency, particularly for wind farms > 30 turbines	Carcass removal biases should be tested throughout the study season. Bias trials should not use numbers greatly in excess of likely number of victims, as this can attract scavengers, biasing the scavenging the estimates. Recommends the use of motion cameras for carcass removal trials to detect scavenging events	Suggests the use of a collision risk calculator that incorporates biased recognized during pre and postconstruction studies.	Vantage point observations recommended.
Australia [11]	NS—recommends to spread monitoring over the life of the wind farm	NS	NS—intensity and temporal scale over which postconstruction monitoring should occur will be determined by the predicted level of impact to key species.	NS—intensity and temporal scale over which postconstruction monitoring should occur will be determined by the predicted level of impact to key species.	NS	NS	Trials to determine capacity to detect carcasses should be undertaken at the site.	Trials to determine carcass scavenging rates should be undertaken at the site. Scavenger exclusion fencing around some turbines may reduce scavenging rates and thus increase capacity for carcass detection.	NS	Bird and bat utilization studies, behavioral response

[1] New York State Department of Environmental Conservation. Division of Fish, Wildlife and Marine Resources. 2009. Guidelines for conducting bird and bat studies at commercial wind energy projects. http://www.dec.ny.gov/docs/wildlife_pdf/finwindguide.pdf

[2] Arizona Game and Fish Department. 2009. Guidelines for Reducing Impacts to Wildlife from Wind Energy Development in Arizona. Web. 22 December 2010. http://www.azgfd.gov/hgis/pdfs/WindEnergyGuidelines

[3] Ohio Department of Natural Resources. 2009. On-shore and bat pre and postconstruction monitoring protocol for commercial wind energy facilities in OH. An addendum to the ODNR Voluntary Cooperative Agreement. 2009. http://www.dnr.state.oh.us/LinkClick.aspx?fileticket=S24B8hy2Iu4%3D&tabid=21467

[4] Pennsylvania Game Commission. 2007. Wind Energy Cooperative Agreement. Exhibit C. Protocols to monitor bat and bird mortality at industrial wind turbines sites. http://www.dcnr.state.pa.us/info/wind/resource1.aspx

[5] California Energy Commission and California Department of Fish and Game. 2007. California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development. Commission Final Report. California Energy Commission, Renewables Committee, and Energy Facilities Siting Division, and California Department of Fish and Game, Resources Management and Policy Division. CEC-700-2007-008-CMF. http://www.energy.ca.gov/2007publications/CEC-700-2007-008/CEC-700-2007-008-CMF.PDF

[6] Polish Wind Energy Association (PWEA). 2008. Guidelines for assessment of wind farms' impact on birds. Szczecin. 26 pp. http://www.psew.pl/backup/en/files/guidelines_for_assessment__of_wind_farms_impacts_on_birds.pdf?PHPSESSID=6e29c56d823542a8a364cb24223b0875

[7] Ontario Ministry of Natural Resources. 2011. Bird and bats habitats: guidelines for wind power projects. First Edition.http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@nr/@renewable/documents/document/stdprod_071273.pdf

[8] Alberta Sustainable Resource Development – Fish and Wildlife Division. 2006. Wildlife Guidelines for Alberta Wind Energy Projects.http://www.srd.alberta.ca/FishWildlife/WildlifeLandUseGuidelines/documents/WildlifeGuidelines-AlbertaWindEnergyProjects-Sep19-2011.pdf

[9] Kingsley A. and B Whittam. 2005. Wind Turbines and Birds. A guidance document for environmental Assessment. Canadian wildlife Service Environment Canada. Draft. http://www.energy.ca.gov/windguidelines/documents/other_guidelines/2006-05-12_Bckgrd_Envirmtl_Assmnt.Pdf

[10] Scottish Natural Heritage. 2009. Guidance on Methods for Monitoring Bird Populations at Onshore Wind Farms. http://www.snh.gov.uk/docs/C205417.pdf

[11] Environmental Protection and Heritage Council. 2010. National Wind farm Development Guidelines. Draft.http://www.ephc.gov.au/sites/default/files/DRAFT%20National%20Wind%20Farm%20Development%20Guidelines_JULY%202010_v2.pdf

[12] US Fish and Wildlife Service, 2011. U.S. Fish and Wildlife Service land-based wind energy guidelines. OMB control number 1018-0148.

3.2.2 Elements of Postconstruction Fatality Monitoring Protocols for Birds and Bats

The basic nature of postconstruction fatality monitoring programs for birds and bats is similar across most countries and regions, and consists of three distinct elements: (1) carcass searches, involving field surveys for bird and/or bat carcasses in established search areas in the vicinity of wind turbines; (2) correction for various well-known biases in carcass searching efforts, including scavenging bias[4], and searcher efficiency bias[5]; and (3) calculation of the overall bird and/or bat fatality rate at the facility. Each of these three elements is discussed in a separate section below.

Carcass Searches

One essential element of a postconstruction fatality monitoring protocol for birds and bats is carcass searching, which entails one or more observers conducting searches for bird and bat carcasses beneath operating wind turbines to document direct observations of bird and bat fatalities at the wind facility. During such searches, carcasses encountered by the field observer(s) are usually assumed to have died because of a collision or near-collision (e.g., barotrauma; Durr and Bach 2004) with the wind turbine rotor or tower. To render quantitative fatality rate estimates, carcass searching areas, effort, and methodology must be strictly defined and standardized (Strickland et al. 2011).

The search areas may take many shapes from circular to rectangular, and typically contain one or more turbines or meteorological (met) towers (NAS 2007; Strickland et al. 2011) depending on the arrangement of turbines. Trained searchers systematically walk pre-established parallel transects, typically established 5 to 6 m apart through the delineated search areas (see section titled Search Area below). Searchers walk transects at a reasonable pace visually scanning the ground out 2 to 3 m on both sides of transects for fatalities. If a carcass is encountered, the searcher marks the location with flagging and continues the search. Once complete, searchers return to each carcass and record appropriate data on a standardized datasheet including the date and time, species, age and sex (where possible), nearest turbine number or identification, distance and direction to nearest turbine, ground condition surrounding carcass, any observed injuries, estimation of the number of days since death, and carcass condition (e.g., fresh,

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[4] The failure to detect carcasses because the carcass had been removed or consumed by a scavenger before the observer conducted the carcass search.

[5] The failure of carcass searchers to successfully detect carcasses that were present during the carcass search.

rigor, scavenged, etc.) (Strickland et al. 2011). If possible, photographs and GPS location of carcasses can be helpful for identification and mapping purposes. All carcasses are often placed in a plastic sealable bag, marked with a unique code and stored frozen for future use in bias correction experiments (see section titled Bias Correction below). If carcass identification is problematic, frozen carcasses may be identified by additional experts (e.g., local university, wildlife organization, museum, etc.).

Search Effort Duration

The duration of the carcass search effort is one of the most important study design elements influencing the cost of the study. Carcass searching is usually initiated following the construction of the facility, although in some cases, monitoring during construction is required (OMNR 2011). A single, continuous year of postconstruction carcass searching effort is sufficient to capture the entire range of seasonal variation present at any site, and is typically regarded in North America, Europe, and Australia as a minimum carcass search duration (see Table 3–1). However, additional years of carcass searching are often required to capture interannual variation in natural bird and bat populations, although such variation is often not as pronounced as seasonal variation within a year. The required or recommended duration of monitoring is usually determined by site-specific factors, including the extent of interannual variation in the ecosystem, with particular attention paid to bird and bat taxa of high sensitivity or risk. Most recent postconstruction bird and bat carcass searching efforts in North America and Europe span between two and five years, with a large majority of environmental managers and regulators in the U.S. requiring three years postconstruction carcass searching (CEC 2007; PGC 2007; AZNR 2009; NYDEC 2009; ODNR 2009; European Commission 2010; OMNR 2011). Subsequent build-out phases of specific wind energy facilities (e.g., phase 2 or 3 of particular sites) are a special case in the U.S., and may require minimal additional surveys, particularly if previous surveys have demonstrated relatively low bird and bat fatality rates at the site (USFWS 2012).

Search Frequency

Search frequency is another important design parameter of postconstruction fatality monitoring programs for birds and bats, exerting a strong influence on the labor effort required to implement the study, and also the bias corrections and statistical methods required to produce a robust fatality rate estimate from the study. Carcass searches are normally conducted at daily, weekly, or monthly intervals at U.S. wind energy facilities (Anderson et al. 1999; Morrison 2002; Arnett et al. 2008; see Table 3–1). Search frequency is often varied to account for seasonal variation in bird and bat abundance at particular sites, with increased search frequency implemented during migratory periods when risk of bird and bat fatalities is greater, and lower search frequency implemented during summer and winter, when bird and bat abundance is typically lower in most regions of North America (PGC 2007; OMNR 201). In higher latitude portions of North America, bird and bat abundances are often so much lower during the cold season than during the warm season, that searches are often not required during the winter months (NYDEC 2009; MIDR 2009; AZNR 2009). Because of the lower latitude of much of Latin America, year-round carcass searching will normally be warranted, as there is no season during which overall bird and bat abundance is expected to be low enough to justify seasonal suspension of carcass searching efforts. Seasonal variation in carcass search effort may be optimal for some Latin American environments in which strong seasonal variations in bird and bat abundance are expected (e.g., tropical deciduous forests, migratory corridors) although other locations with lower seasonal variation and minimal migrant passage may warrant uniform carcass search frequency throughout the year.

Another factor influencing optimal carcass search frequency is the rate at which scavengers are expected to consume bird and bat carcasses in the specific environment of the wind energy facility (Anderson et al. 1999; Morrison 2002; Strickland et al. 2011). In general, increased carcass scavenging rates dictate increased search frequencies (Morrison 2002; Strickland et al. 2011). A carcass search interval equivalent to the average persistence time of carcasses in the environment is often recommended (Strickland et al. 2011). The average persistence time of carcasses is normally determined empirically by scavenging bias trials (see section titled Scavenging Bias below), and may vary significantly across habitat types and seasons (Morrison 2002; Arnett et al. 2005; Strickland 2011). In the U.S., empirically derived average carcass persistence times range from two (Fiedler et al. 2007) to 52 (Tierney 2007) days, and a search interval of seven days is recommended in most cases to answer postconstruction fatality questions (Miller 2008; Strickland et al. 2011, see Table 3–1). For projects in tropical environments, particularly at low elevations, carcass scavenging rates are expected to be higher (Houston 1985; DeVault et al. 2003); therefore, carcass search intervals of less than one week may be optimal. Because bird and bat carcass scavenging rates have not yet been well characterized for Latin American environments, optimal carcass search frequencies for Latin American wind energy facilities cannot yet be firmly established. While some flexibility to adjust search frequencies based on empirical determinations of carcass scavenging rates should be built into Latin American postconstruction fatality monitoring protocols for birds and bats, we recommend applying a one day search interval (see Protocol section below), as this is conservative with respect to introducing uncorrectable levels of scavenging bias.

Subsampling of Turbines for Searching

Subsampling of turbines for carcass searching, if selected appropriately, is a valid technique and can decrease time and costs associated with the monitoring program with minimal reduction in the accuracy and robustness of the resulting fatality rate estimates (Fuller 1999; Strickland et al. 2011). In North America, Strickland et al. (2011) recommended that at least 30% of turbines be searched for projects with greater than 30 turbines, with higher percentages recommended for smaller projects. A wide variation can be seen in turbine subsampling guidelines for carcass search efforts among North American, European, and Australian governmental regulatory agencies (see Table 3–1). Many governmental agencies define their turbine subsampling requirement as a minimum percentage of the total number of turbines at the wind farm that should be searched.

One key consideration regarding turbine subsampling in carcass search efforts is the heterogeneity of the environment. Greater subsampling (i.e., fewer turbines searched) is generally acceptable in more homogeneous environments (e.g., flat plains or cropland), whereas less subsampling (i.e., more turbines searched) is preferable in heterogeneous environments, where there may be significant variation in bird and bat mortality rates among turbines (USFWS 2012). The subsampling must be representative of the habitat types found within the project area.

A further consideration for turbine subsampling in carcass search efforts is the interrelationship between subsampling of turbines and subsampling of the delineated search areas beneath individual turbines. Lower subsampling at one of these levels permits higher subsampling in the other for a given level of overall carcass search effort. Past monitoring programs have emphasized low subsampling of areas beneath individual selected turbines, and higher subsampling of search turbines within overall projects. More recent trends have indicated that higher subsampling of areas beneath individual turbines is more cost effective (Sonnenberg 2011; ODNR 2012), which enables lower subsampling of turbines within projects for the same search effort. The protocols presented in this report incorporate this idea. In essence, older methods selected fewer turbines for searching, but intensive search efforts were conducted to sample the entire circular areas below the individual turbines regardless of the searchability of the habitat below the turbine (Anderson et al. 1999; Arnett et al. 2009). This often results in very large expenditures of effort at individual turbines conducting carcass searching in substrates where searcher success is low (e.g., dense, tall vegetation), hence overall data gathering success per unit of effort is low (Huso et al. 2010). The newer methods, including the Protocol recommended in this report, recommend more extensive subsampling of areas beneath individually selected turbines, specifically cutting out all but the easy-to-moderate searchability ground substrates within the desired radius of the tower (see section titled Search Area below) to maximize the cost effectiveness of carcass searching effort. By adopting higher subsampling at the individual turbine level, lower subsampling of turbines within projects can be achieved for the same level of overall search effort. The extent of subsampling at each of these two levels is interrelated, and should ideally be determined on a case by case basis based on the habitat conditions at the site. For example, projects sited in highly searchable areas (e.g., extensive bare dirt or low grass) may warrant lower subsampling of individual turbine search areas (i.e., most or all of the area below individual turbines is searched) and higher subsampling of turbines within the project (fewer turbines searched), whereas projects sited in less searchable environments (e.g., tall crops, shrubland, forest) may warrant heavy subsampling of the areas below individual turbines (i.e., searching only in the open portions such as access roads, cleared areas), but lower subsampling of turbines within the project (most, or all of the turbines searched).

Search Area

The definition of the area to be searched beneath the individual turbines that have been selected for carcass searching exerts a strong impact on the overall level of effort, and thus the cost of the monitoring program. As with other study parameters, it entails optimizing the cost effectiveness of the effort expended, and different regulatory agencies in North America, Europe, and Australia have specified a range of differently sized and shaped areas for standardized carcass searches (Table 3–1). In the case of defining search areas, the most important influence on the effectiveness is the spatial distribution of bird and bat carcasses that are deposited as a result of collisions or near-collisions with wind turbines. Although this distribution of carcasses has a long tail, with some fatalities being deposited at great distances from the turbines that injured them (e.g., blown by wind or moved far away under its own power before dying, Gauthreaux 1995; Arnett et al. 2008), the vast majority of carcasses are deposited in close proximity to the tower, hence the most efficient carcass search effort design entails searching within a fairly small radius of the base of the tower. Many postconstruction monitoring studies have reported that nearly all (~90%) bird fatalities are found within the turbine height distance measured along the ground from the base of the turbine (Orloff and Flannery 1992; Erickson 2001, 2003; Kerns et al. 2005; Jain et al. 2008; Smallwood and Thelander 2008), and a large majority (> 80%) of bat carcasses are found within a distance equal to 50% of the tower height (Kerns and Kerlinger 2004; Poulton and Erickson 2010; Piorkowski 2010; Grodsky et al. 2011). Based on these empirically documented carcass distributions, we recommend searching within a circular area around the base of the tower of selected turbines, with a radius equivalent to the height of the tower. Although the carcass search area is initially determined as a circle around the base of the turbine towers as described above, these circles may contain unsearchable or very difficult-to-search substrates (Arnett et al. 2005; Smallwood 2007; Huso 2010), hence subsampling of the area within these circles may be optimal for maximizing efficiency and cost effectiveness of carcass searching (Sonnenberg 2012; and see section titled Subsampling above). Unsearchable or low-searchability substrates, include steep slopes or dense or tall vegetation, such as shrubland, forest, or tall, dense cropland (Arnett et al. 2005; Arnett et al. 2009). In such habitats, searcher efficiency ranges may be as low as 15% to 50%, compared with 75% to 100% searcher efficiency in areas that are easily searchable (Johnson et al. 2003; Young et al. 2003; Anderson et al. 2004, 2005; TRC 2008; Smallwood 2007; Arnett et al. 2008; Johnson et al. 2010; Normandeau 2010). The size and coloration of carcasses also causes variation in carcass detectability, with larger animals, and those whose coloration contrasts more strongly with the coloration of the substrate being more efficiently detected by carcass searchers than smaller, more camouflaged carcasses (Arnett et al. 2006; Smallwood 2007).

The carcass searching protocol recommended for Latin America in this report follows recent methodological recommendations for subsampling of habitats within the radius-defined search areas below turbines, to eliminate searching in unsearchable, or low-searchability areas (Sonnenberg 2012). The first step in eliminating such areas is to define visibility classes to describe the variation in substrate searchability (Arnett et al. 2005; Huso 2010). A useful classification was developed by Arnett et al. (2005), and is presented in Table 3–2 below. Using these visibility class definitions, the distributions of the different searchability substrates within the actual search area are then mapped, recorded with GPS, and marked in the field.

Table 3–2. Visibility Classes at Postconstruction Turbine Locations*

Visibility Class	Percent Vegetation Cover	Vegetation Height
Easy	> 90% bare ground	< 15 cm tall
Moderate	> 25% bare ground	< 15 cm tall
Difficult	< 25% bare ground	15 to 30 cm tall
Very Difficult	Little or no bare ground	≥ 30 cm tall

* from Arnett et al. 2005

Subsampling of areas by visibility class can then be performed as desired. The recommended Protocol for Latin America incorporates recent double-sampling innovation (Sonnenberg 2012), which was developed specifically for wind projects located in croplands in North America, in selecting only those areas with easy or moderate searchability for the carcass searching effort. Using the maps of the searched areas, the areal extent of the actually searched areas can then be calculated, and the fatality rate calculation is then adjusted by the appropriate multiplier to account for this subsampling (see section titled Estimation of Mortality below).

As noted previously, extensive visibility-based subsampling for projects in low-searchability landscapes can be balanced by reducing the extent of turbine subsampling (i.e., increasing the number of turbines searched, see section titled Subsampling of Turbines above). This has the effect of keeping overall subsampling levels sufficiently low to render scientifically robust and accurate fatality rate estimates at the project level.

Bias Correction

Even after extrapolating to account for search area subsampling, it is well known that fatality rate estimates based solely on the number of fatalities recovered by observers during the carcass searches would underestimate the actual bird and bat fatality rates at wind energy facilities (Huso 2010). This is because of several sources of bias that cause carcasses to fail to be detected during searches. Although a wide variety of such biases has been described (Smallwood and Thelander 2008), two principal sources of bias are generally regarded to be significant enough to warrant the inclusion of special measures to correct them within postconstruction fatality monitoring protocols for birds and bats at wind energy facilities: scavenging bias and detectability (or searcher efficiency) bias (Linz et al. 1991; Anderson et al. 1999; Morrison 2002; Erickson et al. 2002; Smallwood 2007; Huso 2010; Strickland et. al. 2011). Corrections for each of these potential sources of bias are included within the recommended postconstruction fatality monitoring Protocol for birds and bats in Latin America, presented in the following chapter, and each source of error is reviewed and discussed below.

Scavenging Bias

Scavenging bias is the failure of searchers to detect carcasses because the carcasses have been removed or consumed by scavengers before the carcass search occurred. A wide variety of animals may scavenge bird and bat carcasses at wind energy facilities, and scavenging bias may be significant at sites located virtually anywhere in the world. At wind energy facilities in North America, some of the animals that are known or believed to contribute the most to bird and bat carcass scavenging at wind energy facilities include skunks, possums, and coyotes, as well as vultures, ravens, and other corvids (Strickland et al. 2011). In Latin America, scavenging of bird and bat carcasses at wind energy facilities is not well characterized, but a wide variety of animals are expected to scavenge carcasses, and scavenging rates are likely to be higher than they are in much of North America based on more rapid nutrient cycling processes, particularly in lowland tropical environments during wet seasons (Janzen, 1983; Houston 1985; DeVault et al. 2003).

The most common and widely accepted method of correcting for scavenging bias in bird and bat fatality rate estimates at wind energy facilities is to multiply the observed number of carcasses by a correction factor that represents the proportion of carcasses that have been removed or consumed by scavengers before the searcher has had a chance to conduct a search (Orloff and Flannery 1992; Jain et al. 2008). More specifically, the correction factor is equivalent to the proportion of carcasses that are expected to remain in place (unscavenged) after a duration of time equal to one half of the carcass search interval (Orloff and Flannery 1992; Jain et al. 2008). The reason that one half of the search interval is used, is because bird and bat fatalities are assumed to occur continually over time and have an equal probability of collision on each day after the turbine search. The length of time a carcass remains on the study area before it is removed can be modeled as an exponentially distributed random variable (Arnett et al. 2009; Huso 2010). This assumes that fatality is constant in the interval between searches and the probability of removal over the entire interval is the same for any one carcass. To illustrate this with an example, if seven days have elapsed since the most recent carcass search, then the carcasses that may actually have fallen within the search area since the last search are equally likely to have fallen one, two, three, four, five, six, or seven days previous to the search. Therefore, on average, the carcasses that were deposited within that area during that seven day interval were present at the site for 3.5 days before the next search occurred, or half of the search interval. More recently, Warren-Hicks et al. (*in press*) suggested that a Weibull distribution is preferable to an exponential distribution for representing the shape of the scavenging function over time, as carcasses are expected to decrease in their attractiveness to potential scavengers over time.

The average carcass persistence time is a function of the scavenging rate at the site, which is normally determined empirically at each wind energy facility by conducting carcass removal trials (Orloff and Flannery 1992; Arnett et al. 2005; Strickland et al. 2011; see Table 3–1). In such trials, a number of experimental carcasses (e.g., fresh bird, bat, or surrogate species such as mice or chicken carcasses) are placed in the field at the site. The location of each carcass is recorded with GPS unit so that observers can easily relocate all carcasses, and then each carcass is visited at set intervals until the carcasses have been removed by scavengers. The date of disappearance of each carcass is recorded, so that the average persistence time of carcasses in that environment can be calculated empirically.

To obtain valid results from such trials, it is essential to separate the carcasses widely in space, and to avoid marking the locations of the carcasses in ways that would potentially attract or alert predators to the locations of the carcasses (PGC 2007; CEC 2007; Strickland et al. 2011). A sufficient number of carcasses should be used so that a robust average persistence time can be calculated (Smallwood 2007; Huso 2010), but excessive numbers should be avoided because they may saturate the local food supply for scavengers, or attract larger scavenging rates because of significantly enriched food supply (Smallwood 2007). In North America, the number of experimental carcasses that have been used in carcass removal trials ranges from six to more than 200 (Arnett et al. 2008); and Strickland et al. (2011) recently recommended the use of 50 experimental carcasses in each carcass removal trial. Obtaining this quantity of fresh bird or bat carcasses for these trials is not always practical, and some U.S. regulatory agencies have accepted smaller sample sizes or the use of non-native species (i.e., European Starlings; House Sparrows) or small mice as surrogates for bats or small birds (PGC 2007; CEC 2007; ODNR 2010). Furthermore, scavenging rates at particular sites may exhibit significant variation over the course of a year because of seasonal shifts in the abundance and activity of scavengers (Morrison 2002; Huso et al. 2010; Strickland et al. 2011). To account for this variation, carcass removal experiments are often repeated in different seasons throughout the study year. From this, separate seasonal average persistence times for bird and bat carcasses can then be determined and incorporated into season-specific bird and bat fatality rate estimates.

Another consideration in scavenging bias corrections is that large bird carcasses typically have longer persistence times than do the carcasses of small birds or bats (Smallwood 2007; NAS 2007; Arnett 2006; Strickland et al. 2011). As a result, some authors have suggested conducting separate carcass removal trials for differently sized carcasses, and calculating separate scavenging bias corrections for different size classes of birds accordingly (Strickland et al. 2011). Many studies have used the overall average of all scavenging bias trails conducted throughout the study year for calculation of estimated mortality for birds and bats separately (Erickson 2001, 2003; Kerns et al. 2005; Curry and Kerlinger 2008; Jain et al. 2008). Ideally, the carcass species chosen for bias trials should reflect the species composition local to the area, for those are the common prey items for local scavengers, and the use of carcasses of surrogate species foreign to the site may introduce additional bias.

One way to eliminate the biases in scavenging rate that may be introduced by carcass enrichment, artificial placement of experimental carcasses at the site by researchers, and the use of surrogate species' carcasses is to rely exclusively on the carcasses of birds and bats actually found at the site for the determination of average carcass persistence times. In addition to eliminating these biases, this technique also eliminates significant cost and complexity from the execution of the carcass searching protocol. One potential disadvantage of this technique is that the number, timing, and placement of carcasses is not controlled. However relying on the natural distribution of carcasses at the site captures the most realistic possible representation of the actual carcass scavenging ecology at the site, which should result in the most realistic carcass persistence time estimates. While this technique is not normally available as an option when carcass searching protocols entail the removal of found carcasses upon discovery for identification purposes, the reliance of the recommended Protocol on identification via photographs of the carcasses taken by the searchers in the field enables the application of this technique. Furthermore, because accurate determination of carcass persistence times requires daily monitoring of experimental carcasses, carcass search efforts that apply lower than daily searching frequencies cannot be used for the multiple purpose of documenting carcass persistence times, whereas with the daily carcass searching in the recommended Latin American carcass searching protocol contained in this report, this can be accomplished during normal carcass searching efforts (see Protocol section below for further detail).

Detectability (Searcher Efficiency) Bias

Detectability, or searcher efficiency bias, is the failure of searchers to detect carcasses during their carcass searches even though the carcasses were present at the time of the search. It is well known that observers vary in their ability to detect carcasses in the field (Strickland et al. 2000; Morrison et al. 2002; Arnett et al. 2005; Jain et al. 2007; Huso 2010). Variation among observers in carcass detection efficiency is affected by searcher training, physical ability, and eyesight (Wobeser and Wobeser 1992; Philibert et al. 1993), as well as other factors such as the size and coloration of animal carcasses and weather conditions during searches (Anderson et al. 1999). It is also well known that the detectability of carcasses in the field is strongly affected by the type, height, and density of vegetation present in the carcass searching area, which may exhibit pronounced seasonal variation (Strickland et al. 2000; Morrison et al. 2002; Arnett et al. 2005; Jain et al. 2007; Huso 2010).

One solution to the carcass detectability bias problem that has been suggested by some researchers is to use dogs instead of humans to search for carcasses Arnett (2006) and Kunz et al. (2007). The advantages of using dogs include the increased sensory perceptive abilities of dogs relative to humans, in particular with regard to olfaction, which results in overall higher carcass detection levels, especially in heavily vegetated environments where visually based carcass searching is extremely difficult. Despite this advantage, dog-based carcass searching has not become a widely adopted solution in North America, Europe, or Australia (Table 3–1), and is not likely to be a viable solution for Latin America, as it requires highly specialized staffing and training, and appropriate dogs are not likely to be widely available. Furthermore, variations in skill, training, and behavior among search dogs are very hard to control and measure, and introduce additional biases (Gutzwiller 1990; Arnett 2006; Kronner et al. 2008).

A more widespread solution for correcting carcass detectability bias is to conduct searcher efficiency experimental trials in parallel to the carcass searching effort, to empirically measure searcher efficiency in detecting carcasses and develop study-specific detectability bias correction factors (Anderson et al. 1999; Smallwood 2007; Strickland et al. 2011; and see Table 3–1). Such trials are conducted as follows: unknown to the carcass searcher, an additional field worker places a certain number (50 has been recommended by Strickland et al. 2011) of experimental carcasses within the normal search areas, recording the locations with a GPS so that they can be relocated, but taking care not to mark them or otherwise alter their detectability to the searcher relative to carcasses that have been naturally deposited on the site from actual wind turbine collision or near-collision fatalities. Immediately after the actual search effort is conducted, the second field worker revisits all of the experimental carcasses to see how many have been detected by the searcher. The proportion of experimental carcasses detected by the searcher is then used as the detectability, or searcher efficiency, bias correction factor. Previous searcher efficiency experiments at wind farms have revealed that small birds and bats are more frequently missed by searchers than larger birds (Johnson et al. 2003; Young et al. 2003; Arnett et al. 2006). Such experiments have also illustrated the strong influence of vegetation type on carcass detectability, and have enabled the quantitative characterization of typical carcass detection probabilities in different vegetation types (Arnett et al. 2006; Curry and Kerlinger 2006; Smallwood 2007; Normandeau 2010; Johnson et al. 2010, and see Table 3–2). The disadvantages of conducting searcher efficiency bias correction experiments at wind energy facilities is that they add significant cost and complexity to postconstruction bird and bat fatality monitoring efforts.

A cost-effective alternative to conducting searcher efficiency experiments in the field at each wind energy project is to use carcass detectability rates that have been empirically determined in previous studies. This limits the need for additional staffing, and therefore reduces project complexity and cost. To apply carcass detectability rates measured elsewhere to Latin American carcass searching efforts in a scientifically valid manner, two important steps must be taken, as follows:

- Carcass searching must only be conducted in easy and moderate visibility classes (see section titled Search Area above). Carcass detection rates in such classes, in addition to being higher than in lower visibility classes, are also less variable; hence the application of carcass detection rates measured elsewhere is valid (Smallwood 2007; Smallwood and Karas 2009). The restriction of carcass search efforts to easy and moderate search classes carries other efficiency advantages for postconstruction monitoring protocols, discussed in section titled Search Area (above), and is applied in the recommended Protocol presented in this report.

- Conservative carcass detection rates must be used, so that any possible error introduced by using detection rates that may differ from those actually present at the site are likely to cause a slight overestimation of bird and bat fatality rates, rather than an underestimation. Based on previous studies, a conservative carcass detection rate within easy and moderate visibility class search areas is 60% for bats and small birds, and 80% for moderate to large birds (Johnson et al. 2003; Young et al. 2003; Anderson et al. 2004, 2005; Smallwood 2007; Arnett et al. 2008; Smallwood and Thelander 2008; Johnson et al. 2010; Normandeau 2010). The protocols presented in this report incorporate the application of these carcass detectability bias correction factors in lieu of conducting carcass detectability experiments in parallel to the carcass searching efforts at each wind project.

Estimation of Mortality

Overall fatalities at wind farms are estimated based on the number of carcasses recovered during the standardized searches and corrected for the biases inherent in carcass searching studies. As discussed above, the variations in carcass persistence, detectability, and search plot size are biases that need to be accounted for to accurately portray the fatality estimate of a facility. In recent years, several approaches to estimate mortality have been proposed at wind projects (Johnson 2003; Shoenfeld 2004; Jain et al. 2008; Huso 2010), each incorporating adjustment factors for searcher efficiency and scavenger biases, as well as correcting for the area not searched and the proportion of turbines searched. The selection of an estimator is critical for comparison impacting the results of the monitoring program. There is currently no consensus on which is the best to use, and requirements vary among state and federal regulatory agencies in North America (CEC 2004; PGC 2007; ODNR 2009; OMNR 2011; see Table 3–1).

In general, the differences among these estimators derive from how scavenging and detectability correction factors are determined and incorporated into the calculation for overall fatality. The Johnson (2003) estimator, also referred to as the "naïve estimator", uses the most simplistic model using search intervals, empirically determined carcass persistence time, and detectability rates and accounts for turbines not searched. However, this estimator has been shown to have a tendency to underestimate fatality rates, with a high level of sensitivity to variation in carcass scavenging rates (Huso 2010; Strickland et al. 2011). For example, in sites with high carcass scavenging rates (i.e., short carcass persistence time) this estimator can generate unrealistically low estimates of fatality (Arnett et al. 2009). An important disadvantage of this estimator is that carcass detectability is not taken into account.

The Shoenfeld (2004) estimator is also known as the "modified estimator", because it was an attempt to correct for the underestimation of fatality by incorporating the detection factor into each scavenging rate. It assumes that fatalities, carcass removal, and even search intervals are all Poisson processes. This estimate has also been shown to underestimate fatalities, and exhibits a high degree of sensitivity to on both the carcass persistence time and searcher efficiency parameters (Gritsky et al. 2009; Arnett et al. 2009; Strickland et al. 2011).

Huso (2010) recently provided a new estimator that accommodates variation in searcher efficiency and scavenging rate across trials and across substrate visibility classes present on site. Because bias for each parameter is weighted proportionally for each distinct trial, it is fairly robust to variation in sources and magnitudes in detectability and carcass removal rates (Huso 2010; Strickland et al. 2011). However, this estimator requires specific input data gathered in formal scavenging rate and searcher efficiency bias correction experiments conducted by the placement of experimental carcasses on the site by separate observers for experimental calculation of carcass discovery and disappearance patterns at the site. Because the application of the Huso estimator requires the performance of these experiments, and the necessary input data are therefore unavailable in the recommended Protocol presented in this report for Latin America, this estimator is not appropriate for use with the recommended Latin American post-construction monitoring protocol presented in this report.

The most widely applied estimator, and the one selected as optimal for the Latin American Protocol presented in this report, is the Jain (2008) estimator. Statistically different than the naïve and modified estimators, the Jain estimator provides a basic and straightforward statistical formula for mortality, based on the assumption that a carcass that is missed by searchers once does not have a chance of being picked up again. It separates the derivation of carcass persistence and detectability, limiting the introduction of bias into the overall estimate, and improving the comparability of fatality estimates across sites with varying scavenger rates. This estimator has also been shown to produce conservative fatality estimates with respect to impact assessments, with a slight tendency to overestimate fatality rates (Strickland et al. 2011).

This statistical equation for the calculation of this estimator is as follows:

$$\mathbf{C} = \frac{\mathbf{c}}{(\mathbf{A_x} * \mathbf{S_c} * \mathbf{S_e} * \mathbf{P_t})}$$

where,

C is the overall estimated fatality rate for the facility, expressed in terms of number of fatalities/MW name plate capacity/year and is calculated separately for birds and bats;

c is the number of carcasses actually found during the standardized searches;

A is the proportion of area under turbines that was searched; determined by dividing the total area actually searched by the total area within radius **x** of all searched turbine towers, where **x** is the height of the turbine tower;

$\mathbf{S_c}$ is the proportion of carcasses not removed by scavengers prior to carcass searching; calculated as

$$\mathbf{S_c} = 1 - \frac{1}{1+p}$$

where p is the average number of days that a found carcass persists at the site before being consumed or removed by scavengers

$\mathbf{S_e}$ is a fixed value representing the proportion of carcasses successfully discovered by searchers during carcass searching, predetermined based on prior empirical studies as a conservative minimum searcher efficiency for substrates of easy to moderate searchability (0.6 for bats and small birds, 0.8 for large birds); and

$\mathbf{P_t}$ is the proportion of turbines searched within the overall wind farm (i.e., turbines searched/total number of turbines operating at the wind farm).

Because input parameters to the Jain estimator may vary across taxa and over the course of a year, we recommend calculating fatality rates separately for large birds, small birds, and bats, and calculating each of these values separately for each month. These taxon-specific monthly values can then be combined as desired to produce summary fatality estimates and rates for all flying wildlife and by season, year or entire study as desired.

For comparisons across sites, we recommend reporting the number of fatalities based on the number of name plate capacity of the turbines being studied (i.e., fatalities/MW/study year). This can be determined by dividing the overall estimated fatality rate by the overall capacity of turbine generation within the wind farm inclusive of the monitoring program.

3.3 Postconstruction Fatality Monitoring Protocol for Birds and Bats in Latin American Wind Energy Projects

3.3.1 Introduction

In this section, we present a recommended Protocol for postconstruction fatality monitoring studies for birds and bats to be implemented at IDB-funded wind energy projects. This Protocol was developed based on a comprehensive worldwide review of scientific literature and recommendations, as well as current practice for such protocols, with a prevailing consideration given to optimizing design choices for implementation in Latin America. As discussed earlier, three criteria were weighted heavily in the development of this Protocol, as follows:

1) Scientific validity, robustness, and comparability of results across projects
2) Cost effectiveness and pragmatism of implementation in Latin America
3) Flexibility to accommodate projects of varying scales and levels of potential adverse impact

With respect to flexibility, of particular importance is IDB's classification of projects into three categories, A, B, and C, according to their potential environmental and/or social impacts. Category A projects have higher risk of causing adverse environmental, social, or cultural impacts, and consequently require elevated environmental and/or social compliance measures. Proposed wind projects may be classified as category A projects based on their footprint, , complexity, location in proximity to an important migratory wildlife corridor, protected natural area, or ecologically sensitive habitats, potential for cumulative impacts, or other environmental and/or social characteristics such as the presence of Indigenous Peoples. Category B projects have lower potential for causing adverse environmental and/or social impacts. Category B projects tend to be smaller in scale, located in relatively low ecological and social and/or cultural sensitivity areas, and anticipated adverse impacts are typically low in severity, localized, and short term in nature. Category C projects are operations that are likely to cause minimal or no negative environmental and associated social impacts. This classification serves as a basis for identifying the appropriate environmental impact assessment monitoring, and mitigation measures that will be required as a condition of the project receiving IDB funding. The Protocol presented in this section is expected to apply only to Category A and B wind projects, with Category C projects carrying such low risk as not to warrant the implementation of a post-construction monitoring protocol.

3.3.2 Protocol Summary

A Protocol for establishing a postconstruction fatality monitoring program for birds and bats for implementation at IDB-funded wind energy facilities is presented below, and summarized in

Table 3–3.

Table 3–3. Summary of Recommended Postconstruction Fatality Monitoring Protocol for Birds and Bats for IDB Category A and B Wind Energy Development Projects in Latin America

<table>
<tr><th colspan="2">Project categorization</th><th colspan="7">Category A</th><th colspan="7">Category B</th></tr>
<tr><td colspan="2">Study Duration</td><td colspan="7">Three Years</td><td colspan="7">Two Years</td></tr>
<tr><td colspan="2">Carcass Search Frequency</td><td colspan="14">Daily during principal migratory periods (site specific), Daily for one week per month during other times of year, year-round</td></tr>
<tr><td rowspan="2">Minimum Number of Turbines Searched[6]</td><td>Number of turbines in project →</td><td colspan="2">1–10</td><td colspan="2">11–20</td><td colspan="2">21–40</td><td colspan="2">41–60</td><td colspan="2">61–90</td><td colspan="2">91–120</td><td colspan="2">121 +</td></tr>
<tr><td>Number turbines searched →</td><td colspan="2">all</td><td colspan="2">10 turbines</td><td colspan="2">½ 50% of all turbines</td><td colspan="2">20 turbines</td><td colspan="2">30% of all turbines</td><td colspan="2">30 turbines</td><td colspan="2">25% of all turbines</td></tr>
<tr><td colspan="2">Search area subsampling</td><td colspan="14">Searching restricted to easy to moderate visibility class habitats (Table 3–4) within a circular area around the base of the tower with a radius equivalent to the height of the tower</td></tr>
<tr><td colspan="2">Selection of turbines</td><td colspan="14">Homogenous habitats (randomly)
Heterogeneous habitats (non-randomly in order to cover all habitat types found within the wind farm)</td></tr>
<tr><td colspan="2">Scavenging bias correction</td><td colspan="14">Use a value of S_c calculated as follows,
$$\mathbf{S_c} = 1 - \frac{1}{1+p}$$
where p = the observed average carcass persistence time of found carcasses at the site</td></tr>
<tr><td colspan="2">Detectability bias correction</td><td colspan="14">Use the following values for S_e: 0.6 for small birds and bats, 0.8 for large birds</td></tr>
<tr><td colspan="2">Mortality estimator</td><td colspan="14">$$\mathbf{C = c / (A * S_c * S_e * P_t)}$$</td></tr>
</table>

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[6] Minimum numbers of turbines searched represent the expectation for high carcass detectability substrates in relatively homogeneous habitat, where the greatest level of subsampling of turbines within the wind farm is expected to occur. For projects in more heterogeneous habitats, or habitats with lower amounts of high-moderate visibility substrate located beneath turbines, higher proportions of turbines should be searched.

3.3.3 Protocol

Study Initiation and Duration

Carcass searching should be initiated as soon as possible after the initiation of operation of all turbines within the wind facility. As specified in Table 3–3, projects classified as Category A will require study durations of at least three continuous full years of monitoring, while Category B projects will require a minimum of two continuous full years of monitoring. Additional years of postconstruction monitoring may be added if unexpected high mortality or other adverse wildlife impacts are encountered (see under "adaptive management triggers").

Search Frequency

Searchers will search each selected search turbine once per day every day during the migratory seasons, and once per day every day for one continuous week per month during the non-migratory seasons. The length and timing of migratory seasons should be determined in consultation with IDB prior to the implementation of the carcass searching protocol, based on available bird distributional data for the region (e.g., on www.eBird.org).

Selection of Turbines to be Searched within the Wind Facility

Carcass searches are to be conducted at different numbers of turbines for differently sized projects, as specified in Table 3–3, which presents minimum expected numbers of searched turbines. If a subsample of turbines is to be searched, turbines should be randomly selected if the habitat conditions within the landscape of the wind energy facility are relatively homogeneous across the facility. If a wind site is heterogeneous, and contains habitats of particular wildlife risk concern, turbines should be selected nonrandomly for searching in order to cover all habitat types and areas of specific concern, and a larger proportion of turbines should be selected for searching. If the potential search areas beneath the turbines are dominated by substrates of high-moderate searchability such as bare dirt, search areas beneath individual turbines will be relatively large, encompassing most or all of the entire potentially searched area. This will result in longer search times required for individual turbines, and the number of turbines selected for searching is expected to be at or near the minimum requirement indicated in Table 3–3. If instead the potential search areas beneath the turbines are dominated by substrates of low searchability such as steep slopes, or tall and/or dense vegetation, search areas beneath individual turbines will be relatively small, encompassing small portions of the entire potentially searched area, such as the immediate turbine pad and access road. This will result in shorter search times required for individual turbines, and the number of turbines selected for searching is expected to be larger than the minimum requirement indicated in Table 3–3

Selection and Measurement of Search Areas Beneath Turbines Selected for Searching

Once turbines have been selected for searching, specific search areas should be defined based on field surveys of the searchability of vegetation or other substrates within a radius of the searched turbines equivalent to the height of the turbine tower. Ground conditions within this search area should be designated to visibility classes as defined in Table 3–4, and the area to be searched should be restricted to the entire within the potentially searched circle that falls within the easy and moderate visibility classes. In cases of extremely dense vegetation, search areas may be restricted to relatively clear areas such as access roads and turbine pads.

Table 3–4. Visibility Classes of Searching Substrates below Wind Turbines.

Visibility Class	Percent Vegetation Cover	Vegetation Height	Search
Easy	> 90% bare ground	< 15 cm tall	Yes
Moderate	> 25% bare ground	< 15 cm tall	Yes
Difficult	< 25% bare ground	15 to 30 cm tall	No
Very Difficult	Little or no bare ground	Higher than 30 cm tall	No

During an initial setup visit, the searcher should use a tape measure and GPS unit to map the searchable portion of the potentially searched circle under the turbine, with sufficient detail to calculate the total amount of area within the easy and moderate visibility classes (= actually searched area) within the potentially searched area under the turbine. The proportion of area searched parameter in the fatality estimator ($\mathbf{A}_x$) will be calculated as the sum of the total actual search areas divided by the total potentially searched area (circles) under all turbines selected for searching. Search areas should be redefined, remapped, and these statistics recalculated as needed if the seasonality of plant growth results in significant changes in the amount of area within the low-moderate searchability classes over the course of the study.

Basic Search Procedure

Within the selected and mapped actual search areas, establish parallel transects at a distance of no more than 5 m apart throughout the entire area, marking transects and endpoints with flags as necessary for ease of transect location during searching. Walk along each transect moving from one side of the search area to the other, at a rate of approximately 45 to 60 m per minute, visually scanning both sides out to 2 to 3 m on each side for avian and bat casualties. Weather permitting, turbine ground searches should be initiated at or near sunrise.

At the beginning of each search of a plot, the field technician should use a pre-prepared field sheet to record basic environmental conditions at the beginning of the search, including the following:

- Turbine number
- Time of day
- Observer name
- Approximate temperature
- Approximate wind speed
- Approximate cloud cover
- Presence of precipitation

Field Procedure for Documenting a Discovered or Rediscovered Carcass

If a dead bat or bird is found during carcass searching, the technician should place a flag near the carcass and continue the search until the search area is completely searched. After searching the entire plot, the searcher should return to each carcass for data gathering. If the carcass has not been discovered on a previous search (newly discovered carcass), the field technician should assign the carcass a unique carcass ID number, photograph the carcass (see below), attach an unobtrusively-colored tag containing the unique carcass ID number to the foot or leg, to unambiguously label the carcass as a previously discovered carcass for future searches, and then fill out a standardized fatality data sheet, leaving the carcass where it was initially found when data gathering is complete. If the carcass contains a tag with a carcass ID number, indicating that it is a rediscovered carcass, the field technician only needs to fill out a fatality data sheet, and leave the carcass where it was found. Sample fatality data sheets will be provided by IDB, and will contain, at a minimum, the following information:

- Carcass identification number
- Species of carcass (if identifiable by field technician)
- Date and time carcass was discovered (or rediscovered)
- New carcass or previously discovered (persistent) carcass?
- Searcher identification
- Turbine plot identification
- General weather conditions
- Substrate visibility class (easy, moderate)
- Habitat type of the area surrounding the search plot
- Distance and compass direction from the turbine
- Age and sex of carcass (when possible)
- Reproductive condition (when possible)

- Carcass condition (fresh, rigor, decomposed, intact, scavenged, feather spot, etc.)
- Estimated time of death (e.g., < 1 day, < 2 day, 3 to 5 days, > 5 days)
- Carcass position (face-up or down, sprawled out or balled up, etc.)
- Current and recent weather patterns
- Add photos (optional)
- GPS position of carcass

All carcasses should be photographed on their initial discovery for subsequent identification purposes. Using protective gloves to protect the technician from injury if the animal is not actually dead, and to reduce possible human scent bias on carcasses, manually position the carcass for a series of photographs to be specified by the taxonomic identification experts, based on the specific areas of the animal that should be photographed in order to capture the features that will enable the taxonomic expert to identify the animal. The technician should also write the individual carcass ID number on a small piece of paper, and position the paper, as well as a 10cm graduated ruler to be visible, but not obscuring key parts of the carcass in all photographs. At a minimum, required photographs will normally include the following:

- Entire dorsal surface of animal
- Entire ventral surface of animal
- Spread tail, dorsal and ventral views (birds), or dorsal and ventral view of tail and tail membrane (bats)
- Facial profile close-up
- Head-on facial close-up
- Dorsal and ventral views of spread wing

Expertise, Training, and Supervision of Carcass Searching Personnel

Two types of personnel will be required in order to conduct the post construction monitoring Protocol, as follows:

- Carcass search technician. These technicians must be capable of performing the carcass searching fieldwork described in this Protocol. Required skills of carcass searchers include the following:
    - Ability to perform fieldwork for long periods of time (up to 8 hours with breaks) under rugged field conditions
    - Ability to operate a GPS unit and digital camera

    - Oral and written communication skill sufficient to understand and follow fairly detailed and specific procedural instructions for fieldwork, as outlined in this Protocol.

- Expert scientist. One or more expert scientists are required for the following components of the carcass searching study:
    - Taxonomic expert identification of discovered bird and bat carcasses from photographs
    - Quantitative skill sufficient to perform the required calculations of taxon- and season-specific estimated mortality rates using the formulae presented in this protocol
    - Oral and written communication skill sufficient to summarize and interpret results, describe procedures and methods, and produce periodic reports describing all aspects of the postconstruction fatality monitoring study.

The developer should provide training or hire personnel trained in conducting standardized avian and bat mortality ground searches, and should also provide suitable and sufficient training in Health and Safety protocols and equipment use for all project field personnel

Required Equipment

The following equipment will be required to conduct the postconstruction monitoring Protocol presented in this report:

- Personal protective equipment for all field personnel
- Vehicle for accessing all field sites
- GPS unit with 1m or better precision for documenting carcass locations and relocating them on subsequent visits
- Digital camera for photographing discovered and rediscovered carcasses
- Weather-proof field notebooks and writing implements
- Bite-proof gloves for handling found birds and bats that may still be alive
- String for use as an unobtrusive marker for found carcasses

- Flags for marking carcass search transects
- Tape measure for taking measurements of the dimensions of search areas
- 10 cm graduated ruler

Mortality Rate Calculations

To estimate mortality on a facility-wide scale, a modified version of the Jain et al. 2008 estimator should be used as follows:

$$\mathbf{C} = \frac{\mathbf{c}}{(\mathbf{A_x} * \mathbf{S_c} * \mathbf{S_e} * \mathbf{P_t})}$$

where,

C = the overall estimated fatality at the wind farm;

c = the number of carcasses found during the searches;

A_x = the proportion of area searched beneath turbines (actual area searched/total maximum searchable area beneath turbine)

S_c = the proportion of carcasses remaining unscavenged for searchers, calculated as

$$\mathbf{S_c} = 1 - \frac{1}{1+p}$$

where p = the observed average carcass persistence time of found carcasses at the site, calculated empirically from rediscoveries of previously found carcasses

S_e = searcher efficiency (use 0.80 for large birds, and 0.60 for small birds and bats)

P_t = the proportion of turbines searched (number of turbines searched/the total number of turbines in the wind facility)

This equation should be applied, and fatality rates estimated separately for each month, and for each of three taxa, as follows: small birds, bats, and large birds. This subdivision will enable fatality rates to be lumped across months and taxa as desired.

Adaptive Management Triggers

The developer should provide a discussion of whether observed bird or bat fatality levels should trigger adjustments in either the monitoring protocol or the operation of the wind energy facility. Specific adaptive management triggers may be defined in some cases in consultation with IDB as a result of project-specific consideration of factors including, but not necessarily limited to the following:

- IUCN red list status of impacted taxa
- Other national or international conservation listing status of impacted taxa
- Potential for impacted species to experience population level impacts as a result of the observed mortality
- The observation of species or risk issues at the site that were not identified during the preconstruction risk analysis and which warrant significant consideration with respect to environmental impacts
- Fatality impacts significantly different in extent or composition from those expected based on preconstruction analysis.

Annual Reporting

The developer should provide an annual report to IDB within 3 months of the completion of each full year of postconstruction monitoring, presenting the results of the year's monitoring effort in both summarized and complete form. This information should be synthesized into the Annual Environmental and Social Compliance Report, and should follow postconstruction monitoring annual report guidelines that will be provided to the developer by IDB, and will contain, at a minimum, the following information:

- Range of carcass searching dates covered by the report

- Complete descriptions of the field procedures implemented, including maps of the study site showing all searched turbines, and dates and locations in which all field sampling was conducted

- Complete list of personnel involved with conducting the work and producing the report

- Total number of individual birds and bats that were discovered during the carcass searches, broken out by month and by species, and showing IUCN and all other relevant conservation status and/or listing information for each species discovered during the searches, as well as migrant or resident status of each species

- Complete data on rediscoveries of previously discovered and marked carcasses, as used to develop average carcass persistence times for the mortality estimates
- Summary graph of bird and bat mortality by turbine number, useful for identifying which turbines are causing the highest mortality levels
- Mortality rate calculations, including the formulae, and all raw data and parameter values used to produce them, broken out separately by month and by small birds, large birds, and bats, as well as lumped into annual and monthly rates for birds, bats, and all wildlife
- Interpretation of observed bird and bat mortality patterns in relation to preconstruction environmental risk predictions, and general conservation and environmental impact considerations associated with the project.
- Conclusions and recommendations regarding the need for changes to either the monitoring program or the operation of the wind facility, under the auspice of the facility’s adaptive management program.

4 Suggested Future Research: Empirical Characterization of Migratory Raptor-Wind Turbine Collision Impacts in the Great Central American Raptor Migration Corridor

4.1 Rationale. The Potential Risk of Migrating Raptors Colliding with Wind Turbines Stands as the Single Most Important Wind-Wildlife Risk Issue in Latin America, for the Following Reasons:

- The Central American raptor migratory corridor is the biggest in the world, measured in terms of total bird passage (www.hawkwatch.org). Each year, over 5 million raptors of roughly a dozen species pass through Central America as they migrate between North American breeding grounds and Neotropical wintering areas (www.hawkwatch.org). Of particular importance are 3 species—Broad-winged Hawk, Swainson's Hawk, and Mississippi Kite—for whom nearly all of their global population passes through this migratory corridor annually (www.hawkwatch.org). These 3 species account for 2 million, 1 million, and 200,000 birds, respectively, that pass through the "Rio de Rapaces" hawkwatch stations in Veracruz, MX each fall, and together with a fourth species, Turkey Vulture (1.5 million birds/year), comprise the vast majority of the migrating raptors that use the Central American corridor (www.hawkwatch.org).
- Because of their iconic and symbolic significance to humans, their typically long-lived and slow reproducing demographic patterns, and the international reach of their migratory routes, Nearctic-Neotropical migratory raptors are highly significant from a conservation standpoint, and potential adverse impacts to these species are, therefore, of significant concern for wind development in Latin America.
- The nature and extent of wind-turbine collision susceptibility for Nearctic-Neotropical migrant raptors is virtually unknown. Although there has been significant speculation about the potential for significant adverse impacts from wind turbine collisions placed in American raptor migratory corridors (Kuvlesky et al. 2007, Ledec et al. 2011), data describing the nature and extent of actual collision susceptibility of migrating American raptors are virtually absent. Post-construction monitoring at the La Venta II wind facility, located in the core of the Central American migratory raptor corridor in the Isthmus of Tehuantepec, Oaxaca, Mexico show that migratory raptor collisions with wind turbines are extremely few and extremely rare at this facility (Comisiòn Federal de Electricidad 2008, 2009, 2011). However, these data were gathered under a program of pre-emptive wind turbine operational curtailment during migratory raptor flights through the facility, hence collision susceptibility for migratory

raptors passing over this site is still unknown, and it is unclear how many raptor deaths were prevented by this curtailment, if any. In the US National Academy of Science's 2007 review of the environmental impacts of wind power generation in the US, post-construction bird/bat fatality data were included for 2 wind facilities located along ridge tops in the Appalachian mountains, within the most significant raptor migration corridor in the eastern US. These 2 facilities produced among the lowest measured raptor collision rates of any US wind facilities, with 0.00 and 0.02 raptor fatalities estimated per megawatt per year at Buffalo Mountain, Tennessee and Mountaineer, West Virginia, respectively. Although these results are suggestive of low collision susceptibility for migrating raptors, the monitoring programs that produced them were not designed specifically to examine migratory raptor mortality in detail, and it is possible that some impacts may have occurred that were not detected.

- Post-construction studies at wind facilities located in the Tarifa region of southern Spain, where extensive wind energy development has occurred within 1 of the most significant migratory raptor concentration points in Europe, have shown that collision susceptibility patterns are highly species-specific, wind-farm specific, and turbine specific (Ferrer et al. 2012). Very large numbers of migratory raptors, storks, and passerines migrate through this region, and some of the most abundant species, including Black Kites and White Storks (Janss 2000) have shown negligible wind turbine collision mortality levels (Ferrer et al. 2012). Somewhat higher wind turbine collision rates have been demonstrated for a small handful of species, including Griffon Vultures, kestrels, and Short-toed Eagles, but these impacts were not directly related to the abundance of these species in the region, nor were they predicted, or predictable based on preconstruction risk assessments (Ferrer et al. 2012). In a detailed study of Griffon Vulture wind farm collisions in this region in relation to operational curtailment, de Lucas et al. (2012) demonstrated that with selective shutdown of 10 turbines of 244 total across 6 wind farms, Griffon Vulture mortality was reduced by 50% with a loss of only 0.07% of energy production at the wind farms. These results clearly illustrate the importance of using post-construction monitoring studies to identify which species, which wind facilities, and which turbines are generating potentially significant migratory raptor collision mortality. Only by developing such an understanding for the Latin American migratory raptor corridor can any existing problems be identified, and effective, targeted solutions developed.

4.2 Objectives

1) To obtain a comprehensive, empirical characterization of the susceptibility of migrating raptors to wind turbine collisions in the Central American migratory raptor corridor, focusing on the "big 4" species that constitute bulk of the raptor passage through this region, and on the species-, site-, and turbine-specific nature of any observed collision patterns.
2) To obtain a representative, empirical characterization of the susceptibility of other flying wildlife (birds and bats) to wind turbine collisions in the Central American migration corridor.

4.3 Proposed Research Study Design

<u>Field Methods</u> The core methodology of this study would be to combine continuous raptor migratory passage observations at operating wind energy facilities with intensive carcass searching efforts conducted during the same times at the same turbines. The goal of such methodology is to produce robust, empirical estimations of:

- Raptor passage rates (species specific)
- Bird and bat mortality rates (turbine specific)

Raptor passage data would be gathered using standard hawkwatch raptor migration count techniques, in which experienced raptor identification experts are stationed continuously during daylight hours at selected high-observability vantage points at selected wind facilities. During observation periods, observers would use high quality optics (binoculars and/or telescopes) to detect, identify, and count all raptors observed flying within pre-defined observation areas covering a wind facility or observable portion thereof. In addition, flight altitude and direction would be recorded for all observed birds.

Bird and bat mortality data would be gathered using the post-construction carcass searching and mortality estimation protocol described in section (3.3) of this report. Searches would be performed by technicians trained in the methodology, and directed by a carcass search crew leader who is an experienced bat biologist, capable of identifying bat carcasses discovered during the carcass searching. Each of up to 20 turbines within each of the defined observation areas of the raptor observers would be searched for all bird and bat carcasses once per day, during all raptor migration observation days. To minimize low-value search effort and maximize the number of turbines searched, only the high-searchability substrates (e.g., bare dirt, turbine pad, road) would be searched beneath each turbine, within a radius around the base of the turbine tower equivalent to the height of the tower. During carcass searching, the locations of all found carcasses would be recorded using a GPS unit, and the turbine number would be recorded. All found carcasses would be marked with a piece of dull-colored flagging tape, and would be revisited each day subsequent to discovery until they disappeared, to produce an empirical characterization of carcass persistence time. Each found carcass would be photographed in pre-determined positions and showing key diagnostic features for subsequent identification by taxonomic experts from the photographs (birds identified by the ornithology expert hawkwatchers; bats identified by the bat biology expert carcass search crew leader). Searcher efficiency bias correction would be performed by applying conservative estimates of 80% detection for large birds and 60% detection for small birds and bats. Scavenging bias correction would be performed by applying a scavenging loss correction factor developed from empirical observations of the persistence of all found carcasses at the site during the study.

<u>Timing, Duration, and Taxonomic Coverage</u> Intensive raptor observation and carcass searching would be conducted every day at all of the selected sites from October 1-31 during the fall visit, and from April 1-30 during the spring visit. These intervals were selected to encompass the bulk of the period of migratory passage for the “big 4” raptor species through the Isthmus of Tehuantepec region, based on hawkwatch data from hawkwatch.org for the “Rio de Rapaces” hawkwatch stations in Veracruz, MX (fall migration) and eBird (fall and spring migration). The estimated proportion of the total migratory passage that would be encompassed during this period for these species is shown in Table 4–1, below.

Table 4–1. Percentage of total migratory passage included within the October and April sampling seasons for the suggested research project, for the 4 Nearctic-Neotropical migrant raptor species that collectively comprise the bulk of the raptor migration through the Central American migratory raptor corridor (data sources: www.hawkwatch.org, www.ebird.org)

Species	April 1-30	October 1-31
Swainson's Hawk	85%	90%
Broad-winged Hawk	80%	70%
Mississippi Kite	80%	5%
Turkey Vulture	(unknown)	80%

Because these sampling windows encompass the bulk of the migratory passage period for the "big 4" raptor species during spring and/or fall migrations, this study design would produce a relatively comprehensive characterization of collision mortality patterns during migration through Central America for these species.

In addition to these focal species, data on many other species of birds and bats would be captured during the selected sampling windows. For many Nearctic-Neotropical migrant bird and bat species, including the other 8 species of migratory raptors that pass through Central America, this selected sampling window would also produce relatively comprehensive characterizations of collision risk during the migratory periods, as the migration timing of different bird and bat species overlaps to a great degree, particularly for raptors. However, for many species of migratory birds and bats, migration timing may be slightly or largely different, falling partly or mostly outside of the selected windows. For these species, and also for year-round resident species present at the site, the selected time windows would render representative samples of collision mortality patterns, adding substantial value to the raptor data within the framework of the same field study design and effort.

Location, Spatial Coverage, and Effort Raptor observations and carcass search efforts would be conducted simultaneously on 3 study sites located on operational commercial wind energy facilities within the Isthmus of Tehuantepec region. Only sites not currently applying operational curtailment protocols for raptor collision avoidance would be selected. Each study site would consist of a set of up to 20 turbines that are visible from a single, accessible raptor migration observation vantage point, and that are accessible on a daily basis for carcass searching. To monitor raptor migratory passage during all daylight hours at all 3 sites during the entire selected sampling windows, 4 expert raptor observers would be stationed at the field site, such that each observer works on a 3 days on, 1 day off rotation during each of the months of sampling. Similarly, for carcass searching, a complete day of field effort will be required to search each of up to 20 turbines within each of the 3 sites, hence 4 carcass searchers (including 1 carcass search crew leader) would be stationed at the field site during the entire sampling periods.

Analysis Searcher efficiency and scavenging bias corrections are described above, and these would be combined with an additional correction factor to account for areal subsampling of carcass search effort to produce robust, quantitative estimates of collision mortality rates using the Jain estimator equation. Data on raptor passage rates, and observed bird and bat mortalities would be analyzed together with various characteristics of the monitored wind turbines in order to develop a robust characterization of species-specific bird and bat mortality rates as a function of turbine number, and various turbine microsite characteristics such as position relative to topographic features, slope, and aspect.

Task Structure The execution of this research would be subdivided into 7 tasks, as listed in Table x. These tasks are mostly self-explanatory, or described in the previous sections. The scouting, field site setup trip is envisioned as a 1 week visit to the site by 2 project personnel prior to the first fieldwork visit, including 1 who is fluent in Spanish and capable of conducting the necessary negotiations with local project personnel and resource providers. This trip will serve the purpose of preparing logistical arrangements for housing and vehicle use by the field teams during the fieldwork visits, and to visit prospective field sites to assess the suitability of candidate sites, and then select and prepare to conduct work at 3 sites in advance of the first fieldwork visit.

4.4 Budget

The detailed budget has been developed for the suggested research project as described above, and the total estimated cost is $460,000US. A budget summary is presented in Table 4–2 below. More detailed budgetary information is available on request.

Table 4–2. Summary budget for suggested research project on the collision susceptibility of migrating raptors and other birds and bats in the Central American migration corridor.

Task	Labor	Travel	Supplies	Total
Project kickoff,	$16,165	$0	$0	**$16,165**

Task	Labor	Travel	Supplies	Total
planning				
Scouting, field site setup trip	$14,405	$3,900	$0	**$18,305**
Fall field visit	$162,786	$20,050	$1,250	**$184,086**
Interim report	$19,558	$0	$0	**$19,558**
Spring field visit	$162,786	$20,050	$1,250	**$184,086**
Interim report	$18,118	$0	$0	**$18,118**
Final report	$18,118	$0	$0	**$18,118**
Total	**$411,936**	**$44,000**	**$2,500**	**$458,436**

4.5 Outcomes

Expected outcomes of this research include the following:

- A robust, empirical, and comprehensive characterization of wind turbine collision rates in relation to migratory passage rates as well as per turbine and per megawatt for the "big 4" Nearctic-Neotropical migrant raptor species, as well as a variety of other bird and bat species whose migratory timing through the Isthmus of Tehuantepec region coincides with the months of October and April.
- A robust, empirical, representative characterization of wind turbine collision rates in relation to migratory passage rates (migrants) and/or per turbine and per megawatt (migrants and local resident species) for a wide variety of bird and bat species that are either non-migratory local resident species, or Nearctic-Neotropical migrant species whose migratory periods through the Isthmus of Tehuantepec region only partly coincide with the months of October and April.
- A definitive set of management recommendations for addressing bird and bat collision risk issues at Latin American wind energy facilities. This set of recommendation will be based on the empirically documented collision susceptibility patterns produced by this study, and will include priority issues for pre- and post-construction monitoring efforts, as well as suggested management techniques and strategies to avoid, reduce, and/or mitigate any potentially significant collision impacts that are identified.

5 Literature Cited

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APPENDIX 1: Survey questionnaire distributing to wind-wildlife collision risk modeling experts regarding validation studies and prediction accuracy of preconstruction wind-wildlife collision risk models

I'm Greg Forcey, an avian ecologist with Normandeau Associates and we are working on a report for the Interamerican Development Bank designed to address the question, "How accurately do preconstruction collision risk models predict bird/bat mortality at wind energy facilities?" . Because of the limited extent of available research studies addressing this specific question, we are supplementing our literature review with a survey of professional opinion from selected leaders in the field of wind-wildlife biology. We would be deeply appreciative if you would be willing to answer some questions with regard to validation of collision risk models, for us to include in our report as a "personal communication." The specific questions I'd like to discuss with you are listed below. If you would like to provide written responses to any or all of these questions, that would be great. As an alternative if you prefer, I would be happy to follow up with you by phone in a week or so to discuss these issues verbally with you:

For the purposes of this discussion, a predictive wind-wildlife collision risk model is defined as an automated or algorithmic model for making wildlife mortality predictions based on certain quantitative inputs and assumptions, as distinct from any general mortality predictions that might be presented in a preconstruction risk assessment based purely on qualitative or comparative analysis, or professional judgment

- With which specific predictive wind-wildlife collision models are you familiar? Which have you used in your own professional work?
- Are you aware of any studies in which empirical post-construction mortality data has been used to validate, or assess the accuracy of the predictions of a wind-wildlife collision risk model? (if any are published or otherwise publicly available, please indicate where, or how to obtain a copy)
- How, when, where, and by whom was the validation study(s) performed?
- How accurate were the model predictions in the validation study(s) for different taxa of birds and bats?
- In your professional opinion, what level of accuracy of model predictions is reasonable to expect from the best performing wind-wildlife collision risk models?
    - ○ +/- 0-10%
    - ○ +/- 11-25%
    - ○ +/- 26-50%
    - ○ +/- 51-100%
    - ○ +/- >100%

- In your professional opinion, how much value is added to a preconstruction wind-wildlife risk assessment by the application of a predictive collision risk model, as opposed to making mortality predictions based on purely qualitative or comparative analysis, or professional judgment?