SOSC-59

Arnold Schwarzenegger
Governor

TESTING THE EFFECTIVENESS OF AN AVIAN FLIGHT DIVERTER FOR REDUCING AVIAN COLLISIONS WITH DISTRIBUTION POWER LINES IN THE SACRAMENTO VALLEY, CALIFORNIA

PIER FINAL PROJECT REPORT

Prepared For:
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"Research Powers the Future"

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DISCLAIMER

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

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- Renewable Energy Technologies
- Transportation

Testing the Effectiveness of an Avian Flight Diverter for Reducing Avian Collisions with Distribution Power Lines in the Sacramento Valley, California is the final report for the Avian Transmission System Mitigation Program project (contract number 500-01-032) conducted by Marcus L. Yee. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

Distribution power lines are placed high overhead, safely out of human reach; however, for birds, these overhead wires are a potentially fatal obstacle. Under low visibility conditions, birds may fly into power lines. This study's primary goal was to determine how to reduce avian collisions with distribution power lines. A bird flight diverter designed to increase power line visibility was tested to determine its effectiveness for reducing avian collisions with a distribution power line. The 5.6-kilometer, 12-kilovolt distribution power line was equipped with diverters on five sections, systematically interspersed with five control sections and nine buffer spans (the distance between two power poles). Each of the treatment and control sections was made up of four continuous spans. The researchers compared the number of carcasses found below treatment, buffer, and control power lines with a block analysis of variance. Researchers also studied whether changes in avian flight behaviors were an adequate measure of diverter effectiveness for reducing avian collisions. The study found a 60 percent reduction in the number of fatalities under the treated power lines. However, avian flight height and reaction distance were not significantly different between treatments, suggesting that bird flight behavior alone may not be a sufficient method for testing diverter effectiveness. Based on these results, researchers made study design and protocol recommendations specific to distribution power lines; identified data necessary to increase precision of future avian mortality estimates; and discussed land management recommendations that could help to reduce avian collisions with power lines.

Keywords: Distribution power lines, California, bird flight diverter, power line marker, avian collision, shadowing effect, sandhill crane, avian mortality, Staten Island

Executive Summary

Introduction

As energy demand increases, the network of overhead power lines necessary to distribute electricity will need to expand, increasing the potential for avian collisions with those lines. Currently, little is known about the extent of avian collisions with distribution power lines (less than 60 kilovolts) and how to reduce them, even though these interactions can disrupt electricity delivery and kill birds. In California, the potential number of avian collisions with distribution power lines may be high due to the combination of high concentrations of collision-prone birds, thousands of miles of overhead power lines, and low-visibility conditions resulting from fog, which can render power lines virtually invisible, further increasing the collision potential.

Previous research, on the larger, higher-altitude, higher-voltage transmission power lines (greater than 60 kilovolts) has demonstrated that avian collisions can be reduced by increasing power line visibility. However, the effectiveness of such aerial marking devices (diverters) is highly variable. To date, few studies have attempted to reduce avian collisions with distribution power lines; there is a need to test diverters on distribution power lines. Evaluating the effectiveness of such diverters for reducing avian collisions with power lines relies heavily on recovering carcasses below diverter-marked treatment lines and unmarked control lines. Recently, researchers have begun to incorporate avian flight behaviors in their analyses of diverter effectiveness and have found that birds flying over transmission power lines equipped with diverters fly at higher altitudes and make fewer last-minute reactions, suggesting that they see the lines earlier. However, these behavioral responses are not consistent among different species. Further, it is unclear whether birds will behave similarly when flying over lower-voltage distribution power lines located closer to the ground than the higher-voltage transmission lines previously studied. Understanding how different species react to treated lines is vital for reducing collision risk for threatened and endangered species and groups.

Purpose

This study sought to determine how to reduce avian collisions with distribution power lines.

Project Objectives

This project’s objectives were: to determine the extent of sandhill crane collisions with the distribution lines; to evaluate the efficacy of a bird flight diverter, the FireFly™, for reducing avian collisions with distribution power lines; and to determine land use practices that may aid in reducing bird collisions.

Project Outcomes

The Cosumnes River Preserve, in Sacramento County, is a wildlife refuge that supports tens of thousands of birds seasonally, including one of the largest populations of sandhill cranes (*Grus*

Canadensis tabida)—a threatened species in California. Within the preserve, researchers selected a 3.5-mile stretch of 12-kilovolt distribution power line to study because of its high potential for avian collision: birds regularly use habitats on both sides of the power line, requiring the birds to fly across the line frequently. Furthermore, the area, much of which is below sea level, experiences dense winter fog that reduces visibility.

This study appears to be the first in California to assess bird collisions with distribution lines and to assess measures aimed at reducing collisions with distribution lines, such as installing diverters. It is also the first study to assess the value of using bird flight diverters in an area that experiences dense fog events during a high proportion of the winter months, when bird use is also highest. In addition, this study evaluates the usefulness of behavioral observations to determine the efficacy of bird flight diverters. Given the more than 100,000 miles of distribution lines in state, the global importance of the Central Valley to migrating birds, and the frequency of fog events, the information reported herein provides much-needed information that could help to reduce avian collisions with distribution power lines throughout California and other parts of the nation.

This study was conducted during the winter months of three consecutive years (2003–2006). During the first two winter seasons, the distribution line, consisting of 49 contiguous spans (the area between two distribution power line poles) was monitored to document the number of avian collisions and bird flight behaviors prior to marking the power line with diverters. Bird diverters were placed on the line prior to the final 2005–2006 winter field season. Diverter effectiveness was tested by comparing the number of birds found under the control power lines with the number found under treatment-marked power lines. Researchers also examined whether two bird flight behaviors commonly used in studies of avian collision with transmission power lines were sufficient to determine diverter effectiveness on distribution power lines.

Conclusions

This study found that the diverter reduced avian collisions by 60 percent at diverter-marked treatment spans. Furthermore, the number of collisions per span increased with distance from the treatment spans. In other words, treatment spans appeared to affect neighboring unmarked spans. For example, unmarked spans immediately adjacent to treatment spans had lower numbers of collisions per span than the unmarked spans located two spans away from the treatment spans.

Contrary to observations from previous research on larger transmission lines, flight behaviors observed during this study were not altered significantly by the diverters. This may be because heights of distribution power lines are lower than typical bird flight heights. Based on flight behaviors alone, the research team would have incorrectly concluded that the diverter was ineffective, because the diverter's presence did nothing to change flight heights or reaction distances. The better predictor of flight height was found to be distance to the power line. Flight behaviors, while not significantly different enough to predict diverter effectiveness, were consistent enough to develop management recommendations.

Recommendations

During this study, the buffer spans as previously mentioned (that is, the unmarked spans immediately adjacent to treatment spans) had a lower number of collisions per span than unmarked control spans (located farther from treatment spans), suggesting that the presence of diverters reduced the number of fatalities at adjacent unmarked buffer spans. Therefore, to maximize diverter placement, the research team recommends increasing the distance between diverters within a span (that is, reducing the number of diverters per span). The research team also recommends creating high-use habitats, such as those used for feeding and roosting, along the same side of the power line, reducing the need for birds to fly across the power line. In addition, the research team recommends increasing the distance between power lines and high-use habitats, which will allow the birds to have more time to gather the necessary height to clear the power lines.

Benefits to California

Studies focusing on interactions between birds and distribution power line studies are rare. As the need for more distribution power lines grows with California's population, it becomes more crucial to understand how to prevent these interactions, to mitigate the effect on bird populations and to continue to deliver reliable electricity to the state's citizens. This study's results offer much-needed data regarding the effectiveness of a flight diverter for reducing avian collisions with distribution power lines, study design suggestions for refining such an experiment, identification of vital data gaps (which will help increase the precision of estimates), and management recommendations aimed at reducing avian collisions.

1.0 Introduction

Electricity is transmitted via transmission lines (> 60 kilovolts [kV]) and distribution[1] lines (< 60 kV), making these critical components of land use infrastructure. In California alone there are approximately 40,000 linear miles of transmission lines and more than 100,000 linear miles of distribution lines. These numbers, especially for distribution lines, will only increase, to meet growing demands to transmit more electricity as urban development continues (CEC 2005). Avian collision with overhead wires has been an ongoing concern since it was first documented in the late 1800s (Coues 1876; APLIC 1994; APLIC 1996; APLIC 2006). Such negative interactions with power lines usually result in bird deaths and may disrupt electricity delivery.

Although much progress has been made to understand the extent of electrocution events and how to mitigate them (Janss and Ferrer 1999; Lehman 2001; Tinto et al. 2001; APLIC 1996; APLIC 2006), the extent of collisions with transmission and distribution lines remains poorly understood. (APLIC 1994; Hunting 2002). Because collisions do not usually result in power outages, much less attention has been paid to them (Hunting 2002). Furthermore, most research to date has focused on bird collision with transmission lines (Lee 1978; Meyer 1978; Anderson 1978; James and Haak 1979; Meyer and Lee 1979; Bealaurier 1981; Faanes 1987; Morkill and Anderson 1991; Hartman et al. 1992; APLIC 1994; Savereno et al. 1996; Janns and Ferrer 1998; Alonso and Alonso 1999a,b; Janns and Ferrer 2000; De La Zerda and Rosselli 2002); and little attention has been given to the potential for avian collisions with the more ubiquitous distribution power line. Given that the linear miles of distribution lines is much greater than that of transmission lines, the potential for avian collision with distribution lines is higher.

Many factors contribute to make bird collisions with distribution lines a significant source of avian mortality. California supports 636 species of birds (California Department of Fish and Game 2006), both year-round residents and those only seasonally present for nesting, over-wintering, or during fall and spring migration. In addition, California is located within the Pacific Flyway, a significant migration route for millions of birds flying north to south during seasonally annual migration. In 2001, about 5.5 million individuals of waterfowl alone were documented migrating through California along the Pacific Flyway (Yarris, pers. comm.). Seasonally, the Central Valley hosts up to 100% of the world's population of both the Aleutian Canada (*Branta canadensis leucopareia*) geese and Pacific tule geese (*Anser albifrons elgasi)*, 80% of the nation's population of Ross geese (*Chen rossii)* and cackling Canada geese (*Branta hutchinsii*), and 67% of the nation's population of tundra swans (*Cygnus columbianus)* and Pacific white fronted geese (*Anser albifrons frontalis*; see Hunting 2002 for a discussion of the Pacific Flyway's significance in California). Many of these types of birds, such as waterfowl and water birds, are considered particularly vulnerable to collision due to low wing loading (Bevanger 1994; Crowder 2000). Additionally, migration by waterfowl and other species occurs during winter

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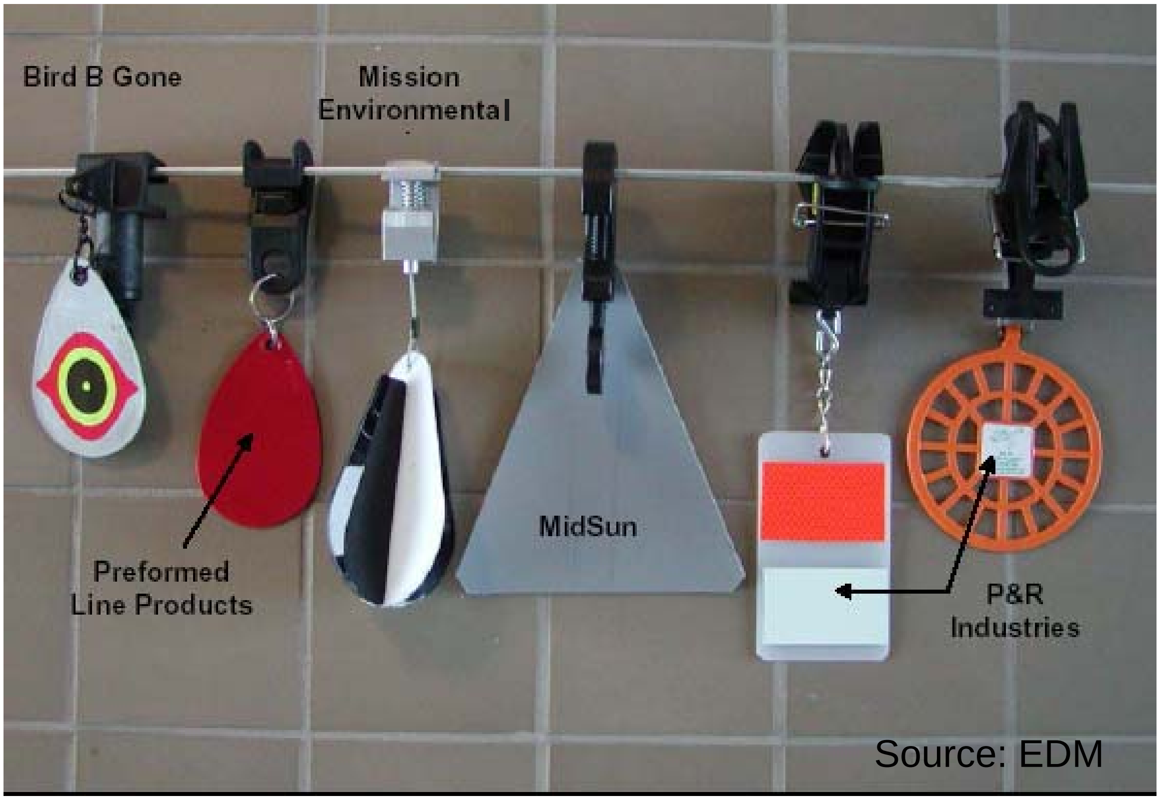
[1] *Distribution* refers to the delivery of electricity from substations to the consumer and is generally < 60 kV. In this report, the terms *distribution* and *low voltage* will be used interchangeably, to distinguish from higher-voltage transmission power lines and associated structures.

when the weather in the Central Valley is often characterized by dense fog, which reduces visibility, further increasing the potential for collision (APLIC 1994; Hunting 2002).

Concern about avian collisions with transmission lines has led to the development of mitigation measures aimed at reducing collisions. Many of these mitigation measures are intended to make the lines more visible to birds as they fly. Enhancing the visibility of lines involves marking the lines with one or more of a multitude of devices collectively referred to as *aerial marking devices* (flight diverters). Although there are numerous diverter designs on the market today (Figure 1); there have been few rigorous studies to determine the efficacy of some of these (Brown and Drewien 1995 Hunting 2002), and many others have yet to be tested. In addition, studies conducted to date have demonstrated variable effectiveness at reducing avian collision with transmission lines. For example, Brown and Drewien (1995) estimated that polyvinyl chloride (PVC) spirals and swinging plates reduced avian collisions by 60% and 63%, respectively. However, Hunting (2002), in a recent review of existing diverters—ranging from spiral vibration dampeners, pendants, and spheres to raptor effigies—found a wide range of effectiveness. Rasmussen (2001) found Swan Flight Diverters “eliminated collisions completely” while Heijnis (1980) found that a somewhat similar bird flight diverter “brought little or no results.” Clearly, while there is need for scientifically rigorous studies of transmission lines marked to divert bird collisions, there is a greater need to test diverters on distribution lines.

Evaluating the efficacy of bird flight diverters relies heavily on comparing the number of dead birds found under power lines treated with diverters to those not treated (APLIC 1994; Bevanger 1999). However, a number of challenges and biases associated with the survey techniques need to be addressed. Within a given length of power line, bird collisions can be relatively rare, reducing the potential for adequate sample size. Further, there are various bias factors that must be taken into consideration, including scavenger bias, crippling bias, habitat bias, and searcher bias (Beaulaurier 1981; APLIC 1994; Bevanger 1999). These biases usually result in underestimating actual mortality, and many are difficult to quantify.

Scavenger bias refers to removal of carcasses by scavengers, such as coyotes, raccoons, and otters, before searchers are able to record the fatality. *Searcher efficiency bias* refers to the degree of difficulty searchers experience when attempting to detect carcasses, either because of searcher error or factors that increase the difficulty of finding the carcass, such as the cryptic coloring of birds. *Habitat bias* involves landscape features such as dense vegetation or large water bodies that make if difficult to locate carcasses. *Crippling bias* refers to a situation where birds colliding with power lines at high speeds or not dying immediately from the trauma may not fall directly beneath the power line and therefore end up beyond the search zone.



Source: EDM

Figure 1. Aerial marking devices (flight diverters) are intended to reduce avian collisions with power lines by increasing power line visibility. This study evaluated the FireFly (second from the right).

In addition to estimating mortality rates based on ground surveys for dead birds, a number of studies have evaluated diverter efficacy by comparing bird flight behavioral observations at treated versus non-treated lines (Moorkill and Anderson 1991; Brown and Drewien 1995; De La Zerda and Rosselli 2002). These studies found that power lines with diverters have fewer last-minute, near-collision behavioral reactions (e.g., abrupt increases in altitude and direction changes), higher mean altitude crossing heights, and fewer avian collisions—suggesting that diverters increase power line visibility. However, while these studies collected flight data on a number of species, behavioral reactions to power line diverters are relatively unknown for most species, and may not be consistent between species (Brown and Drewein 1995). Understanding how different species react to treated lines is vital to increasing the ability to reduce collision risk for threatened and endangered species and groups (Bevanger 1999). Furthermore, with the exception of a minor proportion in Brown and Drewein (1995), all observations were of birds flying over high-voltage transmission power lines.

Studies to evaluate the extent of collisions with transmission and, in particular, distribution lines, are few, and studies to determine ways to reduce collisions with these power lines are even fewer. Many results can be considered area- or species-specific and therefore are difficult to apply to other areas that have unique environmental conditions that have not been studied, such as frequent fog events. Fog can reduce visibility to the extent that flight diverters may not be visible to birds, and therefore, ineffective (Figure 2). Much of California's Central Valley experiences fog during the winter months. There are 38 National Wildlife Refuges, 107 State Wildlife Areas, and 123 State Ecological Preserves, many of which are located in California's Great Central Valley and managed for waterfowl and water birds. The land use management practices designed to attract these birds (e.g., creation of wetlands and ponds) also contribute to the formation of dense fog. Some have large transmission lines present and all have distribution lines to transport energy to housing and office structures, to run water pumps, and to provide other necessary energy-required functions. Together, these factors create a high potential for bird collision with wires and disruptions in energy supply.

Figure 2. Distribution power lines at the study site (Staten Island, Walnut Grove, California). Heavy winter fog reduces visibility of distribution power lines with (left) and without (right) aerial marking devices. These devices, designed to increase line visibility, may not be effective in heavy fog.

The Cosumnes River Preserve, in Sacramento County, is a wildlife refuge that supports tens of thousands of birds seasonally, including one of the largest populations of greater sandhill cranes (*Grus Canadensis tabida*), which is a threatened species in California. Approximately eight miles of distribution lines traverse the refuge, and managers there have reported an ongoing problem with birds dying from collisions with the distribution wires.

This study had three objectives:

1. To determine the extent of sandhill crane collisions with the distribution lines within a particular segment of the Cosumnes River Preserve, namely Staten Island.

2. To evaluate the efficacy of a bird flight diverter (the FireFly™) for reducing avian collisions with distribution power lines.
3. To determine land use practices that may aid in reducing bird collisions.

This study appears to be the first in California to assess bird collisions with distribution lines and to assess mitigation aimed at reducing collisions with distribution lines by installing diverters. It is also the first study to assess the value of using bird flight diverters in an area that experiences dense fog events during a high proportion of the winter months, when bird use is highest. In addition, this study evaluated the usefulness of behavioral observations to determine the efficacy of bird flight diverters. Given the number of distribution lines in state, the global importance of the Central Valley to migrating birds, and the uniqueness of frequent fog events, this study provides much-needed information that can be used to help reduce avian collisions with distribution power lines throughout California and the nation.

2.0 Methods

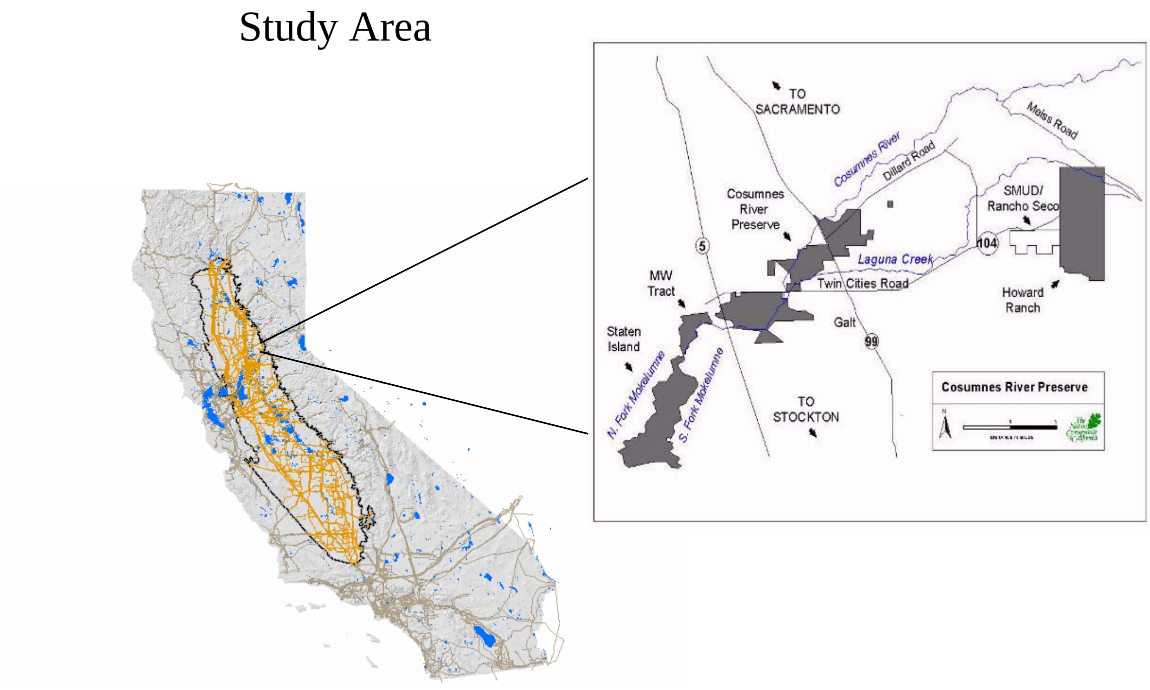


Figure 3. The Staten Island (Walnut Grove, California) study area

Researchers conducted the study along 5.6 kilometers (km; 3.5-miles), of a 12-kV distribution line located at Staten Island in Walnut Grove, San Joaquin County, California (38.2°N, 121.5°W). Staten Island is approximately 3723 hectares (9200 acres) in size with elevations ranging from 8 meters (m; 26 feet) below sea level to sea level. Levees surround the island along the north and south fork of the Mokolumne River, protecting it from winter floods. Staten Island, recently acquired by The Nature Conservancy, is part of the Consumnes River Preserve complex – a consortium of landowners including the California Department of Water Resources, the California Department of Fish and Game, Ducks Unlimited, the Natural Resource Conservation Service, the Sacramento County Department of Regional Parks, the U.S. Bureau of Land Management, and the Wildlife Conservation Board. Management goals consist of demonstrating the compatibility of human uses—particularly agriculture, recreation, and education—with the natural environment. For most of the year Staten Island operates as a commercial farm, hosting crops such as tomatoes, corn, and wheat. Once harvest is complete at the end of fall, portions of the island are left dry with plant stubble while other areas are flooded, creating ideal foraging and roosting habitats for shorebirds and waterfowl. From October to March, Staten Island supports tens of thousands of migratory birds, including one of the largest concentrations of the state-threatened greater sandhill cranes in the Central Valley (Ivey and Herziger 2003). Cranes generally forage in the dry habitat and roost in flooded areas. Waterfowl and shorebirds forage in the flooded areas and roost in the dry habitats. Because the distribution power line runs north to south along a dirt road that bisects the dry and wet habitats, and birds make frequent flights between these habitats every day, there is greater risk of collision with this power line than with lines located in uniform habitat. This situation is exacerbated by low-visibility conditions common during winter conditions.

The climate in nearby Stockton, California, (approximately 40.2 km [25 miles] southeast of the study area) consists of warm, dry summers and cool, wet winters. Mean high and low temperatures in July are 35°C and 16 °C, respectively, and mean high and low temperatures in January are 11.5°C and 4.6°C, respectively. Seventy-three percent of the approximately 35 centimeters of average annual precipitation falls as rain from October through March. The area experiences heavy radiation fog[2] for an average of 42 days per year, 91% of which occurs from November to February (Western Regional Climate Center 2007). Although a short distance away, Staten Island usually experiences a greater number of foggy days than Stockton due to conditions created by the flooded fields, the adjacent rivers, and the protection from wind by the surrounding levees. The fog forms in the early mornings and late evenings, coinciding with the greatest levels of bird flight activity as birds fly between roosting and foraging habitats.

2.1. Methods

The study's first objective, calculating the extent of avian collisions with the distribution power line, was accomplished by estimating mortality from the number of dead birds found during searches of the line. Although the accuracy of the avian mortality estimate would have been increased by applying a number of corrections for bias factors (APLIC 1994), the research team was unable to obtain enough data to apply these bias estimations confidently. The second objective, testing the efficacy of bird diverters, was accomplished by analyzing avian mortality estimates and flight observations. The third objective, determining land use practices that may aid in reducing avian collisions, was based on bird behavioral observations.

The study was conducted during the winter months (November to February) of three consecutive years (2003 to 2006). During the first two winter seasons, researchers monitored 5.6 km (3.5 miles) of distribution line, consisting of 49 contiguous spans (the area between two distribution power line poles) to document the number of avian collisions and bird flight behaviors before marking the power line with diverters. Bird diverters were placed on the line before the final 2005–2006 winter field season.

In this study's novel diverter layout, researchers systematically interspersed diverter-marked and unmarked lines. The study used a systematic block design (Figures 4a and 4b), in which 5.6 km of distribution power lines were divided into five blocks, from north to south. The data were assigned blocks by location (designated as blocks A through E) due to their potential for variation in water levels along the linear landscape and subsequent variation in bird use and flight intensity. Each block systematically alternated one diverter-marked treatment section (four contiguous spans) with one unmarked control section (four contiguous spans). Each

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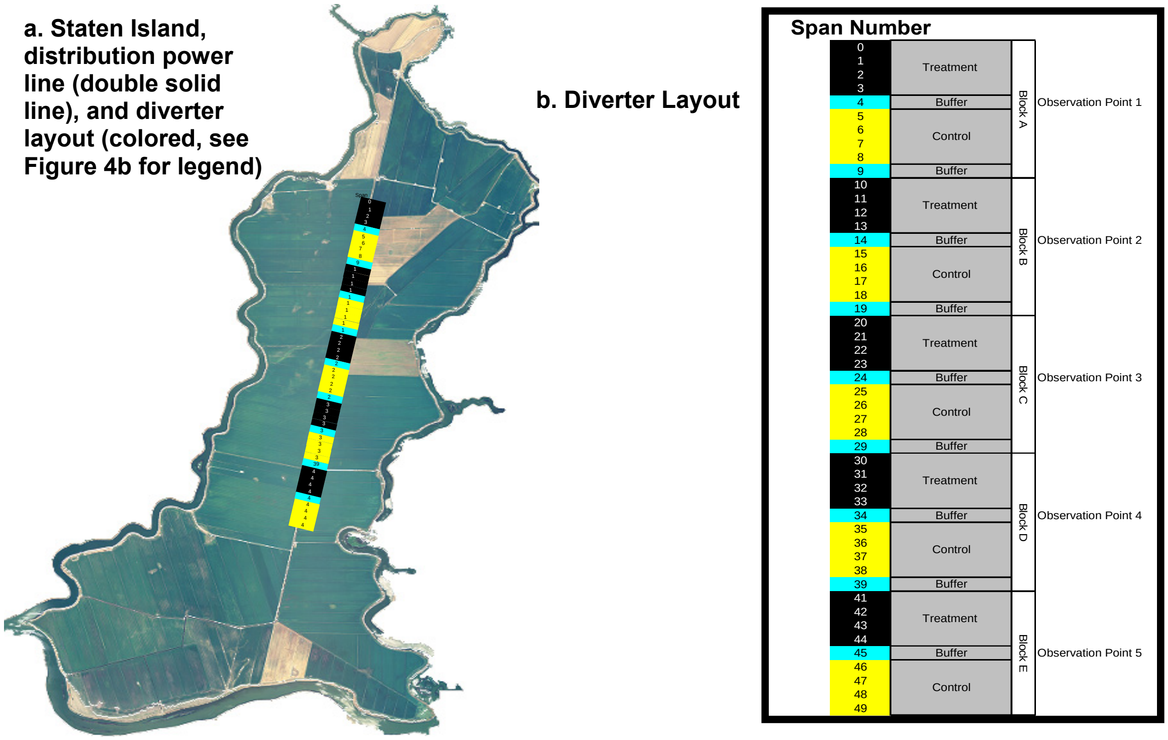
[2] Often referred to in California as *tule fog,* this low-lying fog forms when relative humidity is high (typically after a heavy rain), winds are calm, and the air is cooled rapidly during the night.

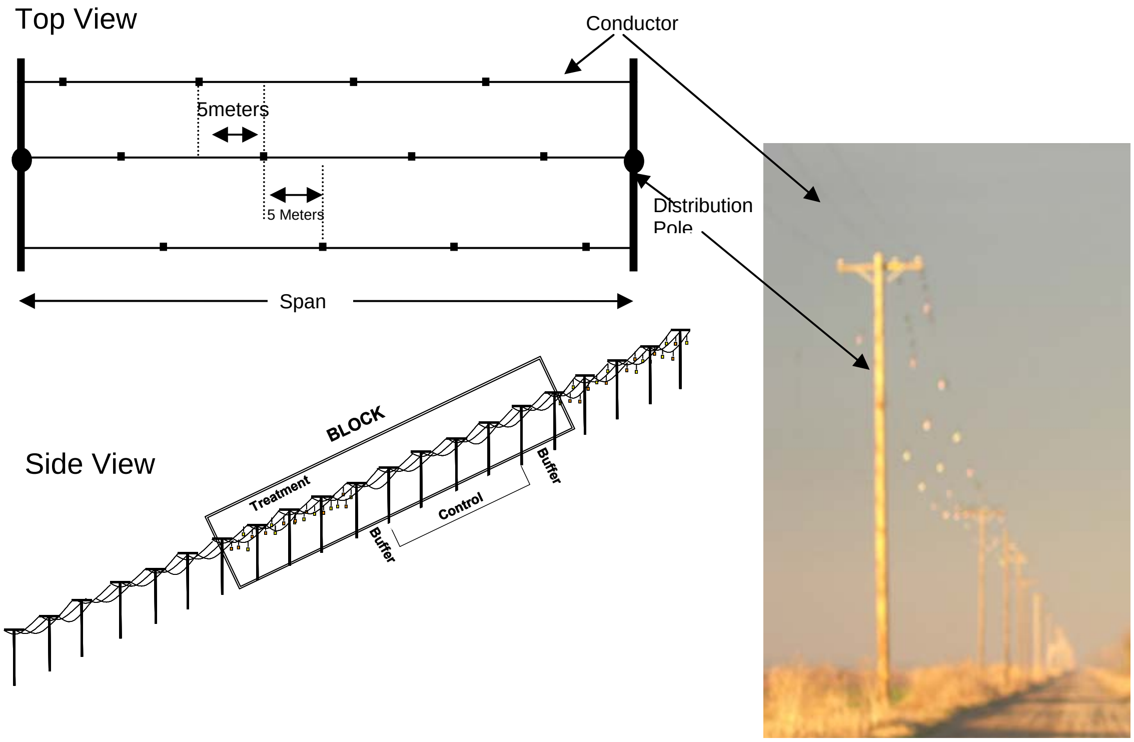
control and treatment section was separated by one unmarked buffer section (one span). This buffer section between the treatment and control sections was left unmarked because of shadowing effects (Crowder 2000)—the potential for diverter-marked treatment spans to affect adjacent unmarked spans. There were a total of five treatment sections (20 spans), five unmarked control sections (20 spans), and nine unmarked buffer sections (nine spans). The sequence of the treatments was not randomized within the blocks but was systematically interspersed. Reversing the sequence would have resulted in one of the treatments occupying a larger continuous portion of the landscape. In such a case, variation associated with the landscape, such as a low concentration of birds due to lack of water, would reduce researchers' ability to distinguish between treatment and landscape effects.



Span Number			
0 1 2 3	Treatment	Block A	Observation Point 1
4	Buffer		
5 6 7 8	Control		
9	Buffer		
10 11 12 13	Treatment	Block B	Observation Point 2
14	Buffer		
15 16 17 18	Control		
19	Buffer		
20 21 22 23	Treatment	Block C	Observation Point 3
24	Buffer		
25 26 27 28	Control		
29	Buffer		
30 31 32 33	Treatment	Block D	Observation Point 4
34	Buffer		
35 36 37 38	Control		
39	Buffer		
41 42 43 44	Treatment	Block E	Observation Point 5
45	Buffer		
46 47 48 49	Control		

Figure 4. Staten Island study area along with 12-kV distribution power line and diverter layout (Figure 4a). The diverter layout consists of the interspersion of treatment (marked with flight diverters), buffer (no diverter), and control (no diverter) sections within the study area (Figure 4a) and within each of 5 blocks (4 treatment, 1 buffer, and 4 control spans; Figure 4b).

The research team evaluated the FireFly Bird Flapper/Diverter (P and R Technologies; Figure 1), which measures 1/8″ × 3.5″ × 6″ and is made of acrylic plastic. It was selected because it had several characteristics previously identified (Beaulaurier 1981) as important when considering a diverter: the color scheme appears visible to the human eye during low-light conditions due to a luminescent strip, and the diverter rotates, alternating between the two contrasting colors under minimal winds speeds. Following the manufacturer's specifications, FireFly diverters were placed on alternate conductors at 5 meter (16.4 ft) intervals, with an average of 15 diverters per span (Figure 5).



Staten Island Road

Figure 5. Diverters were installed on alternating conductors at five meter intervals (top and side views)

2.2. Carcass Searches

Carcass searches were performed up to three times per week, depending on accessibility and land management operations. Although access resulted in differential searching effort between seasons, all spans were searched equally on each given day, allowing comparisons within seasons. Searches were conducted from a vehicle traveling at 5 kilometers (3.1 miles) per hour along a dirt road (Staten Island Road; Figure 5) adjacent to the power line. The presence of this road and the flooded field on the other side limited the effective size of the search zone to 3 meters beyond each of the outside wires (Figure 6). The presence of the road introduced the possibility that birds found beyond the search zone may have died from collision with vehicles; however, very few vehicles were noted using the road during this study.

Figure 6. Distribution power line with flooded field to the west (right) and dry field to the east (left). This figure illustrates the rationale for limiting the search zone to three meters beyond the outside conductors; carcasses found beyond the search zone may have died of other causes and floated in (west) from a neighboring span (floating in) or may have been hit by a car.
Photo credit: C. DiGorgio

Carcasses and feather spots (groups of 10 or more feathers, Figure 7) were both counted as fatalities (Beaulaurier 1981) if found within the 3 m search area. All carcasses and feather spots were recorded and removed to avoid double counting. Characteristics of the carcass such as species, condition (Appendix A), presence of injuries, and burns were noted.

Figure 7. Feather spot discovered under a power line during a routine carcass search

2.3. Behavior Observations

In addition to comparing the number of dead birds attributed to direct collisions with the power lines, the efficacy of the bird flight diverters was evaluated by observing the reaction of birds to the power lines during flight. Observational data were recorded up to three times a week during the final winter season with the aid of light-gathering 8x50 binoculars. Observations were conducted at dusk and dawn from a portable hunting blind situated at one of five observation points selected to allow the researcher a clear view of control and treatment spans (Figure 4B). Behavior data included distance of flight, type of reaction (e.g., direction change, altitude change), distance of reaction, and crossing height above the power line. Estimations of crossing height were made by using the nearest of the two poles at the crossing span as a reference height. These vertical distances were estimated on a continuous scale using the power poles as a reference height of 1. Observations were limited to flocks below 2 pole units above the ground. For reaction distance measurements, 1 foot high pin flags were placed in the field at 10-meter increments to aid in distance estimation. Additional data recorded included crossing span number, species, size of flock, flight direction, temperature, wind speed, wind direction, cloud cover, precipitation, and visibility.

3.0 Analysis

3.1. Evaluating the Extent of Sandhill Crane Collisions with Power Lines

3.1.1. Bias Estimates

Carcass searches by themselves provide a conservative estimate of actual fatalities because searchers do not always find all the carcasses. Factors that may effect searcher detection include searcher efficiency, scavenger bias, crippling bias, and habitat bias (APLIC 1994).

Ideally, it is best to determine the amount of bias resulting from the previously mentioned factors in order to correct for site-specific conditions (e.g., vegetative cover, presence of unsearchable habitat) and differences in human ability to locate carcasses. However, estimating bias factors is not always possible due to limited observations of rare events, such as recovering crippled birds (crippling bias, Brown and Drewien 1995); difficulty in locating sources of appropriate carcasses for searcher and scavenging trials, particularly when focal species are protected (e.g., threatened or endangered); and difficulty identifying volunteers with permits necessary to transport and surreptitiously plant the carcasses. It is assumed that the bias factors apply equally across the 5.6 km long distribution line and therefore will not adversely affect the results of the comparative analyses between treated, control, and buffer spans.

In the case of large birds such as the great bustard (Otis tarda) and sarus cranes (Grus antigone), it may be reasonable to draw from bias estimates calculated in other studies (Janns and Ferrer 2000; Sundar and Choudhury 2005). Estimates of total mortality for large birds are less sensitive to sources of bias than smaller birds. Larger birds, such as the sandhill crane are easier to locate (i.e., lower search bias) due to their size and the lack of cryptic feathers, and are less likely to be removed without a trace (i.e., lower scavenger bias). For example, during this study, a great blue heron (Ardea herodias) found under the line was observed for more than 57 days without being completely removed (Table2). Therefore this study reports a range of estimated mortality, with unadjusted sandhill crane mortality-excluding-bias estimates as the lower bound and mortality-adjusted-by-bias estimates calculated in previous studies of large birds (see Janns and Ferrer 2000 and Sundar and Choudhury 2005) as the worst case scenario. Total mortality rate was calculated as follows:

1/(1-detection or habitat bias) x 1/(1- crippling bias)=

$$1/(1-0.2) \times 1/(1-0.5) = 2.5$$

Total mortality estimate = 2.5 x annual rate of mortality

3.2. Evaluating Diverter Effectiveness

The effectiveness of aerial marking devices for reducing avian collisions with power lines was analyzed by comparing direct carcass counts (no bias estimates) between treatments and by evaluating avian flight behavior relative to the power line. Researchers used SPSS 13.0 and Microsoft Excel 2003 software to analyze the data.

3.3. Effectiveness of Treatment Based on Carcass Counts

To determine if there was a difference in the number of collision-related deaths between diverter-marked treatment, buffer, and control spans, it was necessary to first determine if there were differences in bird collisions along the spans before treatments were applied. The research team tested for differences in the mean number of carcasses per span among treatment, control, and buffer sections with a systematic block analysis of variance (ANOVA). The mean number of carcasses found under each span was determined by dividing the number of carcasses found by the number of spans representative of each span-type: treatment, control, or buffer. Bias factors for data on collision victims, such as searcher detection, crippling, and habitat were assumed consistent across treatments.

The researchers used collision indices (observed/ expected) to calculate the diverter effectiveness. Expected numbers of fatalities per treatment were calculated by multiplying the total number of fatalities by the proportion of the landscape occupied by each treatment (Smallwood 1993; Smallwood 1995). For example, because control spans occupy 40.8% of the landscape and there were a total of 31 fatalities, the expected number of fatalities at control spans = 40.8% × 31 = 12.65. This collision index was used to calculate the diverter effectiveness (1 - collision index × 100).

3.4. Effectiveness of Treatment Based on Flight Behaviors

3.4.1. Flight Height

Univariate analysis of covariance (ANCOVA) was used to assess statistical significance of differences in mean flight height between treatments, using mean flight altitude at power line crossing (CROSSING HEIGHT) as the dependent variable, treatment as a fixed factor, and distance traveled prior to crossing (DEPARTURE DISTANCE) as the covariate. A normal data distribution is expected because each measure is an average of a number of contributing individuals. Equality of variance was tested with Levene’s test.

3.4.2. Reaction Distance

Because reaction distance was not significantly correlated with DEPARTURE DISTANCE, ANOVA was used to assess the statistical significance of differences in reaction distances between treatments, using the mean reaction distance as the dependent variable and treatment as the fixed factor. A normal distribution of the data is expected because each measure is an average of a number of contributing individuals.

4.0 Results

4.1. Carcass Counts

A total of 65 fatalities were recorded for 92 searches over the three winter seasons.

Prior to marking lines with diverters, during the first two seasons a total of 34 carcasses/feather spots were discovered. The peak abundance estimates for avian groups, in addition to the number of fatalities, fluctuated throughout the years (Table 1). No sandhill crane fatalities were discovered during the first two seasons, although the sandhill crane is a common winter resident. However, a farm employee observed a juvenile crane, traveling closely behind its parents, fly into a line less than a mile outside of the study area. Unlike most accounts of avian collision, this bird hit the line close to the pole and burst into flames as it touched two conductors.

Following the installation of diverters to treatment sections, a total of 31 carcasses/feather spots were found. Three sandhill cranes were discovered early in the season: one sandhill crane carcass and one sandhill crane feather spot were discovered under the under control lines; the other carcass was found at a buffer span. No sandhill crane carcasses were discovered under treatment lines.

A lower number of carcasses per span was found at Block E and a higher number at Block C relative to the other three blocks (Table 1). The collision index for Block E indicated that there were 3.5 birds for every 10 expected by chance. The number of collisions per span for blocks A through D was close to the number expected by chance.

4.1.1. Bias Estimates

Although formal bias trials were not conducted, removal rates were evaluated during an initial combined searcher and scavenger removal trial, and carcass decomposition and removal observations (Table 2). Of 23 birds planted within the study zone, only 3 were recovered. The others were either unnoticed or scavenged, indicating that a significant number of birds that collide with lines may go undetected. Further, 6 fresh carcasses were found prior to scavenging and subsequently monitored. Three of these birds disappeared within two days.

As a worst-case scenario, total sandhill crane collisions were adjusted according to bias estimations used for large birds (Janns and Ferrer 2000; Sundar and Choudhury 2005). During the first two winter seasons, the study recorded zero sandhill crane collisions. During the third winter season, three collisions were recorded, raising the annual mortality estimate to 1.34 birds/km.

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	Block A (Poles 0-9)						Block B (Poles 10-19)						Block C (Poles 20-29)						Block D (Poles 30-39)						Block E (Poles 41-49)					
Measurement	Without Diverters Winters 03/04 & 04/05			With Diverter Winter 05/06			Without Diverters Winters 03/04 & 04/05			With Diverter Winter 05/06			Without Diverters Winters 03/04 & 04/05			With Diverter Winter 05/06			Without Diverters Winters 03/04 & 04/05			With Diverter Winter 05/06			Without Diverters Winters 03/04 & 04/05			With Diverter Winter 05/06		
Treatment (number of spans)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (2)	Control (4)	Treatment(4)	Buffer (2)	Control (4)	Treatment(4)	Buffer (2)	Control (4)	Treatment (4)	Buffer (1)	Control (4)
Carcasses/span	0.75	0	1.25	0	1	1.25	0.25	0	0.75	0.25	1	1	0.75	0.5	0.5	0.25	0.5	1.25	1	0.5	0.75	0.75	0	1.25	1	2	0.5	0	0	0.5
Carcasses	3	0	5	0	2	5	1	0	3	1	2	4	3	1	2	1	1	5	4	1	3	3	0	4	4	2	2	0	0	2
Collision index (observed/expected)	1.15			1.11			0.58			1.11			0.86			1.11			1.15			1.26			1.28			0.35		
Number of searches	56			36			56			36			56			36			56			36			56			36		
Number of carcasses	8			7			4			7			6			7			8			8			8			2		
Avg. Number of sandhill crane over flights per day (SD)	-			58.8 (40.6)			-			68.3 (25.0)			-			114 (126.0)			-			90.2 (55.4)			-			37 (28.3)		
Flight Index (observed/expected number of flights)	-			0.77			-			0.91			-			1.52			-			1.20			-			0.55		
Avg. Crossing Height (SE)	1.45 (.160)			1.7 (.070)	1.75 (.048)	1.74 (.044)	1.69 (.105)			1.85 (.052)	1.74 (.125)	1.83 (.066)	1.56 (.022)			1.72 (.067)	1.59 (.037)	1.58 (.035)	1.482 (.021)			1.72 (.031)	1.4 (.104)	1.61 (.060)	1.58 (.038)			1.83 (.055)	-	1.61 (.162)
Avg. Reaction Distance	0.5			1.4	0.4	1.07	.625 (.125)			1.5	1.5	1.8	.915 (.066)			1.75	1.2	1	1.07 (.087)			-	-	-	.995 (.156)			-	-	-

Table 1. Summary table of measures by blocks and treatments. During two winter seasons (2003/2004 and 2004/2005) prior to marking the power line with diverters (years combined and shaded in gray) the number of carcasses per span were not different between treatment, control, and buffer sections. In winter 2005/2006 (unshaded) following the installation of diverters to treatment spans, the number of carcasses per span was different between treatment, control, and buffer spans.

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Carcass Removal Monitoring Table

	Date found	Last seen	Type of Carcass	Less than 2 days?	Treatment	Bird	
1	12/23/2003	2/19/2004	Planted	N	Control	Great Blue Heron	Prior to Marking with Diverters
2	2/24/2004	2/26/2004	Planted	N	Treatment	Rock Pigeon	
3	2/24/2004	2/25/2004	Planted	Y	Control	Northern Mockingbird	
4	2/24/2004	2/25/2004	Planted	Y	Control	Hermit Thrush	
5	2/24/2004	2/26/2004	Planted	Y	Buffer	Northern Mockingbird	
6	2/24/2004	2/25/2004	Planted	Y	Treatment	Rock Pigeon	
7	2/24/2004	2/25/2004	Planted	Y	Control	Mallard (Female)	
8	11/7/2005	11/7/2005	Natural	Y	Treatment	American Coot	Diverters Present
9	12/5/2005	12/19/2005	Natural	N	Treatment	American Coot	
10	12/19/2005	12/19/2005	Natural	Y	Control	European Starling	
11	1/9/2006	1/9/2006	Natural	Y	Control	Unidentified Sparrow	
12	1/26/2006	1/28/2006	Natural	N	Control	Red-winged Blackbird	
13	1/27/2006	1/28/2006	Natural	N	Control	Western Sandpiper	
14	2/5/2006	2/7/2006	Planted	Y	Treatment	European Starling	
15	2/5/2006	2/7/2006	Planted	Y	Control	European Starling	
16	2/5/2006	2/7/2006	Planted	Y	Treatment	Pied-billed Grebe	
17	2/5/2006	2/7/2006	Planted	Y	Treatment	Unidentified Sparrow	
18	2/5/2006	2/7/2006	Planted	Y	Control	House Finch	
19	2/5/2006	2/7/2006	Planted	Y	Buffer	House Finch	
20	2/14/2006	2/16/2006	Planted	Y	Control	Common Moorhen	
21	2/14/2006	2/16/2006	Planted	Y	Treatment	Killdeer	
22	2/14/2006	2/16/2006	Planted	Y	Buffer	Mallard	
23	2/14/2006	2/16/2006	Planted	Y	Treatment	Savannah Sparrow	
24	2/14/2006	2/16/2006	Planted	Y	Control	Brewer’s Blackbird	
25	2/14/2006	2/16/2006	Planted	N	Treatment	Nuttall’s Woodpecker	
26	2/16/2006	2/18/2006	Planted	N	Control	Northern Mockingbird	
27	2/16/2006	2/18/2006	Planted	N	Treatment	Black Phoebe	
28	2/16/2006	2/18/2006	Planted	N	Buffer	American Crow	
29	2/16/2006	2/18/2006	Planted	N	Control	Belted Kingfisher	
30	2/16/2006	2/18/2006	Planted	Y	Control	Nuttall’s Woodpecker	

Table 2. Carcass removal monitoring table. Whole carcasses found under the power line were labeled as natural and monitored to assess the effect of scavengers. Planted carcasses were placed in the field, within the search zone and monitored to asses scavenging bias. ”Less than 2 days?” refers to birds that were removed from the search zone in less than two days.

4.2. Effect of Diverters

In each of the two seasons prior to marking the lines with diverters, although the number of carcasses found varied throughout the study site (SEASON 2: two-way ANOVA, BLOCK, F = 4.08, df= 4, P = 0.043) there was no difference in the number of carcasses per span between treatment, buffer and control sections (Figure 8; SEASON 1: two-way ANOVA, TREATMENT, F = 0.54, df= 2, P = 0.60; SEASON 2: two-way ANOVA, TREATMENT, F = 0.77, df= 2, P = 0.49).

Together these results indicate that although differences in the landscape contribute significantly to the number of carcasses found per span, there was no pre-existing bias to the study design: collisions were not occurring more in areas that would later be established as controls and collisions were not occurring less in areas that would later be established as treatments.

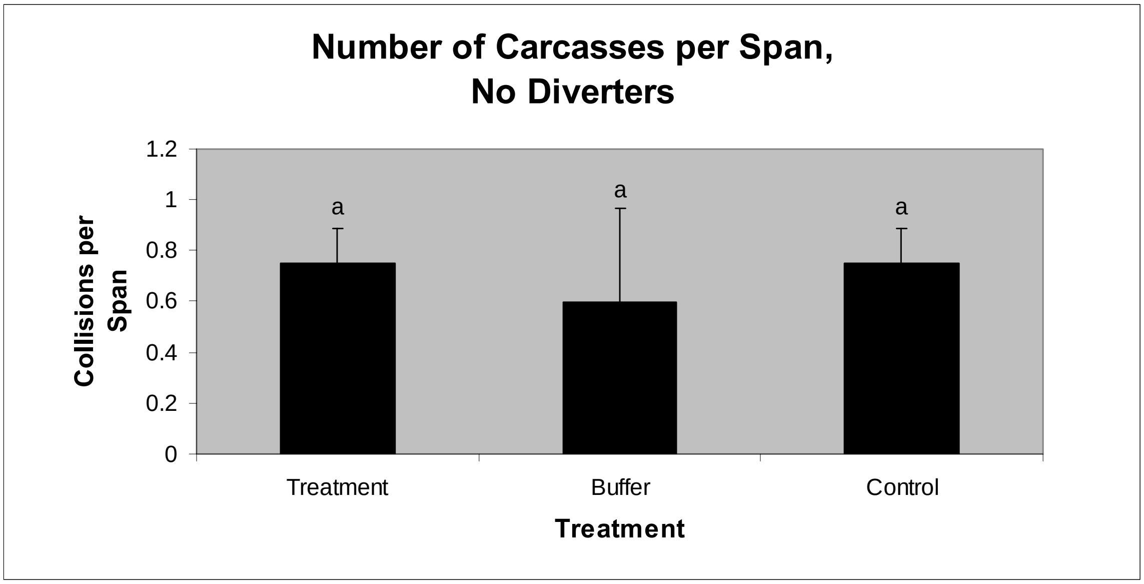

Figure 8. The number of carcasses per span for treatment, buffer, and control spans are shown (±se). Prior to marking power lines with diverters (winters 2003/2004 and 2004/2005) there was no difference in the number of carcasses per span for treatment, buffer, and control spans (*P* = 0.48).

Following the installation of diverters, the number of carcasses found was significantly lower (two-way ANOVA, TREATMENT, F = 6.23, df= 2, P = 0.023; Figure 9) for the diverter-marked section (carcasses found per span +/- SE = 0.25 +/- 0.14), followed by buffer (0.5+/- 0.22) and control (1.05+/- 0.15) spans, but this did not differ by block (two-way ANOVA, BLOCK, F= 1.34, df = 4, P = 0.33). While control spans were 1.6 times more likely than expected by chance to have carcasses associated with them, only four of every 10 birds expected by chance were found at diverter-marked spans (Figure 10). There was a 60% reduction in the number of carcasses found under marked lines. Furthermore, the installation of diverters may also affect adjacent spans (Figure 9).

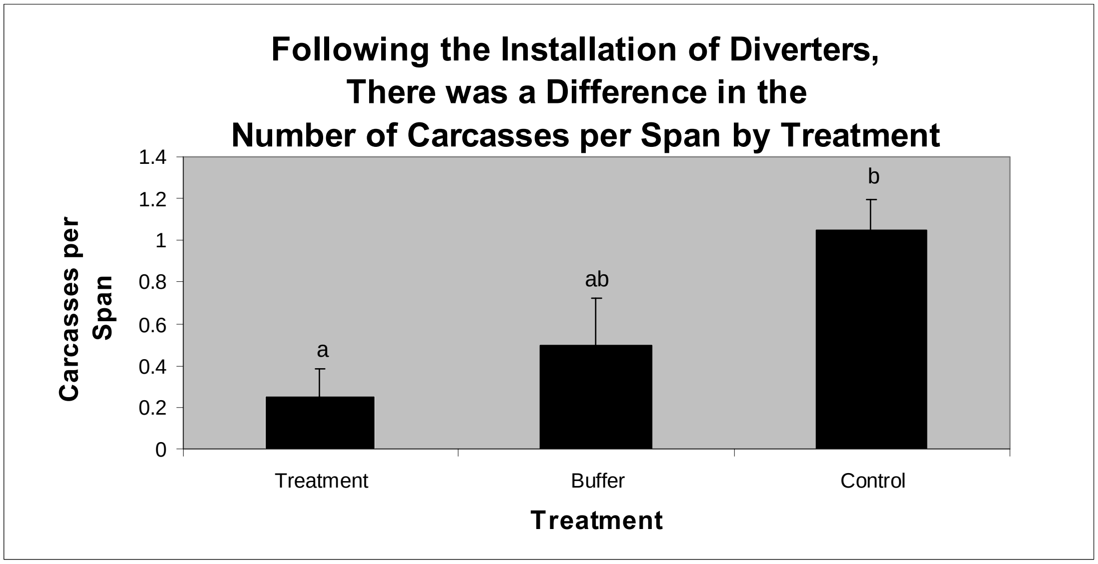

Figure 9. Carcasses per span for diverter-marked treatment and unmarked buffer and control spans (winter 2005/2006) are shown (± se). After installing diverters on the distribution power line there was a difference in the number of carcasses per span found between treatments (P = 0.02). Furthermore, diverter-marked treatment spans may have an effect on adjacent buffer spans. Letters above bars indicate significant differences (*P* < 0.05) between treatments.

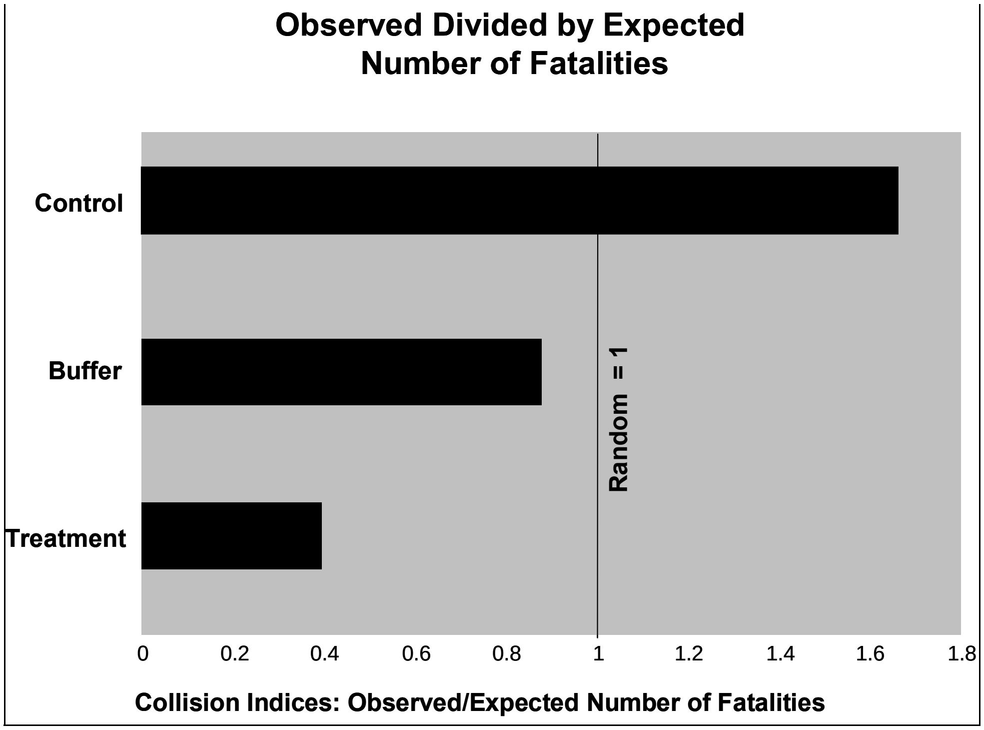

Figure 10. Collision indices (observed/expected number of carcasses per span) for diverter marked treatment and unmarked buffer and control spans (winter 2005/2006). Although collisions at buffers were consistent with what was expected by chance (observed/expected~1), only 4 of 10 carcasses expected were discovered at treatment spans. Associations shown are significant (P < 0.01); $\chi 2$ = 10.222; df = 2.

4.3. Flight Behaviors

Flight observations were recorded on a total of 27 days. Totaling more than 55 hours, 492 separate observations were recorded for 2426 birds. No collisions were seen during the behavioral observations. Aside from two observations of ducks crossing within the observation zone, all of the observations were of sandhill cranes (99.6%).

Following the installation of diverters on the power line, although the covariate of distance was significantly ($P < 0.001$) related to crossing height, there was no difference between TREATMENTS in distance-adjusted average crossing heights, ($F= 1.50$, $df = 2$, $P = 0.23$) and there was no difference between TREATMENTS in reaction distance ($F = 1.06$, $df = 2$, $P = 0.36$). These data indicate that flight behavior did not differ in response to the presence of diverter.

There was a significant difference in the number of flights recorded at each block ($\chi^2 = 41.220$, $df = 4$, $P < 0.0001$) indicating that birds did not use the landscape equally.

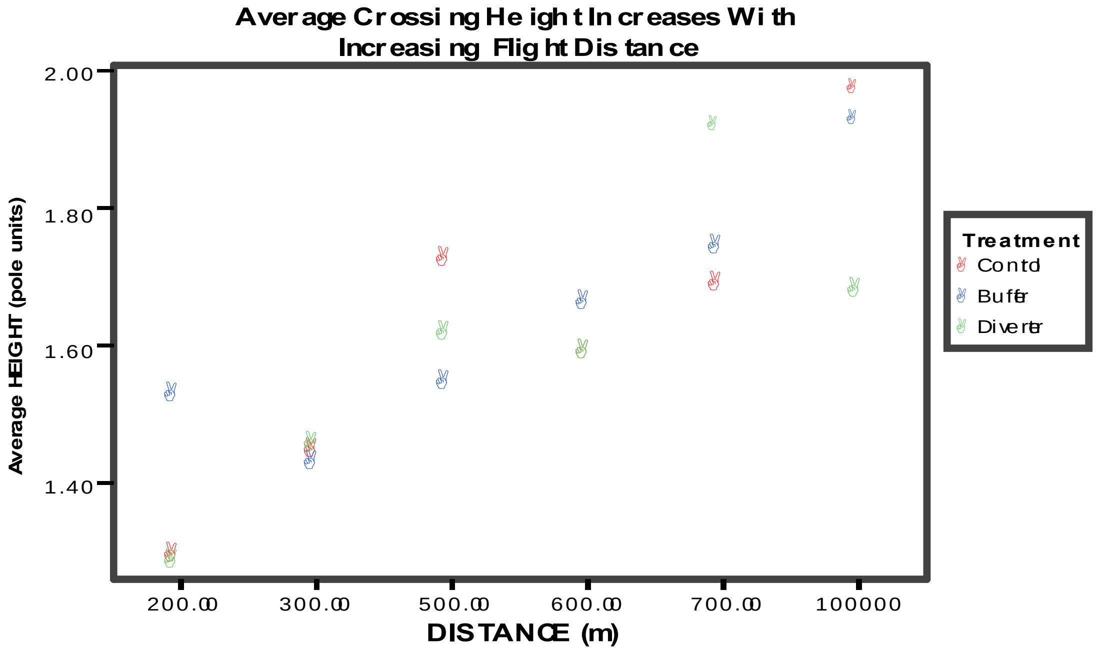

Figure 11. This figure illustrates the significant relationship between flight distance and flight height. Sandhill cranes that traveled greater distances (DISTANCE) prior to crossing the power line also flew at higher altitudes (HEIGHT) regardless of treatment.

Distance may also be important in the analysis of flight height (Figure 11). Birds that travel greater distances prior to crossing the line fly at higher altitudes. Analysis showed that flight heights did not differ between treatments, once the data were adjusted for distance traveled. If these data were not adjusted for flight distance the research team would have incorrectly concluded that flight heights were significantly different between treatments (Figure 12).

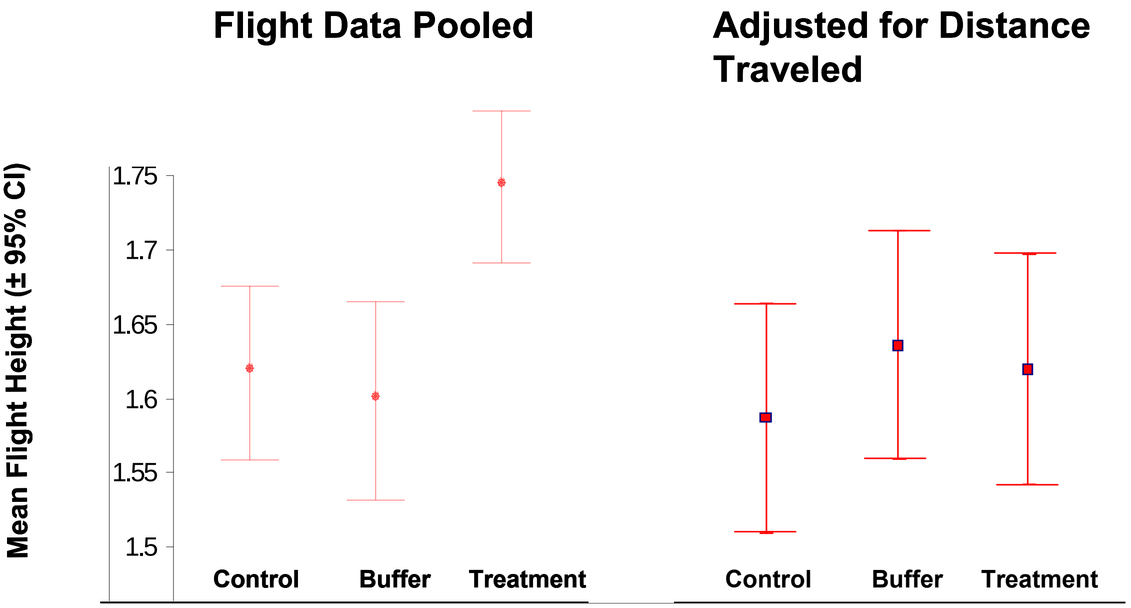

Figure 12. Average flight heights for each treatment. Flight data pooled from each block and analyzed by treatment (left) indicate a significant difference in flight height by treatment; however, when flight heights are adjusted for distance traveled, there is no difference in flight heights among treatments. (CI = confidence interval)

5.0 Discussion

5.1. Collision Estimates

Although collisions with transmission power lines have been reported at locations around the world, estimates are needed for distribution power lines, particularly at California preserves, where bird concentrations are high and power lines are common. It appears that these data represent the first published account of collisions with distribution power lines in California. This study's reported estimates of fatalities did not account for biases due to searcher efficiency, scavenger removal, habitat, and crippling. Therefore, it is likely that they are conservative and that the total number of collisions occurring with the power line is considerably higher than reported here. Based on combined searcher and scavenger removal trial and carcass decomposition and removal observations (Table 2), this study concludes that the number of birds that may have gone undetected as the result of searcher inefficiency or scavenger removal may be considerable, indicating that the study may be severely underestimating the total collision estimate. Rigorous bias studies are needed to determine, with greater accuracy, the total mortality due to collision with power lines. However, to do so it is necessary to determine a minimum search zone.

Estimating the appropriate search zone is vital to calculating habitat bias. Use of a Global Positioning System (GPS) is recommend to collect exact positions of carcasses relative to the power line, to determine minimum search zones and refine estimates of biases due to unsearchable habitat (habitat bias). Distribution power lines have not been well studied, and researchers do not know how far birds will fall from the power line following a collision. Currently, there is no basis on which to recommend a minimum search zone. Further, researchers (see APLIC 1994) calculate habitat bias as the percentage of unsearchable habitat within the search zone, regardless of distance from the power line. However, it is unlikely that, following a collision, birds will fall with equal frequency throughout the search zone. Although the proportion is unknown, it is likely that more birds will fall within the proximity of the power line. Therefore, it is necessary to determine the locations of carcasses relative to the power line, to describe the relative proportions of birds expected to fall within a particular distance of the line. This determination would refine the accuracy of habitat bias estimations by allowing researchers to weight distances from the power line appropriately.

In the absence of bias estimates, this study estimated, as a worst-case scenario, total sandhill crane collisions adjusted according to the bias estimations used for large birds (Janns and Ferrer 2000; Sundar and Choudhury 2005). During the first two winter seasons, there were no sandhill crane collisions. Although sandhill crane abundance was not significantly different between years (Ducks Unlimited 2007), during the third winter season three collisions were recorded, raising the annual mortality estimate to 1.34 birds/km. This estimate was higher than the highest of three years recorded for the sarus crane mortality (0.347) in northern India (Sundar and Choudhury, 2005). Given that sandhill cranes on Staten Island are only on the island from November through February (a 60% shorter period than the sarus canes that were studied in India), this project's estimate is particularly high. However, estimates of annual mortality for sandhill crane at Staten Island fall within the range previously reported and were well below that for common cranes in southwestern Spain. Janns and Ferrer (2000) reported a higher number of common crane carcasses: 25 common crane carcasses in four winters. This study's estimate of mean annual collision mortality between 0–1.34 cranes per kilometer of study line was lower than the Janns and Ferrer (2000) range of mortality estimates of 2.34–5.85 cranes/km. Although their search zone was roughly 55 meters greater than the one in this study, it is not likely that the smaller search zone (due to this study's shorter distribution power lines) would account for much of the difference in fatality estimate. However, in this study, birds falling greater than 3 meters from the line would have gone undetected due to difficulty in locating carcasses landing in water.

5.2. Diverter Effectiveness Based on the Number of Carcasses Found at Control and Treatment Lines

Although this study does not include bias estimates, the researcher team is confident that there was no difference in the amount of scavenging occurring across treatment based on three scavenging deposits (17 birds; $\chi^2 = 0.200$, df = 2, P = 0.90) and monitoring the presence of fresh carcasses (Table 2). Although limited, carcass monitoring suggested that scavengers did not avoid treatment sections, since they removed whole birds and scavenged on parts over several days (Table 2). This study assumes that biases due to searcher efficiency, scavenger removal, crippling, and habitat were equal across treatments.

This study indicates that the tested flight diverter reduced collisions. Effectiveness for the FireFly diverter (60%) was similar to spiral vibration dampeners (61%) and swinging plates (63%, Brown and Drewien 1995), and aviation balls (54%, Moorkill and Anderson 1991 as calculated in Brown and Drewien 1995). Both Brown and Drewien (1995) and Moorkill and Anderson (1991) measured marker effectiveness at high-voltage power lines. Although Brown and Drewien tested diverter effectiveness at both transmission and distribution lines, they did not report separate estimates. Until 1998 little attention had been paid to the relative impact of avian collisions and subsequent assessment of diverters on distribution power lines. Janns and Ferrer (1998) studied the effectiveness of black stripes for reducing avian collisions at a power line similar in height and span length (distance between poles) to the distribution power line at Staten Island. Although their markers did reduce collisions (33.3%), the difference between treatments and controls was not significant (P = 0.157). The authors concluded that the black strips were not effective.

Even though Janns and Ferrer (1998) studied a similar distribution line, differences in the layout of diverters—the spatial arrangement of control versus treatment spans on the landscape—limit the accuracy of comparisons of diverter effectiveness. The layout of diverters is likely to have a strong effect on the effectiveness of the diverter. Although it is likely that the black stripes were ineffective, their assessment, based on the relative number of carcasses found under control and treatment lines, may have suffered from a shadowing effect due to the proximity of treatments relative to control spans. Janns and Ferrer (1998) alternated treatment and control spans, placing one next to the other. This layout may have reduced the sensitivity to detect a treatment effect. The black stripes may have been effective under a different spatial arrangement of treatment and controls. This study indicates that this layout of diverters may be more important in distribution power line studies than on transmission line studies because the shorter distance between spans may result in a stronger shadowing effect: treatments may have a stronger effect on nearby controls; birds traveling over control spans may have greater awareness of markers on adjacent treatment spans. This study found that buffer spans adjacent to treatment spans had lower collisions/span than controls (Figure 9). Although the difference between buffers was not significantly different from controls and treatments, the number of collisions per span at buffers was less than control and more than treatments. Likewise, it is possible that the markers in Janns and Ferrer's (1998) study may have reduced collisions on adjacent spans and that those spans were not true controls. Paradoxically, in such an alternating layout, diverters with the most visibility (i.e., effectiveness) would be less likely to be reported as significant, relative to less-visible diverters. Therefore, it is recommended that diverter assessment studies consider the shadowing effect in study design. As there is a cost associated with purchasing, installing, and maintaining diverters, and because collisions at neighboring spans (buffers) were somewhat reduced, it is recommended that future studies also investigate a different spacing protocol within each marked span, to maximize the number of diverters per span.

In addition to the alternating layout of treatment and control spans adjacent to one another, the opposite layout comprised of many continuous treatment spans (such as studies with half of a line marked and another half left unmarked) may also lead to an incorrect evaluation of diverters. Treatments and controls must be, by definition, within the same landscape and experience similar conditions. If the area and number of spans designated as treatments is too large, researchers may run the risk of placing controls in areas of different conditions. This study's results indicated that had its design incorporated larger treatment sections (i.e., more treatments spans per section), instead of blocks with both control and treatments, differences in the landscape from land management practices would have increased the potential for inaccurate assessment of diverter effectiveness. During season three, blocks were significantly different with respect to average flight intensities ($\chi^2 = 41.220$, df = 4, $P < 0.0001$). The southernmost block, Block E, had the lowest flight intensity and the lowest average carcasses/span (0.22 versus 0.70+ for blocks A–D; Table 1). If this section had been designated as a treatment, rather than a block (with treatments and controls), then this lower number of carcasses found may have been incorrectly attributed to diverter effectiveness, rather than to a lower number of birds using this area relative to controls. At best, the comparison between control and treatments would have been discarded and the importance of different flight intensities discussed. At worst, this data would have been used to incorrectly support the claim that the diverter was effective.

In this study; however, the lower number of flights and the lower number of collisions may be explained by one environmental variable. Block E was also the only block that did not have a flooded field adjacent to it. The lack of water resulted in lower bird usage and subsequently less frequent flights over the power line. Therefore, the lower number of collisions is more likely due to differences on the landscape (e.g., no water). If, instead that southernmost section had been defined as a treatment section, then the lower number of collisions might have incorrectly attributed to diverter effectiveness.

This study may be the first to evaluate the effectiveness of a diverter on distribution power line in California. Researchers should continue to assess the effectiveness of diverters under a variety of environmental conditions.

An important goal of this work was to demonstrate the significance, on low-voltage distribution power lines, of proper spatial arrangement of treatment and control spans. As shown, the layout of treatment relative to control spans can have a significant effect on the validity of analysis.

5.3. Diverter Effectiveness Based on Flight Behavior at Control and Treatment Lines

Flight behaviors at this distribution power line were an inadequate measure of determining diverter effectiveness. Yet the diverters reduced collisions. As stated in the previous section, this diverter was, in fact, effective for reducing avian collisions; however, based on flight observations the research team was unable to detect a difference between control and treatment spans for both flight height and reaction distance. In contrast, researchers reporting significantly effective diverters, based on collision reduction, have also reported concurrent differences in flight behaviors such as flight height and reaction distance (Moorkill and Anderson 1991; Brown and Drewien 1995; De La Zerda and Rosselli 2002), and flight intensity (Alonso et al. 1994).

Differences in flight behavior may have been undetectable because treatments may not have altered normal flight behavior, due to the lower airspace occupied by the power line. This study's observations of cranes generally flying between 10 and 15 meters above the ground was similar to that of other researchers (Moorkill and Anderson 1991). Therefore, local flights between feeding and roosting sites were generally at or above the height of the distribution power line (10 meters). However, there were cranes that hit power lines, so some fly at the height of the lines. The question is, how many of those that flew at the height of the power lines avoided them? No collisions or no near misses were observed, so no data is available to analyze.

Differences in flight height may not have been detectable because most of the birds observed were already flying at a height above that of the lines. Increases in altitude may have been due to distances traveled prior to crossing the power line (DISTANCE as covariate, $P < 0.001$; Figure 11; Moorkill and Anderson 1991). In fact, birds may need a minimum flight distance to gain the necessary height to cross the power line safely (see management recommendations).

In contrast to this study's results, past studies on transmission power lines observed birds crossing power lines that were up to 30 meters higher above the ground. The greater energy required to make it over these lines may have limited flight heights to a minimum altitude necessary to cross, increasing the difference in flight height between control and treatment lines, if in fact reaction to the diverters result in an increase in altitude. Further complicating the issue of flight behaviors are the records of species groups reacting differently to marked lines (Brown and Drewien 1995). One species may react more to marked lines, while another species may react more to unmarked lines.

The power poles themselves may also be responsible for reducing the ability to detect behavioral differences between control and treatment lines. Shorter distance between poles results in more poles on the landscape and greater visual coverage (relative to the larger transmission power lines). Thus, poles may provide cranes with the visual cue necessary to fly over the line. At a distribution power line under construction, adjacent to the study site, sandhill cranes feeding close to the line ascended vigorously to clear the height level of the power lines even though only the poles, and not the power line, had been installed. Birds may use additional features (e.g., poles), in addition to the lines themselves, to determine the height of the power line. Because distribution power line poles are closer together than transmission line towers, birds responding to poles may ascend to heights safely above the power lines, regardless of diverters.

An important conclusion of this work is that the effectiveness of diverters on lower-voltage, lower-altitude, short-span lines should not be assessed by difference in flight behavior alone. If flight heights are analyzed, it is important to include the variation caused by the distance traveled prior to crossing the line. Mitigation measures such as these diverters must reduce avian collisions, regardless of changes in flight behavior.

5.4. Land Management Recommendations to Reduce Collisions

A number of siting measures to reduce avian collision with power lines have been discussed in detail (APLIC 1994). Briefly, these measures aim to reduce avian collision with power lines by routing lines such that they do not cross major flight paths. All of these mitigation guidelines have been directed toward utilities and the measures they can take to reduce avian collisions on new lines; however, because power lines, once constructed, are difficult to reroute and cost prohibitive to underground, it may be more important to explore measures individual land owners/managers may take to reduce avian collisions.

Among other activities, APLIC discusses the following:

- Planting trees along the power line gives birds a visible object to avoid and ascend, reducing collisions with the less visible power line.
- Managing crops and seasonally flooding fields so that feeding and roosting habitats are on the same side of the power line (Figure 13). When feeding and roosting sites are located on opposite sides of the power line, birds must cross over the power line to get to their destination. If however, that destination were located on the same side, flights across the line would be greatly reduced. Placing flooded fields and dry fields on the same side reduces the number of over flights, and therefore the risk of collision.

- Managing the landscape so that habitats separated by the power line and used regularly (such as feeding and roosting habitats) are placed farther away from the power line may reduce collisions (Figure 13).

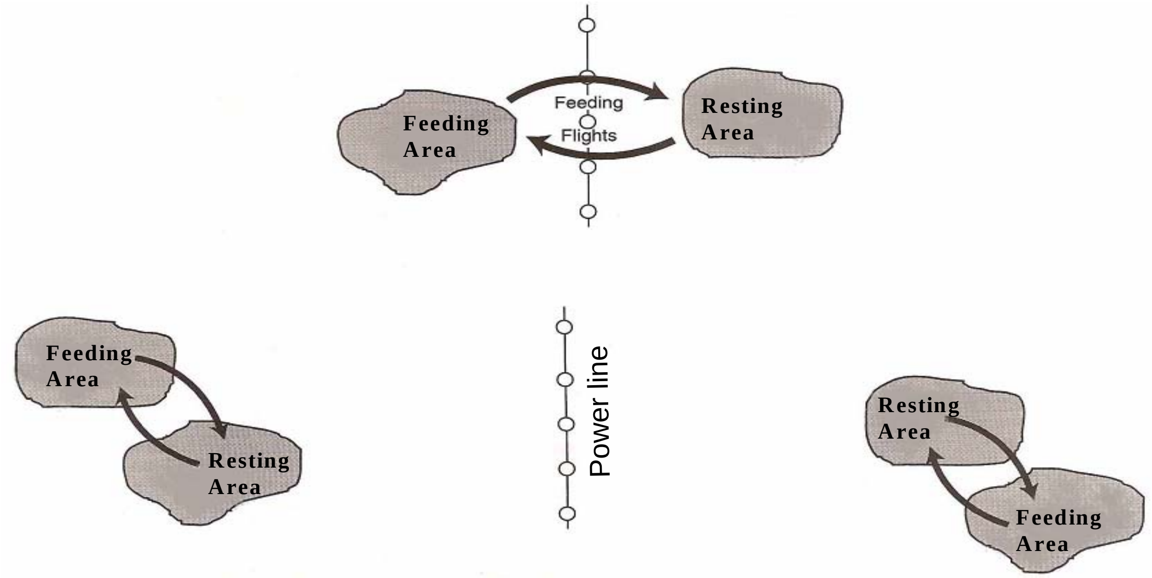

Figure 13. When high-use habitats are separated by a power line (top), risk of collision may be high, as the result of high avian traffic. Increasing the distance between the power line and high-bird-use areas, in addition to creating feeding and roosting sites on the same side of the power line, will reduce the number of flights across the power line (Modified from APLIC 1994).

Many birds, and cranes in particular, rarely fly under the power line, instead opting to fly over. No crane flights below the power line were witnessed in more than 2400 observations of crane flights. This result was similar to flight behavior reported by Moorkill and Anderson (1991). Although their power lines were up to 27 meters above ground, they found that cranes did not fly under the line unless flushed. Flushing due to hunters (Brown and Drewien 1995) or predators can increase the number of nighttime collisions, even if the power lines are marked. Therefore, managing the habitats so that they are farther away from the power line, particularly in habitats likely to flush a large number of birds in the dark (e.g., roosting), will give birds more time to gain the altitude necessary to fly over the power lines and the distance to react.

This study found that an increase in the distance prior to crossing the line was associated with higher flight height (Figure 11). Conversely, habitats within proximity of the line are a greater collision risk for birds. Moorkill and Anderson (1991) and Brown and Drewien (1995) both found that cranes traveling short distances (that is, flights originating within 250 meters of the power line) flew at lower altitudes, requiring them to adjust flight height to avoid striking the line. In addition to such flight adjustments, other flight adjustments that allowed cranes to fly over the power line were recorded. On nine occasions, cranes were observed adjusting their flight path to accommodate the greater distance necessary to gain altitude, initially flying away from the line in a smooth arc steadily making their way back over the line in what amounted to a 180-degree change in direction. Cranes did not make this circle back flight pattern when beginning flights more than 100 meters from the line. Therefore, a minimum 100-meter buffer zone of unfavorable habitat should separate the power line and high-use habitats. The use of both land management recommendations—placing high use habitats (e.g., feeding and roosting) on the same side of the power line and increasing the distance between the habitats and the power line—in conjunction with one another may reduce the number of dangerous flights over the power line.

This work demonstrated the role land management can have in reducing avian collisions with distribution power lines, particularly in areas that experience low visibility.

6.0 References

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Appendix A

List of Identified Carcasses and Feathers

Appendix A

List of Identified and Unidentified Carcasses and Feathers Spots

American Coot	*Fulica americana*	Carcasses, Feather spots
Brewer's Blackbird	*Euphagus cyanocephalus*	Carcass
Double-crested Cormorant	*Phalacrocorax auritus*	Carcass
European Starling	*Sturnus vulgaris*	Carcass
Great Blue Heron	*Ardea herodias*	Carcass
Mallard	*Anas platyrhynchos*	Carcass, Feather spots
Mourning Dove	*Zenaida macroura*	Feather spots
Red-tailed Hawk	*Buteo jamaicensis*	Carcass
Ruddy Duck	*Oxyura jamaicensis*	Carcasses, Feather spots
Sandhill crane	*Grus canadensis*	Carcasses, Feather spot
Tundra Swan	*Cygnus columbianus*	Carcass
Unidentified Duck	*Anatinae*	Feather spots
Unidentified Shorebird	*SCOLOPACIDAE*	Carcass
Unidentified Sparrow	*EMBERIZIDAE*	Carcass
Western Meadowlark	*Sturnella neglecta*	Carcass
Western Sandpiper	*Calidris mauri*	Carcass
White-fronted Goose	*Anser albifrons Greater*	Carcass