



Arnold Schwarzenegger  
*Governor*

**EVALUATING DIVERTER  
EFFECTIVENESS IN REDUCING AVIAN  
COLLISIONS WITH DISTRIBUTION LINES  
AT SAN LUIS NATIONAL WILDLIFE  
REFUGE COMPLEX, MERCED COUNTY,  
CALIFORNIA**

*Prepared For:*  
**California Energy Commission**  
Public Interest Energy Research Program

**Pacific Gas and Electric  
Company**

**Edison Electric Institute**

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Ventana Wildlife Society

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## Preface

The California Energy Commission's 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 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.

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*Evaluating Diverter Effectiveness in Reducing Avian Collisions With Distribution Lines at San Luis National Wildlife Refuge Complex, Merced County, California* is the final report for the Contract Number 500-01-032 conducted by Ventana Wildlife Society. 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/research/](http://www.energy.ca.gov/research/) or contact the Energy Commission at 916-654-4878.





## Table of Contents

Acknowledgments .....	i
Preface .....	iii
Abstract .....	ix
Executive Summary .....	1
1.0 Introduction.....	3
1.1. Background and Overview.....	3
1.2. Project Objectives .....	5
2.0 Project Approach.....	7
2.1. Study Sites .....	7
2.2. Project Design .....	7
2.3. Field Methods .....	13
2.3.1. Flight Observations.....	13
2.3.2. Carcass Searches.....	14
2.4. Statistical Analysis .....	15
2.4.1. Analysis of Flight Observations.....	15
2.4.2. Analysis of Carcass Recoveries .....	17
3.0 Project Outcomes.....	19
3.1. Flight Observations.....	19
3.2. Carcass Recoveries .....	22
4.0 Conclusions and Recommendations.....	25
4.1. Management Implications .....	26
5.0 References.....	29
Personal Communications.....	33
Appendices .....	35

## List of Figures

Figure 1. Bird-Flight Diverter™ (a) and Swan-Flight Diverter™ (b) .....	4
Figure 2. Location of San Luis National Wildlife Refuge Complex, Merced County, California...	9
Figure 3. Selected power lines at the San Luis site, San Luis National Wildlife Refuge Complex, Merced County, California. . . . .	10
Figure 4. Selected power lines at the Kesterson and Blue Goose sites, San Luis National Wildlife Refuge Complex, Merced County, California.....	11
Figure 5. Selected power lines at three sites in the Merced National Wildlife Refuge, San Luis National Wildlife Refuge Complex, Merced County, California.....	12
Figure 6. Observers conducting carcass searches along power lines .....	14
Figure 7. Means of reaction distance categories (with 95% confidence intervals) among guilds recorded during flight observation surveys before and after diverters were installed at San Luis National Wildlife Refuge Complex, Merced County, California. ....	21
Figure 8. American Coots accounted for approximately half of all carcass recoveries at San Luis National Wildlife Refuge Complex, Merced County, California in two winter search seasons from October 2006 to February 2008.....	23
Figure 9. Estimated total collisions and 95% confidence intervals at power lines with Bird-Flight Diverters (BFD), Swan-Flight Diverters (SFD), and no diverters (Control, C) at six sites in San Luis National Wildlife Refuge Complex, Merced County, California in two winter seasons from October 2006 to February 2008.....	24
Figure 10. Some of the apparent victims of collisions at San Luis National Wildlife Refuge Complex were nocturnal species, like the Barn Owl. ....	28

## List of Tables

Table 1. Percentage of reaction distance records in each distance category before and after lines were treated with Bird-Flight Diverters and Swan-Flight Diverters at San Luis National Wildlife Refuge Complex, Merced County, California. ....	20
Table 2. Support for logistic regression models predicting flutter/flare reactions at San Luis National Wildlife Refuge Complex, Merced County, California. ....	22

## List of Appendices

Appendix A. Codes used for data collection during flight observation surveys at San Luis National Wildlife Refuge Complex, Merced County, California. ....	35
Appendix B. Data form used for flight observation surveys at San Luis National Wildlife Refuge Complex, Merced County, California. ....	37
Appendix C. Data form used to record bird mortality at San Luis National Wildlife Refuge Complex, Merced County, California. ....	38
Appendix D. Data form used to document resighting of carcasses found during previous searches at San Luis National Wildlife Refuge Complex, Merced County, California. ....	39
Appendix E. Alphabetical list of species, codes, and guild classifications used at San Luis National Wildlife Refuge Complex, Merced County, California. Guilds are loosely assigned by morphology and foraging class. We recorded four-letter species codes on field data forms and used four-letter guild codes in data analyses. ....	40



## Abstract

Flight observations and carcass searches were conducted at six sites at San Luis National Wildlife Refuge Complex, Merced County, California, to evaluate the effectiveness of Bird-Flight Diverters™ (BFD) and Swan-Flight Diverters™ (SFD)<sup>1</sup> at reducing avian collisions with power lines and identify conditions associated with collisions. In 791 hours of observation in three winter seasons from 2005 to 2008, few actual collisions were observed, but many reactions to power lines were documented, such as altitude changes or more sudden changes in flight direction, called flutter/flares. Birds exhibited reactions at greater distances from power lines after diverters were installed, especially on SFD lines. Along with the presence or absence of diverters, wind conditions and site were the strongest predictors of a flutter/flare reaction. Based on 403 carcass recoveries, adjusted to account for searcher and scavenger bias, 550 total collisions were estimated in two winter seasons from 2006 to 2008. Estimated total collisions were significantly higher for control lines<sup>2</sup> than for BFD or SFD lines. The difference between control and diverter lines was even greater when the analysis excluded American coot (*Fulica americana*), a species accounting for approximately half of all carcasses found. Although conclusions regarding diverter effects are limited by the lack of carcass searches before diverter installation, the consistent pattern of more estimated collisions at control lines, along with the increase in reaction distances after diverters were installed, indicate that both diverter types had a positive effect on reducing the number of avian collisions at San Luis National Wildlife Refuge Complex. However, there were exceptions. Although the estimated number of collisions for BFD lines was considerably less than for control lines at all sites, the estimated number of collisions for SFD lines was relatively high at Merced East and North, indicating that SFD might have been ineffective at those sites. Also, both diverter types were apparently ineffective for American coot, which flies at night. To improve protection for coots and other species with nocturnal flight habits, diverters that illuminate at night or in low-light conditions should be added, particularly at Merced West, where most of the coot collisions occurred, and Blue Goose, a second high-risk site. Because a variety of factors, such as weather and location, can influence the risk of avian collisions, even with diverters on the line, managers should continue to monitor avian mortality after diverter installation.

**Keywords:** Avian collisions, avian mortality, Bird-Flight Diverters, Swan-Flight Diverters, San Luis National Wildlife Refuge

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<sup>1</sup> Bird-Flight Diverters (BFDs) and Swan flight Diverters (SFDs) are devices that are attached to power lines to make the lines more visible to birds.

<sup>2</sup> Control lines are power lines that do not have BFDs or SFDs installed on them.



## Executive Summary

### The Issue

By some estimates, millions of birds are killed annually as a result of collisions with power lines. To reduce the chances that birds will collide with power lines, and avoid power outages or damages, power companies use bird diverter devices, including Bird-Flight Diverters™ (BFD) and the Swan-Flight Diverters™ (SFD). Although results from previous research provide promise that diverters might be effective, more study is needed. It is important to test diverter types at multiple sites under a variety of conditions to help power companies make more informed decisions on which diverters, if any, they should use on their lines. Because much of the previous research focuses on transmission lines, more study is needed for distribution lines, which are far more numerous, generally thinner in diameter than transmission lines, and at relatively lower heights.

### Project Description

San Luis National Wildlife Refuge Complex in Merced County, California, is a high-risk site for avian collisions because approximately 40 miles of low-lying 12 kilovolt (kv) distribution lines border wetlands that are foraging and resting areas for millions of birds, including winter-resident waterfowl and sandhill cranes (*Grus canadensis*). Flight observations and carcass searches were conducted at six sites in San Luis National Wildlife Refuge Complex to evaluate the effectiveness of BFD and SFD at reducing avian collisions with power lines and identify conditions associated with collisions. Sites included Blue Goose, Kesterson, Merced East, Merced North, Merced West, and San Luis. Flight observations began during the winter of 2005-2006, before the addition of diverters, and then continued for the following two winters (2006-2008), after BFDs and SFDs were in place. All of the carcass searches were performed during the final two winters, after diverters were installed. This research was conducted by Ventana Wildlife Society with funding support from the California Energy Commission, Pacific Gas and Electric, and the Avian Power Line Committee.

### Project Approach and Findings

In 791 hours of observation, few actual collisions were observed, but many reactions to power lines were documented, including altitude changes (N=1,863) or more sudden changes in flight direction, called flutter/flares (N=316). Birds exhibited reactions at greater distances from power lines after diverters were installed, especially on SFD lines. Logistic regression with a model-selection approach<sup>3</sup> indicated that, along with the presence or absence of diverters, wind and site were the strongest predictors of a flutter/flare reaction.

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<sup>3</sup> Statistical analysis used to rank the relative importance of variables and to assess interaction effects among the variables.

Based on 403 carcass recoveries, adjusted to account for searcher and scavenger bias, 550 total collisions were estimated for the two winter seasons from 2006 to 2008. Estimated total collisions were 48 percent fewer and 38 percent fewer at BFD or SFD lines, respectively, than at control lines. The difference between control and diverter lines was even greater when the analysis excluded American coot (*Fulica americana*), a species accounting for approximately half of all carcasses found. Although conclusions regarding diverter effects are limited by the lack of carcass searches before diverter installation, the consistent pattern of more estimated collisions at control lines, along with the observed increase in reaction distances after diverters were installed, indicate that both diverter types had a positive effect on reducing the number of avian collisions at San Luis National Wildlife Refuge Complex. However, there were exceptions. Although the estimated number of collisions for BFD lines was considerably less than for control lines at all sites, the estimated number of collisions for SFD lines was relatively high at Merced East and North, indicating that SFD might have been ineffective at those sites. Also, both diverter types were apparently ineffective for American coot, which flies at night.

### **Recommendations**

To improve protection for coots and other species with nocturnal flight habits, diverters that illuminate at night or in low-light conditions should be added, particularly at Merced West, where most of the coot collisions occurred, and at Blue Goose, a second high-risk site.

Because a variety of factors, such as weather and location, can influence the risk of avian collisions, even with diverters on the line, managers should continue to monitor avian mortality after diverter installation and respond to local conditions warranting additional protection.

### **Benefits to California**

Wildlife protection is vital to conserve the natural beauty and ecological diversity of California. This study assures power companies that bird diverters have a positive effect at San Luis National Wildlife Refuge Complex, and that diverters can be part of a cost-effective strategy for reducing mortality associated with collisions along California power lines.



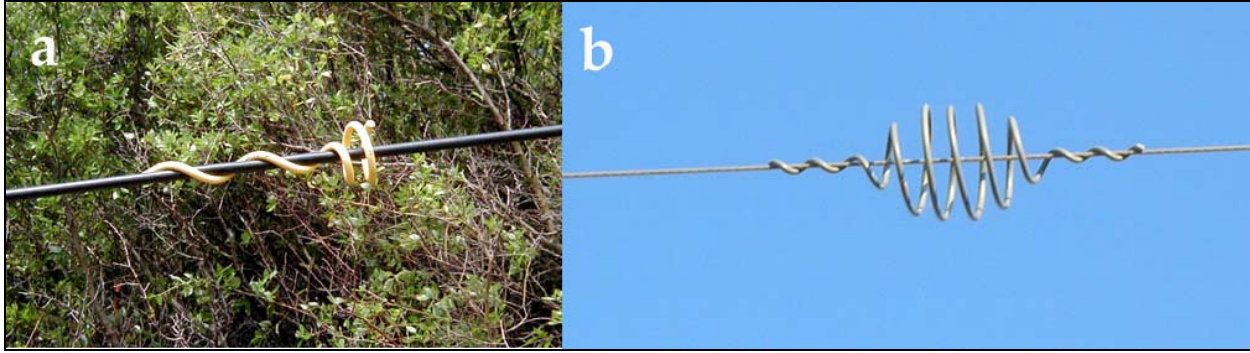
## 1.0 Introduction

### 1.1. Background and Overview

The integration of power lines into natural landscapes has impacted many avian communities. Some birds benefit from the addition of nesting and perching sites in habitats otherwise lacking those qualities. However, the impact of power lines is negative for many birds that become victims of collisions and electrocutions.

Estimates of avian mortality due to collisions range from tens of thousands to 174 million birds each year (Erikson et al. 2001, Dorin and Spiegel 2005). Avian mortality due to collisions has been documented in 350 bird species, with possible population-level impacts (Avian Power Line Interaction Committee (APLIC) 1994, Bevanger and Brøseth 2004, Janss and Ferrer 2000, see Hunting 2002 for a full review). Causing such fatalities can place the responsible entity in violation of the Migratory Bird Treaty Act, the Golden and Bald Eagle Protection Acts, the Endangered Species Act, or in California, the California Endangered Species and Environmental Quality Acts. Based on recent growth models for power systems in the United States, bird collisions with power structures, including transmission and distribution lines, could reach as many as 1 billion avian fatalities annually (Hunting 2002). The threat of power lines to birds extends onto wildlife refuges, where habitat is managed with the hope of attracting birds. If managed habitat is close to power lines that pose a threat to birds in flight, the refuges could be compromising their conservation and protection goals by placing birds at a greater risk of mortality.

Bird diverter devices have been developed to improve line visibility for birds and reduce the chances that birds will collide with power lines. Two types of diverters commonly used for minimizing collisions are the Bird-Flight Diverter™ (BFD) and the Swan-Flight Diverter™ (SFD, Fig. 1). BFDs and SFDs have been used by power companies for over 25 years (Hunting 2002). These diverters enhance the effective width of the line, and sometimes brightness, thereby improving line visibility. These devices consist of a PVC spiral that is rotated onto the line at regular-spaced intervals. Their ease of application, durability, and lack of corona, or electrical discharge, make both BFDs and SFDs extremely popular for use in mitigating bird-related outages or collision-induced bird mortality (M. Best, personal communication, EDM 2004, Hurst 2004). However, the relative effectiveness of the diverters in reducing avian collisions is unclear, especially under certain line and weather conditions (APLIC 1994, Brown and Drewien 1995, Hunting 2002).



**Figure 1. Bird-Flight Diverter™ (a) and Swan-Flight Diverter™ (b) Source: PG&E (a) and Ventana Wildlife Society (b).**

**Source: authors**

Several studies evaluating BFDs and SFDs have demonstrated the effectiveness of diverters, but conclusions among studies vary (Eskom 2003). Based on carcass recoveries under lines, Janss and Ferrer (1998) reported an 81% decrease in avian mortality associated with SFD-like white spirals on a transmission line crossing wintering grounds for the common crane (*Grus grus*) in west-central Spain. Alonso et al. (1994) reported a 60% decrease in avian collisions and a 61% decrease in flight frequency over ground wires marked with PVC spirals. Crowder (2000) reported that BFDs reduced collisions by as much as 73.3% and SFDs by 37.5% in a study of transmission lines along the Wabash River in southwest Indiana. Brown and Drewien (1995) likewise noted a significant reduction in bird mortality with both transmission and distribution lines marked with yellow spiral vibration dampers in the San Luis Valley, Colorado. Other studies did not demonstrate a diverter effect. For example, Roy Churchwell, Landbird Program director at San Francisco Bay Bird Observatory, did not find an effect of BFDs on carcass recoveries and observational data along a transmission line crossing over tidal pools of the San Francisco Bay (R. Churchwell, personal communication). Likewise, Anderson (2001) found no reduction in collisions in a study of BFDs in South Africa.

Although results of previous research provide promise that diverters might be effective, more study is needed. It is important to test diverter types at multiple sites and under a variety of field conditions to better understand optimum use and help power companies make informed decisions on which diverters, if any, they should use on their lines in the future. Another consideration is the need for more information on the effectiveness of diverters on distribution lines. Most studies have focused on transmission lines rather than distribution lines. The effectiveness of diverters on distribution lines should be studied because distribution lines are more numerous than transmission lines, lower in height, and relatively thin; these lines could present greater obstacles that are more difficult for birds to see while taking off and landing.

The San Luis National Wildlife Refuge Complex in Merced County, California, is a high-risk site for avian collisions. The refuge complex, a group of important winter and migration stopover sites along the Pacific Flyway, is comprised of approximately 35,000 acres of wetlands and riparian habitat juxtaposed with about 36 miles (65 km) of 12 kV distribution lines. The

distribution lines border wetlands and bisect important foraging and resting areas for millions of birds, especially winter-resident geese and sandhill cranes (*G. canadensis*). Because of such high-volume bird activity close to power structures, along with the confounding effects of valley fog, refuge staff considers power lines a chronic source of mortality for birds. In 1997 and 1998, biologists documented twelve cases of fatalities due to line strikes or electrocutions. Also, a small number of crane and goose carcasses were collected under power lines almost every winter at Merced National Wildlife Refuge, part of San Luis National Wildlife Refuge Complex (Dennis Woolington, personal communication). The loss of cranes can be particularly costly from a conservation perspective. The greater sandhill crane (*G. c. tabida*) is listed as state-threatened in California (California Department of Fish and Game 2006) and are present at the refuge complex, though in smaller numbers than the lesser sandhill crane (*G. c. canadensis*). These initial findings alerted biologists to the immediate need for a more systematic assessment of and mitigation for avian power line collisions on the refuge complex.

In 2005, Ventana Wildlife Society began a three-year study at San Luis National Wildlife Refuge Complex to evaluate the effectiveness of Bird-Flight Diverters and Swan Flight Diverters at reducing avian collisions with distribution lines, and better understand conditions associated with collisions. Bird flight observations were conducted during winter 2005-2006 along select power lines before the addition of diverters, and then continued for the following two winters, after BFDs and SFDs were in place. Patterns in observed bird collisions and flight-adjustment reactions to the lines were evaluated. During the final two seasons, systematic carcass searches were conducted along the same power lines to estimate mortality and determine differences associated with BFD, SFD, and untreated control lines. This report presents final results for the three seasons of flight observations and two seasons of carcass searches. Results are intended to benefit power companies and public interests by:

- Implementing and refining diverter assessment method.
- Evaluating power industry-approved bird diversion products.
- Making suggestions to improve existing bird-diversion technology.
- Working to reduce and/or eliminate negative impacts from avian interactions with California's distribution system.
- Providing a method for complying with state and federal statutes.

## 1.2. Project Objectives

The primary objectives of this project were to:

- Evaluate the effectiveness of Bird-Flight Diverters and Swan-Flight Diverters at reducing avian collisions with distribution lines at San Luis National Wildlife Refuge Complex, Merced County, California.
- Identify conditions (risk variables) associated with power line collisions.



## 2.0 Project Approach

### 2.1. Study Sites

The San Luis National Wildlife Refuge Complex is located in the San Joaquin Valley, Merced County, California, and includes San Luis, Merced, and San Joaquin River National Wildlife Refuges, and the Grasslands Wildlife Management Area (Fig. 2). Six sites with power lines were selected for study. Three sites, San Luis, Blue Goose, and Kesterson (Figs. 3 and 4), were located on the San Luis National Wildlife Refuge: San Luis along the San Luis Drain in the San Luis Unit; Blue Goose in the Blue Goose Unit; and Kesterson within the Kesterson Unit. The remaining three sites were located on Merced National Wildlife Refuge: Merced North on the northeast corner parallel to Sandy Mush Road; Merced West behind the refuge maintenance shed and powering wells 6 and 10; and Merced East along the southeast refuge boundary starting at well 14 (Fig. 5). There were approximately 36 miles (58 km) of total distribution line at San Luis (9 miles, 14.5 km), Blue Goose and Kesterson (7 miles, 11.3 km), and the Merced National Wildlife Refuge (20 miles, 32.2 km). The lines selected for study in this project accounted for 7.8 miles (12.5 km) of that distribution system. The portion of those lines selected as our actual survey sites accounted for 2.2 miles (3.6 km), or about 6% of the entire distribution system on the refuge complex.

### 2.2. Project Design

Each of the six sites were divided into three 200-m experimental line sections. Lines were selected based on the following criteria:

- Anecdotal evidence of avian collisions and outage data.
- Distance from avian high-use areas.
- Line position relative to habitat edges, and/or bisection of avian roosting and foraging areas.
- Prevalence of low-visibility conditions.
- Access.

In the first season, November 2005 – February 2006, none of the sections were fitted with diverters. All data for this season were categorized as pre-treatment. Early in the second season, October 2006 – February 2007, PG&E personnel treated some of the lines with diverters. Data for this season were categorized as pre-treatment if collected before diverters were attached and post-treatment if collected after diverters were attached. All data for the third season, October 2007 – February 2008, were categorized as post-treatment. During the treatment process, PG&E fitted one section from each site with yellow Bird-Flight Diverters (Preformed Line Products, Inc., Cleveland, OH, range 0.450-0.599, Fig. 1a) and another section with gray Swan-Flight Diverters 1140 (Dulmison, Tyco Electronics, Fuguay-Varina, NC, range 0.450-0.599, Fig. 1b). The center section of line for each site remained untreated and served as a control. The center sections were selected for controls to maximize space between the two diverter types. Diverters were spaced at intervals of 15 feet and staggered between three phases. SFDs were slightly larger than BFDs (Fig. 1). The SFD design consisted of a spiral, with both ends pigtailed; at its

greatest radius, the spiral increased phase profile by 4 inches. The BFD was pigtailed at only one end; the spiral at the other end increased phase profile by 2 inches. Between each 200-m experimental section, single buffer spans were designated to maximize independence among monitored sections.

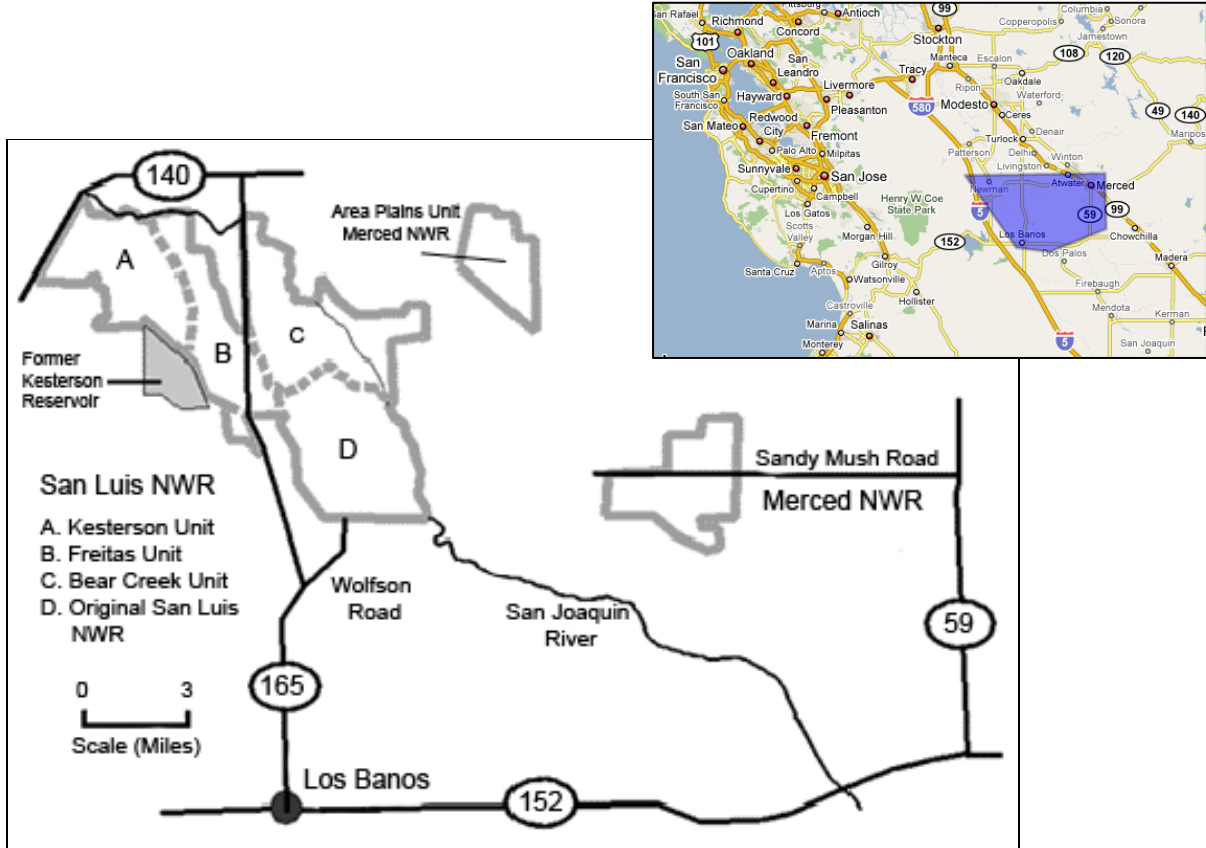
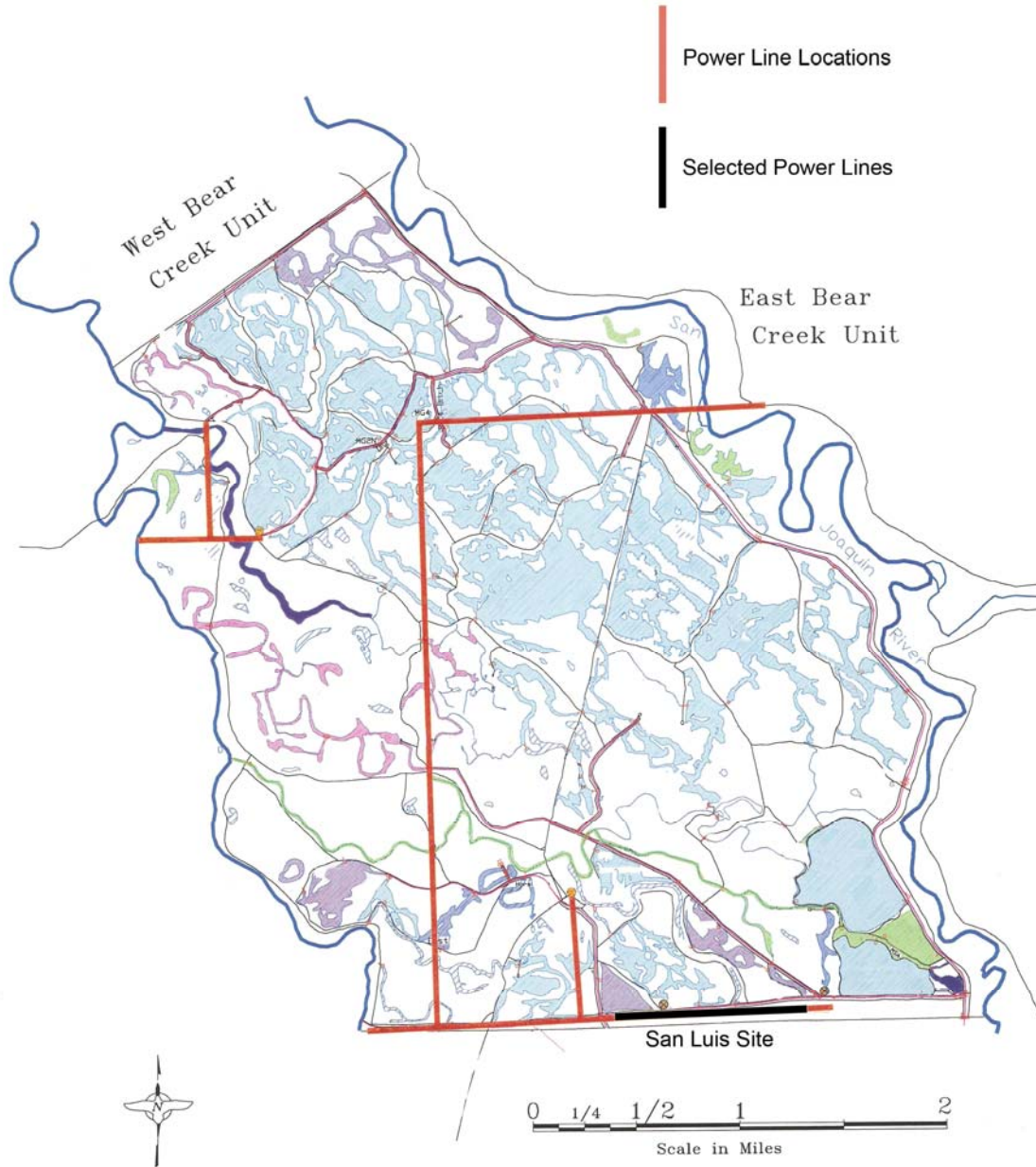


Figure 2. Location of San Luis National Wildlife Refuge Complex, Merced County, California. Map courtesy of U.S. Fish and Wildlife Service.

Source: Authors

# San Luis Site

## San Luis National Wildlife Refuge Complex

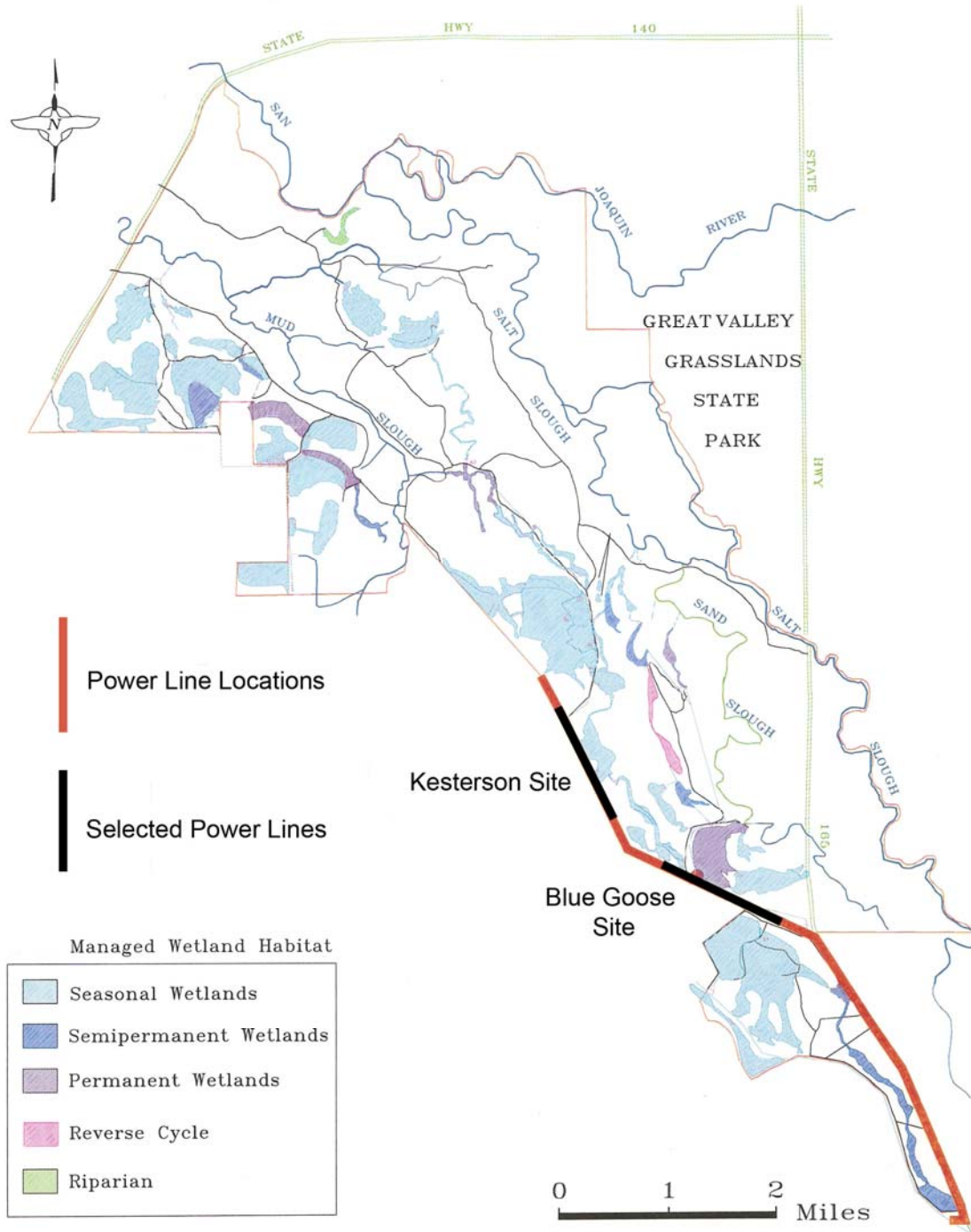


**Figure 3. Selected power lines at the San Luis site, San Luis National Wildlife Refuge Complex, Merced County, California. Map courtesy of U.S. Fish and Wildlife Service.**



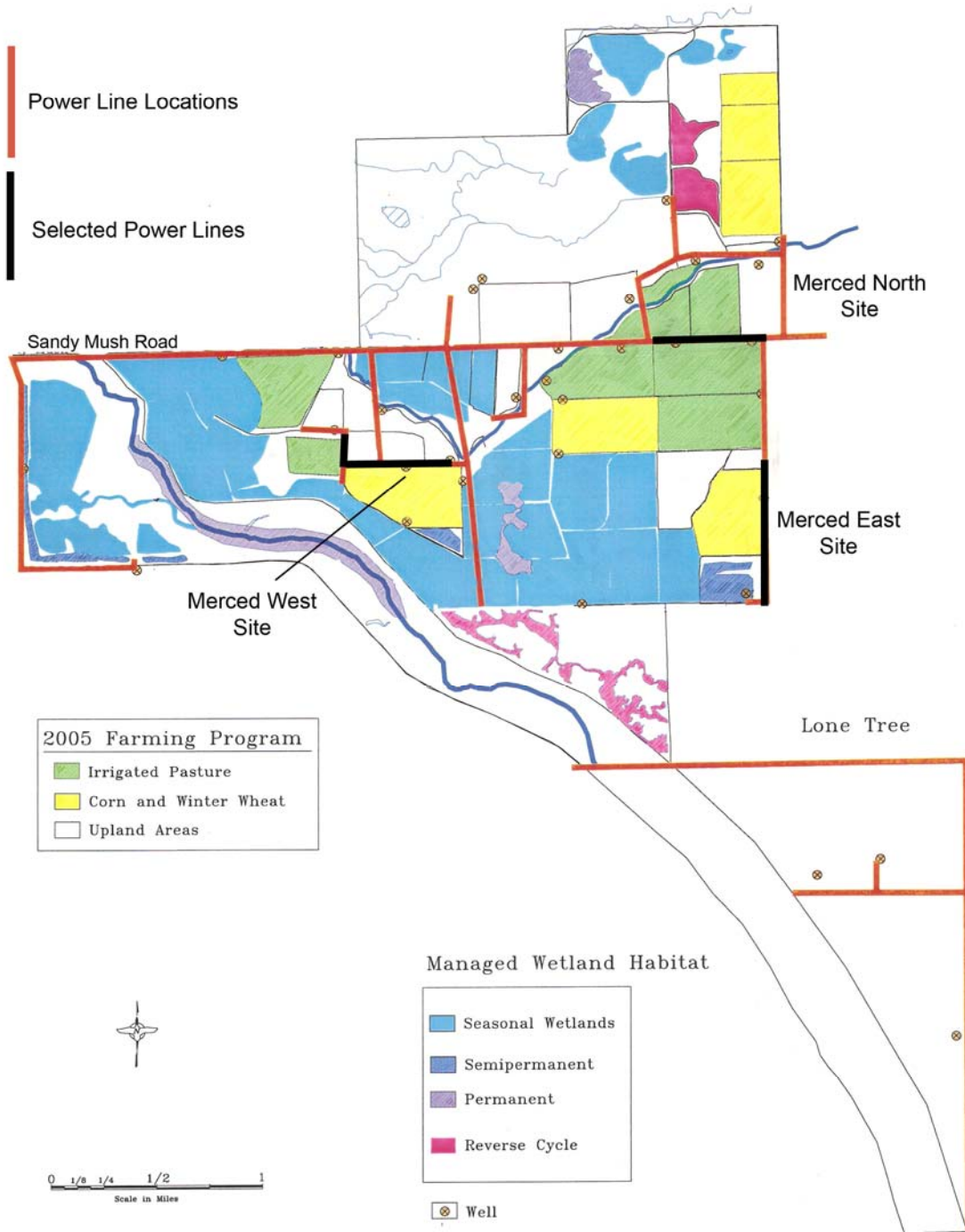
# Kesterson and Blue Goose Sites

## San Luis National Wildlife Refuge Complex



**Figure 4. Selected power lines at the Kesterson and Blue Goose sites, San Luis National Wildlife Refuge Complex, Merced County, California. Map courtesy of U.S. Fish and Wildlife Service.**

# Merced National Wildlife Refuge



**Figure 5. Selected power lines at three sites in the Merced National Wildlife Refuge, San Luis National Wildlife Refuge Complex, Merced County, California. Map courtesy of U.S. Fish and Wildlife Service.**

## 2.3. Field Methods

Method was adapted from APLIC (1994), Hartman et al. (1992), Yee (2007), and G. Barton (personal communication).

### 2.3.1. Flight Observations

Thirty-minute bird flight observations were conducted along power lines at each site during three winter seasons. During the first season, before diverters were in place, 40 half-hour observation periods were completed for each of the 18 line sections (one control, one BFD, and one SFD per site). To incorporate carcass searches and account for a decrease in funding, the number of observation periods was reduced to 32 during the second season and 16 during the third season. Approximately half of the observation periods at each line section occurred during the morning (within four hours after sunrise) and half during the evening (within four hours before sundown). The three sites at Merced National Wildlife Refuge were surveyed on the same day because of their close proximity. Likewise, San Luis, Kesterson, and Blue Goose were surveyed together, but because these sites were greater than a 30-minute driving distance from the Merced sites, they were surveyed on a different day than the Merced sites. Within each group of three sites, visitation was rotated randomly with respect to site and start time.

Each flight observation was conducted by a single observer positioned so that the entire section of line could be viewed clearly with binoculars. Observations were postponed for a section if birds were perched across more than half of the line, because it was thought that these perched birds, often blackbirds or swallows, increased line visibility enough to confound study design. At the beginning of each observation period, weather data was recorded, including an ordered, categorical sky value (e.g., 1=clear, 2=partly cloudy, etc., Appendix A), temperature in degrees Celsius, wind speed converted to the Beaufort wind scale, wind direction, and time. During the observation period, the occurrence of flocks was recorded as they crossed over or under the line section. Flocks were considered to be one or more individual birds of the same species. Mixed species groups were recorded as multiple flocks of one species to simplify species- or guild-specific analyses. For each flock, species, flock size, flight height relative to the line, reaction types, and reaction distance relative to the line were recorded (see APLIC 1994).

Flight height, reaction type, and reaction distance rankings were modified from Yee (2007) and APLIC (1994), and designed to indicate a flight diversion associated with a line section. Flight height relative to the line when crossing was separated into four categories: (1) >25 m above the line, (2) 10-25 m above or below the line, (3) 5-10 m above or below the line, and (4) <5 m above or below the line. Reaction type, ranked in severity of response from 1-4, consisted of (1) a bird demonstrating no apparent reaction, (2) a bird changing altitude as it approached the line, (3) fluttering to achieve an immediate increase in altitude, and flaring, a general stop in forward momentum and upward shift in flight altitude, and (4) a collision. For reaction types 2 and 3, a reaction distance relative to the line was recorded according to three categories: (1) >25 m from the line, (2) 10-25 m away, and (3) <10 m away. Distance did not apply for reaction types 1 and 4.

Appendix A provides a list of rankings used by observers to categorize weather and flight. A sample observation datasheet is provided in Appendix B.

### **2.3.2. Carcass Searches**

Bird flight observations were augmented with carcass searches during the final two seasons (Fig. 6). During the first year of searches (October 2006 – February 2007), eight visits were conducted for each of the 18 line sections among the six sites. Each of the visits consisted of five consecutive search days. Search effort was reduced to four visits per site during the second year (October 2007 – February 2008). Each 200-m line section was searched on foot along three transects: a center transect directly under the line and two transects 10 m from the center transect on either side of the line and extending parallel to the line. The carcass recovery search area extended to 25 m on either side of the line section. Transect searches were conducted by two biologists during the middle of the day, between flight observation periods. It took one searcher approximately 30 minutes to walk and search all three transects per line section. At the start of each carcass search, the percentage of unsearchable habitat within the search area was estimated. Unsearchable habitat consisted of dense vegetation, water, or any other condition that limited the ability of the observer to find carcasses. When a carcass or sign of a carcass (e.g., feather scatter) was located, it was assigned a number, marked with a flag, photographed, and identified to species whenever possible. Universal Transverse Mercator (UTM) coordinates were recorded, and its distance from the line estimated in meters. Cause of death was determined in the field, whenever possible, via simple necropsy to rule out non-collision or electrocution-induced mortality (Electric Power Research Institute 2003). Carcasses were not collected but left on site. Carcass recovery and resight datasheets are provided in Appendices C and D.



**Figure 6. Observers conducting carcass searches along power lines**

**Source: Ventana Wildlife Society.**

Because searcher efficiency and scavenging of carcasses can influence estimates of the total number of dead birds (Lehman et al. 2006), a carcass planting experiment was conducted to determine bias values (see APLIC 1994). These values account for the number of carcasses present but which observers are unable to find (i.e., searcher bias) and the number of carcasses removed from the search area by scavengers before they could be found (i.e., scavenger bias). Thirty-two bird carcasses were planted underneath a line section 200 m in length in an area extending 20 m from the line on either side. Fourteen of the planted carcasses were large (e.g., owls, coots, and raptors). Eighteen carcasses were small (e.g., passerines). During a 30-minute search, the same duration as other carcass searches, searcher bias was determined as the percentage of all planted birds that were relocated. The same carcasses were flagged and left at the planted site for five days, the same duration as the carcass search period for any line section. The carcasses were visited daily during that time to determine scavenger bias, the rate that scavengers ostensibly removed carcasses.

## **2.4. Statistical Analysis**

Statistical analyses were performed using SYSTAT® Version 10 statistical software (SPSS 2000). Unless otherwise indicated, for all statistical tests the alpha level, or the probability of rejecting the null hypothesis when it is actually true (Type I error), was  $P=0.05$ .

### **2.4.1. Analysis of Flight Observations**

Flight observations are summarized by the total number of observation hours, flocks, and birds. Total observation hours were calculated by adding the number of observation periods and multiplying by 0.5 (i.e., half-hour, the duration of each observation period). In addition to total observation hours, differences in observation hours between sites, treatment types (BFD, SFD, or control), and pre- and post-treatment categories, are presented. T-tests are used to compare the number of flocks and birds per hour between pre- and post-treatment periods. Analysis of variance is used to compare the number of flocks and birds per hour among the six sites. Data were normalized using the square root transformation.

Changes were identified between pre- and post-treatment in the proportion of flocks reacting to line sections. Reaction types could help indicate diverter effectiveness. For example, in the most severe case, a decrease in observed collisions (reaction type 4) after diverters were in place could be evidence that diverters were effective preventing collisions. A decrease in the number of flutter/flare reactions (reaction type 3) associated with treated lines could indicate that diverters helped birds perceive lines at a greater distance, thereby reducing the need for such sudden flight adjustments. Finally, an increase in the number of birds observed changing flight height in relation to the line (reaction type 2) could also support the effectiveness of diverters at improving line visibility. The number of observed collisions is reported, including details about the circumstances associated with the collisions. The percentage of flocks exhibiting reaction types 2 (changing flight height) and 3 (flutter/flare) is reported for both pre- and post-treatment categories. Because observing actual collisions is rare, statistical analyses is reserved for reaction

types 2 and 3. For BFD-designated and treated lines, t-tests were used to determine if percentages of flocks exhibiting flight height changes or percentages exhibiting fluttering/flare reactions changed after diverters were added. Similar tests were conducted for SFD-designated and treated lines. An increase in the proportion of flocks adjusting their flight height and a decrease in fluttering/flare reactions were considered to be indicative of flight diverter effectiveness. A similar pre- and post-treatment comparison for control line sections is made, based on the date diverters were installed elsewhere, even though no treatments were performed for these lines.

Because the distance of a reaction from a line could indicate the effectiveness of diverters in improving line visibility, recorded distances for reaction types 2 (changes in flight height) and 3 (flutter/flare) were tested against treatment status (pre- and post-treatment) for each treatment type (BFD, SFD, and control) to determine if diverters influenced the distance at which birds responded to a line. Multinomial logistic regression was used to predict the odds or likelihood of reaction distances belonging to one of three categories: 1) >25 m from the line, 2) 10-25 m from the line, and 3) <10 m from the line. Categories that exhibited a significantly high response relative to references were identified using maximum-likelihood adjusted p-values. An odds ratio was then generated from these results. The odds ratio is a ratio between the odds associated with two groups, in this case pre- and post-treatment, for a particular category. It is used to ascertain the amount of an effect. For example, an odds ratio of 2.0 for distance category 1, relative to another distance category, indicates that the odds of category 1 doubled after the treatment. An odds ratio with a 95% confidence limit overlapping 1.0 indicates odds between two groups that are statistically similar.

Mean values of reaction distance categories among guilds and treatment status categories are also presented to determine if diverters might be more effective for certain bird species or groups of species. Guilds were defined loosely by general morphology and foraging class. We designated the following guilds: ducks, geese, gulls, passerines, raptors, shorebirds, swallows, and wading birds (Appendix E). Although clearly a wading bird, sandhill crane was also considered here as a separate guild because of the California state-threatened status for one subspecies. Some guilds were not included here because of their infrequent representation in the data. These included pelicans, kingfishers, cormorants, and woodpeckers. American coot (*Fulica americana*) was included in the duck guild for this flight observation analysis because of their similarity to ducks in size and shape and because very few flyovers were observed.

To identify which conditions are most associated with a collision, or the next most severe reaction, flutter/flare, logistic regression was used to evaluate hypotheses concerning the effects of treatments, weather, location, and guild variables on the presence of a collision or flutter/flare reaction. Hypotheses were represented by a set of *a priori* models, including 1) treatment (i.e., status, before and after), 2) treatment + weather (with covariates wind, sky, and temperature), 3) treatment + site, 4) treatment + guild, 5) weather + site, 6) a global model with all covariates, and 7) a null model with no covariates. Akaike's Information Criteria (AIC) was used to rank models (Akaike 1973), with the most parsimonious model selected based on the lowest AIC value (Burnham and Anderson 1998).

### 2.4.2. Analysis of Carcass Recoveries

The number of collisions was estimated based on carcass search results and an equation which incorporates bias, as outlined in APLIC (1994) and modified according to the Periodic Search Model (Shoenfeld 2004). To extrapolate the number of carcass recoveries to an estimate of total collisions, several factors should be accounted for, including searcher bias, scavenger bias, proportion of searchable habitat, and crippling bias. Searcher bias was considered to be the percentage of carcasses recovered during the carcass planting experiment. Scavenger bias was calculated as the mean carcass removal time, based on a rate of carcass loss during the five-day monitoring period of the planting experiment. This rate was calculated using Program MARK Version 4.3 (White 2007). Proportion of searchable habitat was an average of the values recorded at each visit. Crippling bias was not included in our equation because information was lacking on birds that might have left the site after collisions. An additional factor was added to account for the possibility that some of the recovered birds died from causes other than a collision. This correction factor was a multiplication by 0.81, based on two other studies which reported percentages of recovered birds found to be killed by collisions (84%, Brown and Drewien 1995; 81%, R. Churchwell, personal communication). Therefore, the total number of bird collisions was estimated with the following equation:

$$ETC = \left[ \frac{\left( \frac{I \cdot C}{t \cdot p} \right) \left( \frac{e^{1/t} - 1 + p}{e^{1/t} - 1} \right)}{h} \right] 0.81$$

where ETC is the estimate of total collisions, I is the interval between search days, C is the number of carcasses detected, t is the mean carcass removal time in days (scavenger bias), p is the rate of observer efficiency locating planted carcasses (searcher bias), h is the proportion of searchable habitat, and e is a mathematical constant, the base of the natural logarithm. This equation was used to calculate ETC for the monitored portion of each site, for each type of line section (BFD, SFD, and control), and for all sites combined. The effect of site, diverter type, and their interaction on ETC per 200 meters of line was tested using analysis of variance. Data were normalized using the square root transformation.





## 3.0 Project Outcomes

### 3.1. Flight Observations

A total of 34,113 flocks and an estimated total of 948,612 birds were recorded during 791 observation hours in three winter field seasons from 2005 to 2008. Although more surveys per site were conducted in the first year of the study, the timing of diverter installation on treatment lines early in the second season resulted in a similar number of observation hours before (389.5) and after (401.5) the treatments. The number of observation hours was also fairly equally distributed among sites (range 130.5-133.0) and treatments (range 260.5-267.0). Fewer birds per hour were observed after the diverters were installed ( $t=-3.03$ ,  $df=35$ ,  $P=0.005$ ). The difference in the number of observed flocks per hour was not statistically significant ( $t=-0.26$ ,  $df=36$ ,  $P=0.795$ ). Both the average number of flocks per hour ( $F\text{-ratio}=4.60$ ,  $df=5$ ,  $P=0.001$ ) and the number of birds per hour ( $F\text{-ratio}=5.43$ ,  $df=5$ ,  $P=0.000$ ) varied by site. More flocks per hour were recorded at Blue Goose and Merced North and more individual birds per hour were recorded at each of the three Merced sites. The numbers of observed flocks per hour and birds per hour were among the lowest at Kesterson and San Luis.

Observations of collisions were rare during the study; one apparent collision was observed during a survey in the first season and another was noted incidentally between surveys in the second season. A northern harrier (*Circus cyaneus*) apparently hit a line at Blue Goose on 8 December 2005 at 2:25 p.m. The observer concluded that it was a collision based on the sound and movement of the wire as the bird crossed. The bird continued to fly and did not appear injured. This was a line designated for Bird-Flight Diverter installation, but as with all lines, no diverters were in place during that first season. The second observation occurred when a white-tailed kite (*Elanus leucurus*) hit one of the control lines at San Luis at 13:12 p.m. on January 17, 2007. The observer noted that the kite was in pursuit of a red-tailed hawk (*Buteo jamaicensis*) and hit the outermost wire at the base of its legs. The kite was able to continue its flight, but its condition could not be ascertained.

Of the 34,113 flocks observed crossing power lines during the study, 1,863 (5.5%) were observed changing altitude as they approached the line, and 316 (0.9%) exhibited a flutter/flare reaction. A slightly greater proportion of flocks exhibited altitude change reactions after the diverters were installed, relative to the proportion before, but this difference was not significant at alpha 0.05 ( $t=1.73$ ,  $P=0.089$ ). When grouping the data by diverter type, there was an increase in the proportion of flocks changing altitude at BFD lines after the diverters were installed, relative to the proportion for those same lines before the BFDs were installed ( $t=2.22$ ,  $df=20$ ,  $P=0.038$ ). The difference was not significant for SFD ( $t=0.40$ ,  $df=17$ ,  $P=0.696$ ) or control lines ( $t=0.813$ ,  $df=19$ ,  $P=0.426$ ). There was a substantial reduction in the proportion of flocks exhibiting flutter/flare reactions after diverters were installed ( $t=-3.82$ ,  $df=46$ ,  $P=0.000$ ). However this pattern of reduced flutter/flare reactions might not have been exclusively associated with diverters; the difference in proportions before and after treatments was nearly significant for control lines ( $t=-2.10$ ,  $df=12$ ,  $P=0.057$ ), even though diverters were not installed on those lines.

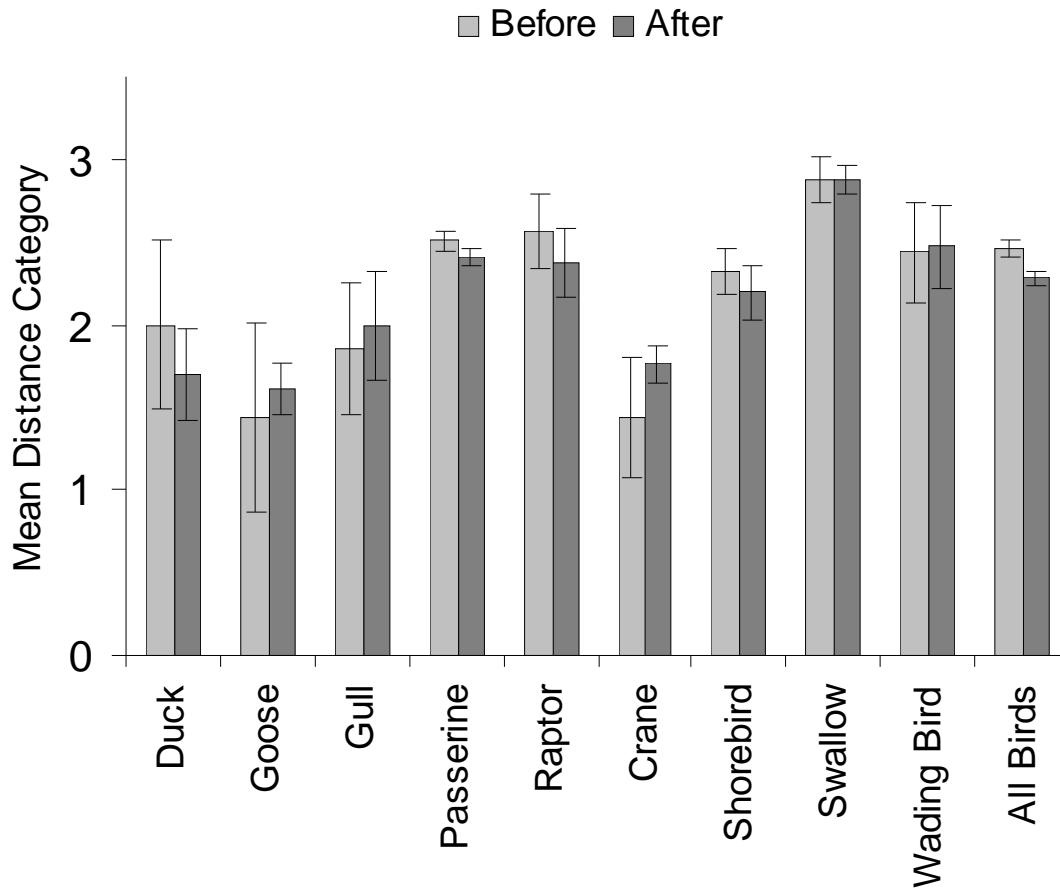
For altitude change and flutter/flare reaction types, the recorded distances of the reactions from power lines before treatments were compared to distances after treatments. After treatments, there was a general decrease in the proportion of distance observations in the closest distance category (i.e., distance category 3, <10 m away from the line) (Table 1). Conversely, proportions in the more distant categories 2 (10-15 m away) and 1 (>25 m away) increased after treatments, indicating that flocks reacted further from lines after diverters were installed. This pattern of increased flock reaction distances after treatments was strongest for SFD lines.

**Table 1. Percentage of reaction distance records in each distance category before and after lines were treated with Bird-Flight Diverters and Swan-Flight Diverters at San Luis National Wildlife Refuge Complex, Merced County, California. Although no diverters were installed on control lines, we separate pre- and post-treatment proportions for control lines based on the date diverters were added to the other lines.**

	Before Treatment	After Treatment	Difference
<b>Control Lines</b>			
Distance 1 (>25 m away)	17%	17%	0
Distance 2 (10-15 m away)	23%	29%	+6%
Distance 3 (<10 m away)	58%	53%	-5%
<b>Swan-Flight Diverter Lines</b>			
Distance 1 (>25 m away)	10%	22%	+12%
Distance 2 (10-15 m away)	23%	35%	+12%
Distance 3 (<10 m away)	63%	42%	-21%
<b>Bird-Flight Diverter Lines</b>			
Distance 1 (>25 m away)	17%	26%	+9%
Distance 2 (10-15 m away)	17%	23%	+6%
Distance 3 (<10 m away)	65%	51%	-14%

Odds ratios generated by multinomial logistic regression also indicate shifts in flock reaction distances to more distant categories after treatments, particular for SFD lines. The odds, or likelihood, of a reaction at distance category 1 (>25 m away), relative to distance category 3 (<10 m away), increased by a factor of 2.7 after the treatments at SFD lines (odds ratio=2.68, 95% CI=1.67-4.29, P=0.00). Similarly, the odds of a reaction at distance category 2 (10-25 m away), relative to category 3, increased more than twofold after the treatments at SFD lines (odds ratio=2.35, 95% CI=1.60-3.45, P=0.000). The effect of treatments on reaction distance categories was also strong for BFD lines. The odds of a reaction at distance category 1, relative to category 3, increased nearly twofold after the treatments at BFD lines (odds ratio=1.90, 95% CI=1.23-2.94, P=0.004). The odds of a reaction at distance category 2, relative to category 3, increased by a factor of 1.6 after treatments at BFD lines (odds ratio=1.60, 95% CI=1.04-2.49, P=0.035). There was not find a similar pattern for control lines. The odds of a reaction at distance category 1 at control lines, relative to category 3, did not show a significant increase (odds ratio=1.17, 95% CI=0.79-1.73, P=0.445).

Guilds differed somewhat in reaction distances. Swallows reacted to power lines at closer distances than other guilds, as indicated by a mean of distance category records approaching 3 (i.e., <10 m away) (Fig. 7). Sandhill cranes and geese were among the groups reacting furthest from the lines, as indicated by means of distance category records below 2. Although the means of distance category records for all birds combined indicate that birds reacted further from power lines after diverters were installed, overlapping confidence intervals within most guilds indicate considerable uncertainty regarding the effects of diverters on individual guilds (Fig. 7).



**Figure 7. Means of reaction distance categories (with 95% confidence intervals) among guilds recorded during flight observation surveys before and after diverters were installed at San Luis National Wildlife Refuge Complex, Merced County, California. Distance Category 1 = >25 m from the line; Category 2 = 10-25 m from the line; and Category 3 = <10 m from the line.**

The probability of a flutter/flare reaction, the most severe reaction type regularly observed, was modeled to evaluate conditions that might favor an increased risk of collision. The best-supported model, based on AIC, was the global model; despite containing all of the evaluated variables, it was the most parsimonious model to predict a flutter/flare reaction (Table 2). A likelihood ratio test indicated that this model fit the data well ( $P=0.000$ ). The global model contained treatment status (before and after), weather (wind, sky conditions, and temperature),

guild, and site. Of the variables, treatment status, wind, and site had the greatest effect. Other competing models, all with fewer variables, were poor relative to the global model, even though all but the null model fit the data adequately. For example, the treatment model (i.e., treatment status) was one of the lowest-ranking models, indicating that diverter installation alone, though having an effect, was not nearly as good of a predictor for a flutter/flare reaction as diverter installation in combination with one or more other variables.

**Table 2. Support for logistic regression models predicting flutter/flare reactions at San Luis National Wildlife Refuge Complex, Merced County, California.**

Model	Log Likelihood	Parameters	AIC	$\Delta$ AIC
Global	-1436.80	23	2919.60	-
Treatment + Weather	-1495.24	5	3000.48	80.88
Treatment + Guild	-1558.25	15	3146.50	226.91
Treatment + Site	-1582.40	7	3178.80	259.21
Weather + Site	-1586.67	9	3191.34	271.74
Treatment	-1601.87	2	3207.73	288.14
Null	-1701.96	1	3405.92	486.32

### 3.2. Carcass Recoveries

A total of 403 bird carcasses were recovered under power lines in two seasons of searches from October 2006 to February 2008. American coots were the most commonly encountered bird carcasses, accounting for 214 (53%) of the total (Fig. 8). Many of the carcasses (74, 18%) could not be identified to guild or species level. Forty-nine (12%) passerines, 35 (9%) ducks, and 16 (4%) wading birds were recovered. One of the wading birds was identified as a sandhill crane. Shorebirds, geese, and raptors together accounted for the remaining 4% of the total. Most of the carcasses (N=231, 56%) were found within 5 m out from the line. Another 106 (26%) were 6-10 m out from the line. Only 3 carcasses (<1%) were found in our most distant zone (20-25 m), indicating that the designated search area provided sufficient opportunity to find carcasses that collided with monitored lines.

Of the 32 carcasses planted under lines as a test to determine searcher efficiency, 22 (68.8%) were recovered. This percentage was used as an estimate of searcher bias. Based on encounter rates obtained over the next five days for those carcasses, a mean carcass removal time of 10.99 days was calculated. This removal rate was used to estimate scavenger bias. Searcher and scavenger bias estimates, along with carcass recoveries and averages of searchable habitat, were used to estimate the number of total collisions.

An estimated 550 (95% CI=530–585) total collisions occurred at our six sites during the two seasons of study. Estimated total collisions varied significantly by site ( $F=17.86$ ,  $df=5$ ,  $P=0.000$ ). The highest number of estimated total collisions occurred at Merced West (206, 198–219), followed by Blue Goose (131, 126–139), Merced East (72, 70–77), San Luis (65, 62–69), Merced North (46, 44–49), and Kesterson (30, 30–33).

The number of estimated total collisions also varied significantly by diverter type ( $F=7.58$ ,  $df=2$ ,  $P=0.001$ ). Estimated total collisions for control lines (257, 248–273) was considerably higher than for either BFD (134, 129–143) or SFD (159, 153–169) lines. Because American coots accounted for approximately half of the recovered carcasses, and this species flies almost exclusively at night (Brisbin and Mowbray 2002), when diverter visibility is presumably poor, the analysis of variance test was repeated to evaluate how this species influenced our results. For birds other than coots, diverter type had a strong effect on estimated total collisions ( $F=10.22$ ,  $df=2$ ,  $P=0.000$ ). For coots alone, diverter type had no significant effect on estimated total collisions ( $F=0.76$ ,  $df=2$ ,  $P=0.470$ ). Although the presence of diverters did not have a significant effect on coots, site was associated with estimated total collisions for coots ( $F=10.72$ ,  $df=5$ ,  $P=0.00$ ), primarily because a considerable percentage (60%) of coot carcasses were found at Merced West. The difference in number of recovered coot carcasses at Merced West is likely responsible for the relatively high number of collisions estimated for all species at that site.



**Figure 8. American Coots accounted for approximately half of all carcass recoveries at San Luis National Wildlife Refuge Complex, Merced County, California in two winter search seasons from October 2006 to February 2008. Source: Ventana Wildlife Society.**

Although each diverter type was associated with fewer estimated total collisions than control lines, 95% confidence intervals indicate that fewer collisions occurred at BFD lines than at SFD lines. This difference is due to relatively high numbers of estimated total collisions occurring along SFD lines at Merced East and Merced North (Fig. 9). SFD and BFD lines at the remaining four sites had similar numbers of estimated collisions.

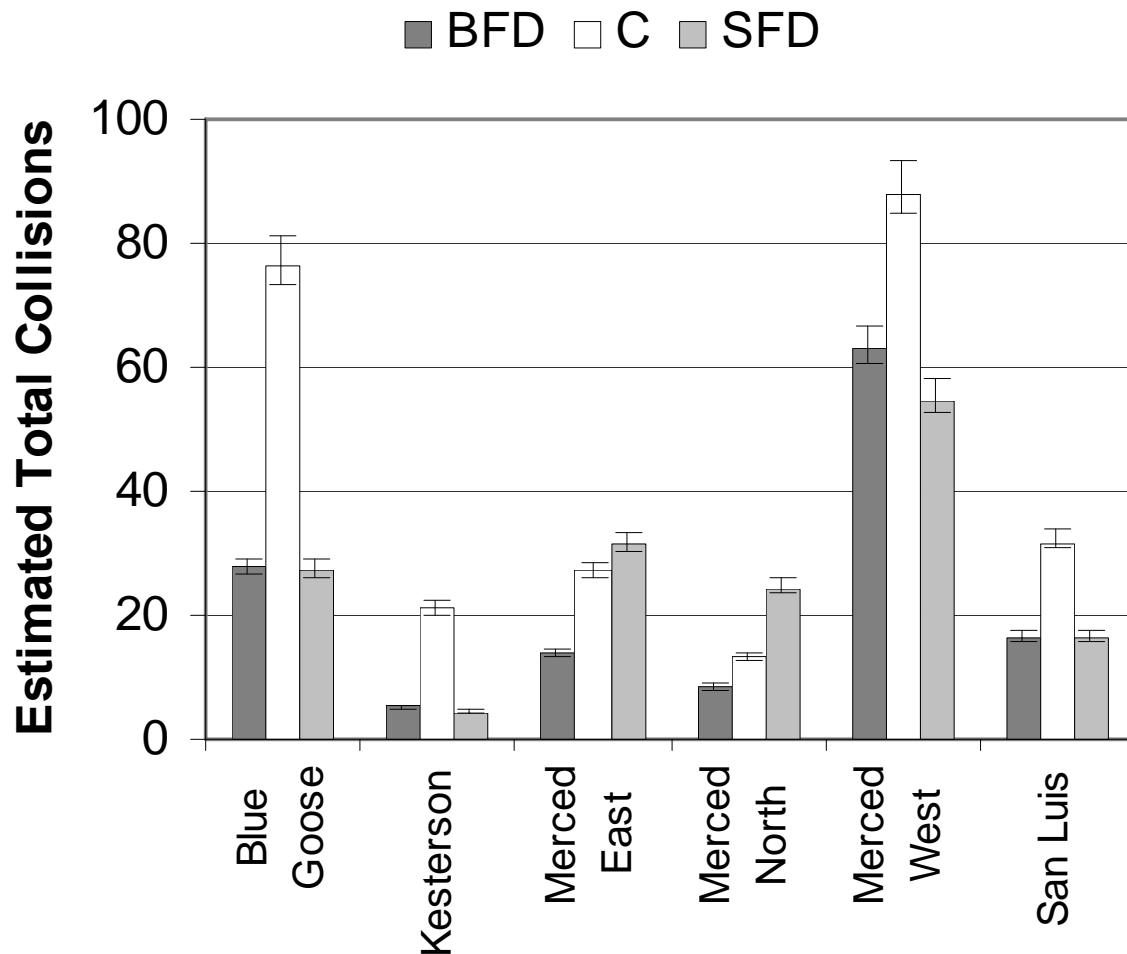


Figure 9. Estimated total collisions and 95% confidence intervals at power lines with Bird-Flight Diverters (BFD), Swan-Flight Diverters (SFD), and no diverters (Control, C) at six sites in San Luis National Wildlife Refuge Complex, Merced County, California in two winter seasons from October 2006 to February 2008.

## 4.0 Conclusions and Recommendations

The occurrence of fewer estimated total collisions under power lines with diverters provides some evidence that both Bird-Flight and Swan-Flight Diverters are effective. It can not be concluded with certainty that diverters reduced the number of avian collisions at San Luis National Wildlife Refuge Complex because carcass searches were not conducted in the first field season, before diverters were installed. However, because estimated collisions at control lines were significantly greater than BFD lines at all six sites and greater than SFD lines at four of the six sites, it is likely that the diverters helped reduce the risk of avian collisions. Bird-Flight Diverters might have been more effective than Swan-Flight Diverters in this study, based on the overall difference in estimated collisions. However, Merced North and East were the only sites where more collisions were estimated at SFD lines than at BFD lines. It is unclear if the Swan-Flight Diverters were ineffective at these two sites, or if other local factors created a higher risk of avian collisions along the SFD portion of the lines, relative to the BFD portion.

Birds reacted to power lines at greater distances after diverters were installed, a pattern that further supports diverter effectiveness, particularly in improving line visibility. The effect was especially strong at SFD lines, where a more than two-fold increase was measured in the odds of a flock reacting at a further distance category after Swan-Flight Diverters were installed. If birds are able to react to lines at greater distances from the lines, the risk of a collision is likely reduced.

Other patterns of reactions derived from flight observations are less meaningful for evaluating diverter effectiveness, primarily because results are unclear or the reactions can be interpreted in multiple ways. For example, a significant decrease in flutter/flare reactions was observed after diverters were installed, but the importance of diverters in this effect is unclear, because a similar decrease, bordering significance at alpha 0.05, was shared by the control lines, where no diverters were installed. Evaluating diverter effectiveness based on flutter/flare reactions is problematic. In designing the study, it was thought that birds exhibiting flutter/flare reactions might be having difficulty seeing the line; therefore, flutter/flare reactions at lines with diverters would indicate poor diverter performance. However, diverters could also prompt flutter/flare reactions by birds that would otherwise collide with, or narrowly miss, a line; if this is true, the flutter/flare reactions could indicate good diverter performance. Similarly, evaluating diverter effectiveness from altitude change reactions can not be done without considerable uncertainty. The analyses of reaction distances and carcass recoveries, for which diverter effects were found, is more compelling evidence of diverter effectiveness at San Luis National Wildlife Refuge Complex than analyses of the reaction types.

Although there was support for the effectiveness of both Bird-Flight and Swan-Flight Diverters, comparisons of the two diverter types are confounded by the use of different colors at the site. Bird-Flight Diverters were yellow and Swan-Flight Diverters were gray. Others have shown that diverter color can affect the risk of a collision (Brown and Drewien 1995, Crowder 2000). A yellow diverter might be more visible to birds than a gray diverter, because yellow provides a



greater contrast to the color of the line. If so, Bird-Flight Diverters could appear more effective than Swan-Flight Diverters at the site, even if the designs are equally effective.

Another potentially confounding factor was the decision to use the center lines as controls at each of the sites. In an effort to put as much distance as possible between BFD and SFD lines, bias between sampling units could have been created. If diverters are effective, birds might avoid the lines with diverters at either end of the line section and fly more often over the center, or control, portion. This bias probably was not a factor, however, because more flocks or individual birds were not observed over the control lines. Another consideration is that the presence of diverters at either end might render the entire line section, including the control portion, more visible. Such a bias, if it occurred, would more likely mask a diverter effect than contribute to one.

#### **4.1. Management Implications**

Carcass recovery and flight reaction results are reasons to be encouraged that both diverter types are having a positive effect on reducing avian collisions at San Luis National Wildlife Refuge Complex. At the same time, there should be concern that the diverters are apparently ineffective for one local resident species, American coot, which accounted for approximately half of all carcasses in this study. American coot is a locally abundant waterbird and not a species of conservation concern. The status of coots notwithstanding, excessive mortality of coots is reason to improve protection, particularly at Merced West, where most of the deaths occurred. With the next highest number of estimated total collisions and coot collisions, Blue Goose could be a second priority, although about 80% fewer coot carcasses were recovered at Blue Goose than Merced West. Based on documented patterns of nocturnal activity for coots (Brisbin and Mowbray 2002), and the disparate lack of coot flight observations during daytime surveys, coots were likely colliding with power lines at night. Adding bird flight diverters that illuminate at night or in fog can improve line visibility for coots and other species with nocturnal flight habits (Fig. 10). However, other than the presumed increase in visibility at night, no evaluation is made here of the appropriateness of other diverters for power line installation based on other characteristics, such as durability.

Results of logistic regression model selection demonstrate that multiple factors, in combination with diverter installation, affect the risk of a flutter/flare reaction. Although these factors might not affect the risk of avian collision in the same way, weather and patterns of avian use at a site are likely important predictors. Diversion devices rely on the concept that increased line visibility leads to fewer collisions. However, with a combination of other factors, such as high wind, abundance of large birds with high wing loading, and close proximity of quality bird habitat, improving line visibility might not be enough to reduce avian collisions to an acceptable level. If this is the case, reducing avian collisions is more complex than simply installing diverters. Strategies might require the relocation of lines away from high-use habitat, especially if these habitats are used by species of conservation concern. By installing diverters on some of the lines at San Luis National Wildlife Refuge Complex, Pacific Gas and Electric took a positive step toward reducing avian collisions. An additional step should be installing more diverters, including types that promise more effectiveness in low light, with Merced West and



Blue Goose as top priority sites. Another alternative could be to manage habitat in a manner that shifts areas of high avian use (e.g. feeding areas) away from power lines, provided there is no net reduction in the amount of quality habitat in that process. Patterns of avian mortality should continue to be monitored through carcass searches, and managers should be responsive to local conditions that prompt the need for avian conservation solutions beyond the installation of diverters.

In California, collisions of sandhill cranes with power lines is of considerable concern (Tacha et al. 1992, Littlefield 2008), because of the state-threatened status for greater sandhill crane, low annual recruitment, and physical attributes (e.g., large size and high wing loading) that limit their ability to evade lines. Habitat management can influence the foraging patterns of sandhill cranes and be used as a strategy for reducing collisions. In 2005, a grain crop was grown west of and adjacent to the power line at Merced East, and cranes foraged in that area. In subsequent seasons, cranes foraged further from the spans. Perhaps as a result, only one crane carcass was identified, and observers noted that cranes usually flew high over lines without taking off and landing in close proximity to the lines. Fortunately, results and observations in this study do not identify a pattern of substantial crane mortality. However, even a small number of mortalities can be excessive for a species of conservation concern. The occurrence of one apparent sandhill crane carcass, along with anecdotal reports of crane mortality before the study, is incentive to continue managing habitat in a manner compatible with avian power line avoidance, documenting sandhill crane mortality, and implementing strategies for mitigating collisions where and when needed.



**Figure 10. Some of the apparent victims of collisions at San Luis National Wildlife Refuge Complex were nocturnal species, like the Barn Owl. Source: Ventana Wildlife Society.**

## 5.0 References

- Akaike, H. 1973. "Information Theory and an Extension of the Maximum Likelihood Principle." Pages 267-281 in *Second International Symposium on Information Theory* (B. Petran and F. Csaki, editors), Akademiai Kiado, Budapest.
- Alonso, J. C., J. A. Alonso, and R. Muñoz-Pulido. 1994. "Mitigation of Bird Collisions With Transmission Lines Through Groundwire Marking." *Biological Conservation*, 67(2):129-134.
- Anderson, M. D. 2001. *The Effectiveness of Two Different Marking Devices to Reduce Large Terrestrial Bird Collisions With Overhead Electricity Cables in the Eastern Karoo, South Africa*, Karoo Large Terrestrial Bird Powerline Project, Directorate Conservation and Environment, Kimberley.
- Avian Power Line Interaction Committee (APLI). 1994. *Mitigating Bird Collisions With Power Lines: the state of the art in 1994*, Edison Electric Institute, Washington, D.C., U.S.A.
- Bevanger, K., and H. Brøseth. 2004. "Impact of Power Line on Bird Mortality in a Subalpine Area." *Animal Biodiversity and Conservation* 27(2):67-77.
- Brisbin, I. L., Jr., and T. B. Mowbray. 2002. "American Coot (*Fulica americana*) and Hawaiian Coot (*Fulica alai*)." In *The Birds of North America*, No. 697 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.
- Brown, W. M., and R. C. Drewien. 1995. "Evaluation of Two Power Line Markers to Reduce Crane and Waterfowl Collision Mortality." *Wildlife Society Bulletin* 23(2):217-227.
- Burnham, K. P., and D. R. Anderson. 1998. *Model Selection and Inference. A Practical Information-Theoretic Approach*, Springer-Verlag, New York, New York.
- California Department of Fish and Game. 2006. "California Natural Diversity Database Special Animals List (824 taxa)." State of California, The Resources Agency, Department of Fish and Game, Biogeographic Data Branch, Sacramento, California.  
<http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/SPAnimals.pdf>
- Crowder, M. R. 2000. "Assessment of Devices Designed to Lower Incidence of Avian Power Line Strikes." M.S. Thesis. Purdue University.
- Dorin, M., and L. Spiegel. 2005. *Assessment of Avian Mortality From Collisions and Electrocutions*, Technical Report CEC-700-2005-015. California Energy Commission. Sacramento, California.
- EDM International, Inc. 2004. *Corona Testing Devices Used to Mitigate Bird Collisions*, California Energy Commission, Public Interest Energy Research (PIER) Program. Technical Report P500-04-086F. Sacramento, California.

- Electric Power Research Institute. 2003. *Bird Strike Indicator/Bird Activity Monitor and Field Assessment of Avian Fatalities*. California Energy Commission, Public Interest Energy Research (PIER) Program. Technical Report P500-03-107F. Sacramento, California.
- Erikson W. P., G. D. Johnson, M. D. Strickland, D. P. Young, Jr., K. J. Sernka, and R. E. Good. 2001. *Avian Collisions With Wind Turbines: a Summary of Studies and Comparisons to other Sources of Avian Collision Mortality in the United States*. National Wind Coordinating Committee. Washington D.C., [www.nationalwind.org/pubs/avian\\_collisions.pdf](http://www.nationalwind.org/pubs/avian_collisions.pdf).
- Eskom. 2003. *The Management of Wildlife Interactions With Overhead Power Lines. Southern African Power Pool Environmental Sub-Committee Training Manual*. African Centre for Energy and Environment (ACEE), Johannesburg, South Africa. 62 pp.
- Hartman, P. A., S. Byrne, and M. F. Dedon. 1992. *Bird Mortality in Relation to the Mare Island 115-kV Transmission Line: Final Report 1988-1991*. PG&E Report 443-91.3, submitted to Department of Navy, Western Division, San Bruno, California, 118 pp.
- Hunting K. 2002. *A Roadmap for PIER Research on Avian Collisions with Power Lines in California*. California Energy Commission, Public Interest Energy Research (PIER) Program. Technical Report P500-02-071F. Sacramento, California.
- Hurst, N. 2004. *Corona Testing of Devices Used to Mitigate Bird Collisions*. EDM International, Inc. California Energy Commission, Public Interest Energy Research (PIER) Program. Technical Report 500-04-086F. Sacramento, California.
- Janss, G. F. E., and M. Ferrer. 1998. "Rate of Bird Collision With Power Lines: Effects of Conductor-Marking and Static Wire-Marking." *Journal of Field Ornithology* 69(1):8-17.
- Janss, G. F. E., and M. Ferrer. 2000. "Common Crane and Great Bustard Collision With Power Lines: Collision Rate and Risk Exposure." *Wildlife Society Bulletin* 28(3):675-680.
- Lehman, R. N., P. L. Kennedy, and J. A. Savidge. 2006. "The State of the Art in Raptor Electrocutation Research: a Global Review." *Biological Conservation* 36:159-174.
- Littlefield, C. D. 2008. "Lesser Sandhill Crane (*Grus canadensis canadensis*)." Pages 167-172 in Shuford, W. D., and Gardali, T., eds. *California Bird Species of Special Concern: a Ranked Assessment of Species, Subspecies, and Distinct Populations of Birds of Immediate Conservation Concern in California*. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento, California.
- Shoenfeld, P. S. 2004. *Suggestion Regarding Avian Mortality Extrapolation*. Staff report. West Virginia Highland Conservancy, Davis, West Virginia. <http://www.wvhighlands.org/Birds/SuggestionsRegardingAvianMortalityExtrapolation.pdf>.
- SPSS, Inc. 2000. SYSTAT® Version 10 Statistical Software. Chicago, Illinois.

- Tacha, T. C., S. A. Nesbit, and P. A. Vohs. 1992. "Sandhill Crane (*Grus canadensis*)." In *The Birds of North America*, No. 31 (A. Poole, P. Stettenheim, and F. Gill, eds.). Philadelphia, Pennsylvania: The Academy of Natural Sciences; Washington, D.C.: The American Ornithologist's Union.
- White, G. C. 2007. Program Mark Version 4.3. "Mark and Recapture Survival Rate Estimation." Dept of Fishery and Wildlife, Colorado State University, Fort Collins, Colorado.  
<http://www.cnr.colostate.edu/~gwhite/mark/htm>.
- Yee, M. 2007. *Evaluating and Reducing Avian Collisions With Distribution Power Lines at Cosumnes River Preserve*. California Energy Commission, Public Interest Energy Research (PIER) Program and California State University, Sacramento, California.



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## Appendices

### **Appendix A. Codes used for data collection during flight observation surveys at San Luis National Wildlife Refuge Complex, Merced County, California.**

#### **Flight Height/Altitude at Line Crossing**

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- 1 (>25) GREATER THAN 25 M ABOVE TOP WIRE
  - 2 (>10) 10-25 M ABOVE OR BELOW WIRE
  - 3 (>5) 5-10 M ABOVE OR BELOW WIRE
  - 4 (<5) 0-5 M ABOVE OR BELOW WIRE, THROUGH WIRES
- 

#### **Reaction Distance Relative to Line**

---

- 1 (>25) GREATER THAN 25 M AWAY FROM LINE
  - 2 (>10) 10-25 M AWAY FROM LINE
  - 3 (<10) LESS THAN 10 M AWAY FROM LINE
- 

#### **Reaction Behavior**

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- 1 NO REACTION
  - 2 TURN AND LEAVE OR LAND ON GROUND; INCREASE OR DECREASE IN ALTITUDE
  - 3 FLUTTERING TO ACHIEVE MORE RAPID CHANGE IN FLIGHT ALTITUDE; FLARE, GENERAL STOP OF FORWARD MOMENTUM
  - 4 COLLISION AND FLY or COLLISION AND FALL
- 

#### **Flock take-off locations**

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- 1 (>100) GREATER THAN 100 M AWAY FROM LINE
  - 2 (>50) 50-100 M AWAY FROM LINE
  - 3 (<50) LESS THAN 50 M AWAY FROM LINE
- 

<b>Wind Code</b>	<b>Wind Speed (mph)</b>	<b>Description</b>
0	< 1	Calm
1	1 – 3	Smoke indicates wind direction
2	4 – 7	Wind felt on face; leaves rustle
3	8 – 12	Leaves in constant motion, small flags extended
4	13 – 18	Dust, leaves raised up; small branches move
5	19 – 24	Small trees begin to sway
6	25 – 31	Large branches in motion
7	32 – 38	Whole trees in motion; resistance while walking
8	39 – 46	Twigs and small branches break off trees

9      47 – 54      Slight structural damage occurs

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**Sky**

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- 1 – Clear
  - 2 – Partly Cloudy
  - 3 – Overcast
  - 4 – Hazy
  - 5 – Fog
  - 6 – Drizzle
  - 7 – Rain
  - 8 – Snow
  - 9 – Hail
  - 10 – Sleet
-







**Appendix E. Alphabetical list of species, codes, and guild classifications used at San Luis National Wildlife Refuge Complex, Merced County, California. Guilds are loosely assigned by morphology and foraging class. We recorded four-letter species codes on field data forms and used four-letter guild codes in data analyses.**

Species	Species Code	Guild Description	Guild Code
American Avocet	AMAV	Shorebird	SHOR
American Coot	AMCO	Duck	DUCK
American Crow	AMCR	Raptor	RAPT
American Goldfinch	AMGO	Passerine	PASS
American Kestrel	AMKE	Raptor	RAPT
American Pipit	AMPI	Passerine	PASS
American Robin	AMRO	Passerine	PASS
American White Pelican	AWPE	Pelican	AWPE
American Wigeon	AMWI	Duck	DUCK
Audubon's Warbler	AUWA	Passerine	PASS
Bald Eagle	BAEA	Raptor	RAPT
Barn Swallow	BARS	Swallow	SWAL
Belted Kingfisher	BEKI	Kingfisher	BEKI
Black Phoebe	BLPH	Passerine	PASS
Black-bellied Plover	BBPL	Shorebird	SHOR
Black-crowned Night-Heron	BCNH	Wading Bird	WADE
Black-necked Stilt	BNST	Shorebird	SHOR
Bonaparte's Gull	BOGU	Gull	GULL
Brewer's Blackbird	BRBL	Passerine	PASS
Brown-headed Cowbird	BHCO	Passerine	PASS
Bushtit	BUSH	Passerine	PASS
California Gull	CAGU	Gull	GULL
Canada Goose	CANG	Goose	GOOS
Cliff Swallow	CLSW	Swallow	SWAL
Common Merganser	COME	Duck	DUCK
Common Raven	CORA	Raptor	RAPT
Common Yellowthroat	COYE	Passerine	PASS
Cooper's Hawk	COHA	Raptor	RAPT
Double-crested Cormorant	DCCO	Cormorant	DCCO
Downy Woodpecker	DOWO	Woodpecker	WOOD
Dunlin	DUNL	Shorebird	SHOR
European Starling	EUST	Passerine	PASS

<b>Species</b>	<b>Species Code</b>	<b>Guild Description</b>	<b>Guild Code</b>
Ferruginous Hawk	FEHA	Raptor	RAPT
Gadwall	GADW	Duck	DUCK
Golden-crowned Sparrow	GCSP	Passerine	PASS
Great Egret	GREG	Wading Bird	WADE
Great Blue Heron	GBHE	Wading Bird	WADE
Greater White-fronted Goose	GWFG	Goose	GOOS
Greater Yellowlegs	GRYE	Shorebird	SHOR
Great-tailed Grackle	GTGR	Passerine	PASS
Green-winged Teal	GWTE	Duck	DUCK
Heermann's Gull	HEGU	Gull	GULL
Horned Lark	HOLA	Passerine	PASS
House Finch	HOFI	Passerine	PASS
House Sparrow	HOSP	Passerine	PASS
Killdeer	KILL	Shorebird	SHOR
Lark Sparrow	LASP	Passerine	PASS
Least Sandpiper	LESA	Shorebird	SHOR
Loggerhead Shrike	LOSH	Passerine	PASS
Long-billed Curlew	LBCU	Shorebird	SHOR
Long-billed Dowitcher	LBDO	Shorebird	SHOR
Mallard	MALL	Duck	DUCK
Marbled Godwit	MAGO	Shorebird	SHOR
Merlin	MERL	Raptor	RAPT
Mourning Dove	MODO	Passerine	PASS
Northern Flicker	NOFL	Woodpecker	WOOD
Northern Harrier	NOHA	Raptor	RAPT
Northern Mockingbird	NOMO	Passerine	PASS
Northern Pintail	NOPI	Duck	DUCK
Northern Shoveler	NSHO	Duck	DUCK
Nuttall's Woodpecker	NUWO	Woodpecker	WOOD
Peregrine Falcon	PEFA	Raptor	RAPT
Prairie Falcon	PRFA	Raptor	RAPT
Red-necked Phalarope	RNPH	Shorebird	SHOR
Red-shafted Flicker	RSFL	Woodpecker	WOOD
Red-shouldered Hawk	RSHA	Raptor	RAPT
Red-tailed Hawk	RTHA	Raptor	RAPT
Red-winged Blackbird	RWBL	Passerine	PASS

<b>Species</b>	<b>Species Code</b>	<b>Guild Description</b>	<b>Guild Code</b>
Ring-billed Gull	RBGU	Gull	GULL
Ring-necked Pheasant	RNEP	Wading Bird	WADE
Rock Pigeon	ROPI	Passerine	PASS
Ross' Goose	ROGO	Goose	GOOS
Ruby-crowned Kinglet	RCKI	Passerine	PASS
Sandhill Crane	SACR	Wading Bird	WADE
Savannah Sparrow	SAVS	Passerine	PASS
Say's Phoebe	SAPH	Passerine	PASS
Sharp-shinned Hawk	SSHA	Raptor	RAPT
Snow Goose	SNGO	Goose	GOOS
Snowy Egret	SNEG	Wading Bird	WADE
Song Sparrow	SOSP	Passerine	PASS
Tree Swallow	TRES	Swallow	SWAL
Tricolored Blackbird	TRBL	Passerine	PASS
Turkey Vulture	TUVU	Raptor	RAPT
Unknown Accipiter	ACCI	Raptor	RAPT
Unknown Bird	BIRD	Unknown bird	BIRD
Unknown Blackbird	BB	Passerine	PASS
Unknown Dowitcher	UNDO	Shorebird	SHOR
Unknown Duck	DUCK	Duck	DUCK
Unknown Falcon	FALC	Raptor	RAPT
Unknown Goldfinch	GOLD	Passerine	PASS
Unknown Goose	GOOS	Goose	GOOS
Unknown Gull	GULL	Gull	GULL
Unknown Passerine	PASS	Passerine	PASS
Unknown Raptor	RAPT	Raptor	RAPT
Unknown Shorebird	SHOR	Shorebird	SHOR
Unknown Sparrow	SPAR	Passerine	PASS
Unknown Swallow	SWAL	Swallow	SWAL
Unknown Teal	TEAL	Duck	DUCK
Unknown Wading Bird	WADE	Wading Bird	WADE
Unknown White Goose	WHGO	Goose	GOOS
Unknown Zonotrichia	ZONO	Passerine	PASS
Western Meadowlark	WEME	Passerine	PASS
White-crowned Sparrow	WCSP	Passerine	PASS
White-faced Ibis	WFIB	Wading Bird	WADE



<b>Species</b>	<b>Species Code</b>	<b>Guild Description</b>	<b>Guild Code</b>
White-tailed Kite	WTKI	Raptor	RAPT
Wilson's Snipe	WISN	Shorebird	SHOR
Wood Duck	WODU	Duck	DUCK
Yellow-billed Magpie	YBMA	Passerine	PASS
Yellow-rumped Warbler	YRWA	Passerine	PASS